EDUCATEE'S THESAURUS AS AN OBJECT OF MEASURING LEARNED MATERIAL OF THE DISTANCE LEARNING COURSE

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ABSTRACT

Monitoring and control over the process of studying the distance learning course are based on solving the problem of making out an adequate integral mark to the educatee for mastering entire study course, by testing results. It is suggested to use the degree of correspondence between educatee's thesaurus and the study course thesaurus as an integral mark for the degree of mastering the distance learning course. Study course thesaurus is a set of the course objects with relations between them specified. The article considers metrics of the study course thesaurus complexity, made on the basis of the graph theory and the information theory. It is suggested to use the amount of information contained in the study course thesaurus graph as the metrics of the study course thesaurus complexity. Educatee's thesaurus is considered as an object of measuring educational material learned at the semantic level and is assessed on the basis of amount of information contained in its graph, taking into account the factors of learning the thesaurus objects.

Keywords: e-learning, thesaurus, learning management system, thesaurus metrics, knowledge measurement, study course material, knowledge testing.

INTRODUCTION

Educational process presupposes purposeful influence on the educatee's thesaurus. Currently, there is no possibility of knowledge monitoring based on the degree of correspondence between educatee's thesaurus and the study course thesaurus in distance learning systems. In distance learning system, educational process consists of sequence of the cycles of providing educatee with educational material and learning the educational material by the educatee. The cycle of learning certain educational material by educatee results in expansion of the educatee's thesaurus. Definition of the "individual's professional thesaurus" concept is given in the I.R.Abdulmyanov's work (2010). Study course thesaurus is a set of the study course objects (concepts, laws, theorems, statements, etc.) with relations between them specified.

Educatee's thesaurus is an object of measuring educational material learned at the semantic level. Let us assume that a distance learning system with the study course described by the thesaurus $I_d$ provides educatee with an educational material described by the thesaurus $I_s$. Possibility of learning the educational material, described by the thesaurus $I_f \subseteq I_d$, by the educatee can be as follows:
1) If \( I_f \subseteq I_s \) then there will be no changes in the educatee's thesaurus during the education since this information is already known to the educatee.

2) If \( I_f \cap I_s \neq \emptyset \) and \( I_s \subset I_f \) then the educational material can be learned by the educatee if desired, and as a result educatee's thesaurus will be expanded.

The educatee acquires a maximum amount of semantic information when their thesaurus is coordinated with the study course material's thesaurus i.e. if the educational material is understandable to the educatee and carries an information, which is absent in their thesaurus.

Thesaurus presentation of the educational material and also of the current educatee's state of knowledge ensures adaptive selection and ordering of the educational information. Process of the thesaurus forming based on using the knowledge presentation methods is described in detail in the S. Bechhofer's and C. Goble's work (2001). Understanding of not only thesaurus object's attributes, but also relations of the object with other objects are characteristic of the process (D. Soergel, B. Lauser, A. Liang, F. Fisseha, J. Keizer, S. Katz, 2004).

Metrics described in the works by D. Bonchev and G. A. Buck (2005) and A. Gangemi, C. Catenacci, M. Ciaramita and J. Lehmann (2005) can be used for quantitative assessment of complexity of the thesaurus presented in the form of a graph. Metrics used for ontologies can be used for comparative analysis of thesauruses since thesauruses can be considered as ontology types. But to use the ontologies comparison metrics, described in the works by A. Lozano-Tello and A. Gomez-Perez (2004) and A. Maedche and S. Staab (2002), for comparative analysis of the study course thesaurus and educatee's thesaurus, the metrics must be improved since the result of comparison of the educatee's thesaurus and the study course thesaurus must be a mark describing not only correspondence between their structures, but also the degree of mastering the study course.

In distance learning systems, degree of mastering the study course is assessed by the results of educatees testing (J. Myrick, 2010). Currently, much attention is given to increasing accuracy of assessing results of education in distance learning systems. For this purpose, A. A. Rybanov's work (2013) suggests taking into account the process of forming final answer to test items by the user, and the work by K. Scalise and B. Gifford (2006) suggests innovative test item forms for computer-aided knowledge testing. Integral mark for quality of mastering the distance learning course is calculated on the basis of educatee's marks for all tests within the study course. For example, the Moodle system has the following approaches to calculation of integral mark for quality of mastering study course (S. S. Nash, W. Rice, 2010): "mean of grades", "weighted mean of grades", "simple weighted mean of grades", "mean of grades" (with extra credits), "median of grades", "lowest of grades", "highest of grades", "mode of grades", "sum of grades". Among all the approaches, only the "weighted mean of grades" takes into account complexity of learning an educational module by determining the weight factor for the test associated with the module. There is a problem of determining weight factors of educational modules within the distance learning course. Determining the factors by the subjective weighing method (i.e. the factors are determined by the author of the distance learning course) results in error in the final mark value. Thesaurus presentation of the study course will allow determining weight of each thesaurus object more soundly and objectively. Weights of the tests can be determined by comparing test items with thesaurus objects within the study course.
Thesaurus objects, which are difficult for learning, can be identified on the basis of thesaurus presentation of the educational material and comparative analysis of the educatees testing results. Set of such thesaurus objects can be used for more well-grounded strategy of correcting educational material and tests.

More precise learning curves can be constructed by using degree of correspondence between educatee’s thesaurus and the study course thesaurus as a learning achievements metric (Figure: 1). Learning curves are a basis for classification of educatees into extroverts and introverts: introverted subjects have a concave learning curve that is caused by a long phase of latent accumulation of knowledge and skills.

![Figure 1](image1.png)

Dynamics of changing learning achievements during education.

All above mentioned directions of monitoring and control over the process of studying within the distance learning course are based on solving the problem of making out an adequate integral mark to the educatee for mastering entire study course, by testing results. This problem can be solved by measuring degree of correspondence between educatee's thesaurus and the study course thesaurus.

**MATHEMATICAL DESCRIPTION**

**Model of the distance learning course thesaurus**

*Thesaurus describing the system of the study course objects* can be presented in the form of an oriented graph $G = (V, E)$; where $V$ is a set of vertexes (study course thesaurus objects), $E$ is a set of arcs (oriented edges describing the logic of studying the study course objects). Let us introduce the following symbols: $n = |V|$, $m = |E|$. Let us consider the set $E$ of the logical relations between the study course thesaurus objects. Let us assume that $(v_i, v_j) \in E$ if $v_i$ is a direct semantic component of $v_j$. Let us also assume that $A$ is an adjacency matrix of the study course thesaurus graph $G$, where the matrix element $a_{ij} = 1$ if $(v_i, v_j) \in E$, and otherwise $a_{ij} = 0$. Then $A^L$ is a matrix showing quantity of the paths with the length $L$ which are between any two objects $v_i$ and $v_j$. 

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The quantity of these paths is determined by the figure on intersection of \(i\) th line and \(j\) th column of the matrix \(A^i\). Let us designate an element of the matrix \(A^i\) as \(a_{ij}^{(i)}\).

Then:

\[
a_{ij}^{(i+1)} = a_{ij}^{(i)} + \sum_{k=0}^{n} a_{ik}^{(i)} a_{kj}^{(i)} \quad (1)
\]

\[
a_{ij}^{(i)} = \sum_{k=0}^{n} a_{kj}^{(i)} \quad (2)
\]

The graph \(G\) describing the study course thesaurus must meet the following requirements:

1) There must be no isolated vertexes in the study course thesaurus graph:

\[
\sum_{i=1}^{n} a_{ik}^{(i)} + \sum_{j=1}^{n} a_{kj}^{(i)} \neq 0, \quad \forall k = 1, n \quad (3)
\]

2) There must be no circuits in the study course thesaurus graph, i.e. any matrix \(A^i\) must meet the following condition:

\[
\sum_{k=1}^{n} a_{kk}^{(i)} \neq 1 \quad (4)
\]

3) There must be no duplicate connections between vertexes of the study course graph, i.e. if there are arcs \((v_i, v_j), (v_j, v_k)\) and \((v_i, v_k)\), the arc \((v_i, v_k)\) can be removed as it, according to the transitivity property, duplicates requirements to the sequence of studying the thesaurus objects \(v_i\) and \(v_k\).

Let us assume that the entrance study course thesaurus objects are all objects \(v_k\) which meet the following condition:

\[
\sum_{i=1}^{n} a_{ik}^{(i)} = 0 \quad (5)
\]

Let us also assume that the exit study course thesaurus objects are all objects \(v_k\) which meet the following condition:

\[
\sum_{j=1}^{n} a_{kj}^{(i)} = 0 \quad (6)
\]

When analyzing the subject matter thesaurus, it is important to know what objects are used for forming other objects, and what these other objects are. To describe relative duration of forming the study course thesaurus objects, the reachability matrix \(D\) is used:

\[
D = \sum_{i=1}^{N} A^i \quad (7)
\]

Here \(d_{ij}\) is an element of the matrix \(D\) which shows in what quantity of the cycles after the object \(v_i\), the object \(v_j\) will be formed; \(N\) is the order of the study course thesaurus graph: \(A^N \neq 0, A^{N+1} = 0\).
Metrics Of Complexity Of The Distance Learning Course
Thesaurus On The Basis Of The Graph Theory

To describe characteristics of the study course thesaurus presented in the form of graph \( G \), the following graph metrics can be used:

1) Order of the study course thesaurus graph: \( n(G) = n \).

2) Size of the study course thesaurus graph: \( s(G) = m \).

3) Diameter of the study course thesaurus (length of the maximum path between the entrance objects \( v_i \) and the exit objects \( v_j \) of the thesaurus, expressed by a number of the arcs, which make this path):

\[
diam(G) = \max_{d_{ij} \in D} d_{ij}.
\]  

4) Structural redundancy \( R(G) \) of the study course thesaurus graph shows excess of the total quantity of connections between vertexes of the graph \( G \) over the minimum quantity of connections:

\[
R(G) = \frac{m}{n-1} - 1.
\]

5) Edge density \( Q(G) \) (characterizes proximity of the graph \( G \) to the fully connected graph):

\[
Q(G) = \frac{2m}{n(n-1)}.
\]

6) Absolute depth of the graph \( H'(G) \) (A.Gangemi, C.Catenacci, M.Ciaramita, J.Lehmann, 2005):

\[
H'(G) = \sum_{j} N_{j \in P}.
\]

7) Average depth of the graph \( h(G) \) (A.Gangemi, C.Catenacci, M.Ciaramita, J.Lehmann, 2005):

\[
h(G) = \frac{1}{|P|} \sum_{j} N_{j \in P}.
\]

Quantitative characteristics of the study course thesaurus objects can be described by the following metrics:

1) Let us define the weight of the study course thesaurus object associated with the vertex \( v_k \) as a quantity of all paths passing through the vertex \( v_k \):

\[
w_k = \sum_{i=1}^{d_{ik}} \sum_{j=1}^{d_{kj}} d_{ij}.
\]

Here \( d_{ij} \) is an element of the reachability matrix \( D \), which shows how many paths, irrespective of their lengths, there are between the vertexes \( v_i \) and \( v_j \).

2) Rank of the object \( v_j \) of the study course thesaurus (equal to quantity of the arcs entering the maximum length path in the graph \( G \), from the entrance study course thesaurus object to the object \( v_j \)):  

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\[ P_j = L \text{ at } \sum_{i=1}^{q} a_{ij}^{(L)} > 0 \text{ and } \sum_{i=1}^{q} a_{ij}^{(L+1)} = 0. \]  \hspace{1cm} (14)

When ranks of all study course objects are determined, it is possible to construct the study course thesaurus graph ordered by cycles.

3) Degree of the study course thesaurus object is determined by summing up in-degree and out-degree of vertex \( v_k \) associated with the thesaurus object:

\[ a_k = \sum_{j=1}^{q} a_{kj} + \sum_{i=1}^{q} a_{ik}. \]  \hspace{1cm} (15)

The metrics presented above allow assessing topological complexity of the study course thesaurus graph and give an idea about complexity of learning the distance learning course.

Metrics of Complexity of the Distance Learning Course
Thesaurus on the Basis of The Information Theory

Let us describe the metrics of complexity of the study course thesaurus on the basis of the Shannon’s information theory (C. E. Shannon, W. Weaver, 1949). According to the information theory, informational entropy \( H(\alpha) \) of a message of \( N \) symbols divided, according to some criterion, into \( k \) groups of \( N_1, N_2, ..., N_k \) symbols is calculated by the following formula:

\[ H(\alpha) = - \sum_{i=1}^{k} \rho_i \log_2 \rho_i = - \sum_{i=1}^{k} \frac{N_i}{N} \log_2 \frac{N_i}{N}, \]  \hspace{1cm} (16)

Here \( \rho_i = \frac{N_i}{N} \) is probability of presence of the \( i \)th group symbols in the message.

Study course thesaurus graph is specified by a final set of elements (vertexes, edges, arcs, cliques, etc.). Let us assume that \( N \) is a quantity of the study course thesaurus graph’s elements. Weight of each study course thesaurus graph’s element is \( w_i \), \( i = 1, N \).

Let us determine the total weight of the study course thesaurus graph by the following expression:

\[ W = \sum_{i=1}^{N} W_i. \]  \hspace{1cm} (17)

Probability of presence of \( i \)th element with weight \( W_i \) in the study course thesaurus graph is calculated as follows:

\[ \rho_i = \frac{W_i}{W}. \]  \hspace{1cm} (18)

Thus probability scheme of the study course thesaurus graph can be described by Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Element</th>
<th>1</th>
<th>2</th>
<th>...</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>( w_1 )</td>
<td>( w_2 )</td>
<td>...</td>
<td>( w_N )</td>
</tr>
<tr>
<td>Probability</td>
<td>( \rho_1 )</td>
<td>( \rho_2 )</td>
<td>...</td>
<td>( \rho_N )</td>
</tr>
</tbody>
</table>
Entropy of the study course thesaurus graph with total weight \( W \) and weights of the elements \( w_i, i = 1, N \) for the specified probability scheme (Table: 1) is determined by the following expression:

\[
H = - \sum_{i=1}^{N} \frac{w_i}{W} \log_2 \frac{w_i}{W} = - \sum_{i=1}^{N} \frac{w_i}{w_j} \log_2 \frac{w_i}{w_j} + \sum_{i=1}^{N} \frac{w_i}{W} \log_2 \frac{W}{w_j} = \log_2 W \cdot \sum_{i=1}^{N} w_i \log_2 w_i. \tag{19}
\]

According to the Shannon's information theory, amount of information is defined as decrease in the system entropy relative to the maximum entropy, which can exist in the system with the same quantity of elements:

\[
I = H_{\text{max}} - H. \tag{20}
\]

Informational entropy of the study course thesaurus graph possesses the maximum value when \( w_i = 1 \) (Formula 19) and is determined as follows:

\[
H_{\text{max}} = \log_2 W. \tag{21}
\]

Thus expression for determining amount of information contained in the study course thesaurus graph takes the following form:

\[
I = \frac{1}{W} \sum_{i=1}^{N} w_i \log_2 w_i. \tag{22}
\]

This expression is the metrics of complexity of the study course thesaurus and can be used for assessing degree of correspondence between the educatee's thesaurus graph and the study course thesaurus graph.

**Educatee's thesaurus model**

Let us define educatee's thesaurus graph \( G' = (U, E') \) as a subgraph of the set of vertexes of the study course thesaurus graph \( G = (V, E) \); where \( U \subset V \) and \( E' \) consists of all those arcs of the graph \( G \) whose both ends belong to \( U \). Each vertex of the graph \( G' \) is associated with a learned object of the distance learning course and, as a quantitative characteristic, is described by degree of mastering \( \lambda_k \in [0;1] \) the educational material connected with the concept \( u_k \).

Let us present **dynamics of the process of studying the educational material** described by the thesaurus \( G = (V, E) \) as a final ordered sequence of the educatee's thesaurus graphs:

\[
\rho = \{ G_1, G_2, \ldots, G_{r-1}, G_r \},
\]

\[
G_i \cap G_{i+1} = G_i, \quad i = 1, r-1,
\]

\[
G_r \cap G = G_r,
\]

\[
\Delta_{i+1} = n(G'_{i+1}) - n(G'_i).
\]

Here \( G'_i \) is a subgraph of the set of vertexes of the graph \( G'_{i+1}, U_i \subset U_{i+1} \); \( G'_j \) is a subgraph of the set of vertexes of the graph \( G' \), \( U_r \subset V \); \( \Delta_{i+1} \) is a quantity of new objects with which the educatee's thesaurus graph \( G'_r \) has been expanded. The set \( \rho \) describes the process of changing the educatee's thesaurus, connected with learning new objects of the study course thesaurus. During learning the study course, there is an expansion of conceptual base of the educatee's thesaurus which leads to increase in relations between the concepts. Let us determine the weight of an object in the educatee's thesaurus, associated with vertex \( u_k \), as product of the degree of mastering \( \lambda_k \in [0;1] \) the study course thesaurus object by the educatee and weight of this object in the study course thesaurus graph.
\[ w'_{k} = \lambda_{k} w_{k} \]. \hfill (23)

Metrics of the study course thesaurus can be used as metrics of complexity of the educatee’s thesaurus.

Degree of correspondence \( \delta(G'_i) \) between the educatee's thesaurus graph \( G'_i \) and the study course thesaurus graph \( G' \) can be determined as follows:

\[
\delta(G'_i) = \frac{I'(G'_i)}{I(G)} \times 100\%,
\]

Here \( I'(G'_i) \) is amount of information in the educatee's thesaurus graph \( G'_i \) which is calculated by the formula (22).

**RESULTS AND DISCUSSION**

To analyze the metrics suggested in this paper (Formulas 8-12, 22, 24), the experiment has been carried out in which the process of studying educational material has been modeled. Educational material thesaurus graph presented in Figure: 2 consists of 50 objects. Entrance objects of the educational material thesaurus are the objects 1, 4, 12, and 44. The educational material thesaurus graph has the following values of the metrics: \( \text{diam}(G) = 8 \), \( n(G) = 50 \), \( R(G) = .020 \), \( Q(G) = .041 \), \( H'(G) = 809 \), \( h(G) = 3.487 \), \( I(G) = 1796.002 \).

![Figure: 2](image_url)

*Educational material thesaurus graph \( G \)*
The purpose of the experiment was tracking the changes in the metric characteristics of the educatee's thesaurus graph formed during studying the educational material.

Initial data for carrying out the experiment are as follows:

Dynamics of the process of studying the educational material presented with the thesaurus graph $G$ is described by the following sequence of changing the educatee's thesaurus graph (See Appendix):

$$\rho = \{G'_1, G'_2, G'_3, G'_4, G'_5, G'_6, G'_7, G'_8, G'_9, G'_{10}\}.$$

Metrics of the educatee's thesaurus graphs are shown in Table: 2.

<table>
<thead>
<tr>
<th>Educatee's thesaurus graph</th>
<th>$diam(G'_i)$</th>
<th>$n(G'_i)$</th>
<th>$R(G'_i)$</th>
<th>$Q(G'_i)$</th>
<th>$H'(G'_i)$</th>
<th>$h(G'_i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G'_1$</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>.400</td>
<td>4</td>
<td>1.000</td>
</tr>
<tr>
<td>$G'_2$</td>
<td>3</td>
<td>10</td>
<td>0</td>
<td>.200</td>
<td>26</td>
<td>1.625</td>
</tr>
<tr>
<td>$G'_3$</td>
<td>3</td>
<td>15</td>
<td>0</td>
<td>.133</td>
<td>39</td>
<td>1.560</td>
</tr>
<tr>
<td>$G'_4$</td>
<td>4</td>
<td>20</td>
<td>0</td>
<td>.100</td>
<td>77</td>
<td>1.833</td>
</tr>
<tr>
<td>$G'_5$</td>
<td>5</td>
<td>25</td>
<td>0</td>
<td>.080</td>
<td>157</td>
<td>2.309</td>
</tr>
<tr>
<td>$G'_6$</td>
<td>5</td>
<td>30</td>
<td>0</td>
<td>.067</td>
<td>204</td>
<td>2.345</td>
</tr>
<tr>
<td>$G'_7$</td>
<td>7</td>
<td>35</td>
<td>0</td>
<td>.057</td>
<td>324</td>
<td>2.723</td>
</tr>
<tr>
<td>$G'_8$</td>
<td>7</td>
<td>40</td>
<td>0</td>
<td>.050</td>
<td>430</td>
<td>2.886</td>
</tr>
<tr>
<td>$G'_9$</td>
<td>8</td>
<td>45</td>
<td>0</td>
<td>.044</td>
<td>499</td>
<td>2.970</td>
</tr>
<tr>
<td>$G'_{10}$</td>
<td>8</td>
<td>50</td>
<td>.020</td>
<td>.041</td>
<td>809</td>
<td>3.487</td>
</tr>
</tbody>
</table>

Figure: 3

Dynamics of changing the degree of correspondence between the metrics $n(G'_i)$, $Q(G'_i)$, $H'(G'_i)$, $h(G'_i)$ and similar metrics of the educational material thesaurus graph.
The metrics based on the graph theory (Formulas 8-12) do not take into account the degree of mastering the objects of the educational material thesaurus by the educatee and therefore will have identical values for identical in topology thesaurus graphs of various educatees. Besides, the process of expanding conceptual base of the educatee’s thesaurus not always means changing values of the metrics \( \text{diam}(G_i') \), \( R(G_i') \) and increase in the metrics \( h(G_i') \) (for example, educatee’s thesaurus graphs \( G_2' \) and \( G_3' \)). The metrics \( n(G_i') \) and \( Q(G_i') \) do not take into account the weight of the objects of the educational material thesaurus; therefore the degree of correspondence between these metrics for educatee’s thesaurus and educational material thesaurus depends linearly on quantity of the objects with which the conceptual base of the educatee’s thesaurus is expanded.

The metrics \( H'(G_i') \) takes into account the weights of the educational material thesaurus objects and can be used only for assessing complexity of the study course thesaurus.

- **Degree of mastering** \( \lambda_k \) the educational material connected with the concept \( u_k \) of the study course thesaurus graph \( G : \lambda_k \in [0;1], \forall k = 1, n \). The quantity \( \lambda_k \) is described by the following concept mastering categories: unsatisfactorily - \([0;0.61)\); satisfactory - \([0.61;0.76)\); good - \([0.76;0.90)\); excellent - \([0.90;1]\). Since in case of unsatisfactory mastering the study course concept all the concepts arising out of it cannot be mastered, the quantity \( \lambda_k \) changed within the interval \( \lambda_k \in [0.61;1] \).

- **Expansion of conceptual base of the educatee’s thesaurus occurs with increments** \( \Delta = 5 \) concepts.

Results of changing the metrics \( I(G_i') \) are shown in Table: 3, and the correspondence degrees \( \delta(G_i') \) are shown in Table: 4.

<table>
<thead>
<tr>
<th>Educatee’s thesaurus graph</th>
<th>( \lambda_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_1' )</td>
<td>( [0.61;0.76) )</td>
</tr>
<tr>
<td>( 1.675 )</td>
<td>( 2.208 )</td>
</tr>
<tr>
<td>( 28.339 )</td>
<td>( 33.437 )</td>
</tr>
<tr>
<td>( 46.415 )</td>
<td>( 57.029 )</td>
</tr>
<tr>
<td>( 127.073 )</td>
<td>( 166.283 )</td>
</tr>
<tr>
<td>( 265.555 )</td>
<td>( 276.504 )</td>
</tr>
<tr>
<td>( 337.307 )</td>
<td>( 389.449 )</td>
</tr>
<tr>
<td>( 459.584 )</td>
<td>( 551.091 )</td>
</tr>
<tr>
<td>( 610.144 )</td>
<td>( 690.862 )</td>
</tr>
<tr>
<td>( 677.172 )</td>
<td>( 809.849 )</td>
</tr>
<tr>
<td>( 1005.884 )</td>
<td>( 1221.713 )</td>
</tr>
</tbody>
</table>
Table: 4
Values of the correspondence degree $\delta(G')$ (%)

<table>
<thead>
<tr>
<th>Educatee's thesaurus graph $G'$</th>
<th>$\lambda_k$</th>
<th>[.61; .76)</th>
<th>[.61; .90)</th>
<th>[.76; .90)</th>
<th>[.76; 1]</th>
<th>[.90; 1]</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_1'$</td>
<td>.093</td>
<td>.123</td>
<td>.173</td>
<td>.273</td>
<td>.329</td>
<td>.376</td>
<td></td>
</tr>
<tr>
<td>$G_2'$</td>
<td>1.578</td>
<td>1.862</td>
<td>2.130</td>
<td>2.668</td>
<td>2.940</td>
<td>3.279</td>
<td></td>
</tr>
<tr>
<td>$G_3'$</td>
<td>2.584</td>
<td>3.175</td>
<td>3.868</td>
<td>4.453</td>
<td>5.083</td>
<td>5.423</td>
<td></td>
</tr>
<tr>
<td>$G_7'$</td>
<td>25.589</td>
<td>30.684</td>
<td>35.479</td>
<td>40.410</td>
<td>42.710</td>
<td>46.243</td>
<td></td>
</tr>
<tr>
<td>$G_8'$</td>
<td>33.972</td>
<td>38.467</td>
<td>44.486</td>
<td>51.530</td>
<td>55.487</td>
<td>59.467</td>
<td></td>
</tr>
<tr>
<td>$G_9'$</td>
<td>37.704</td>
<td>45.092</td>
<td>51.382</td>
<td>55.742</td>
<td>62.431</td>
<td>67.275</td>
<td></td>
</tr>
<tr>
<td>$G_{10}'$</td>
<td>56.007</td>
<td>68.024</td>
<td>75.384</td>
<td>81.146</td>
<td>92.839</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Comparative analysis of the experimental data (Figure: 4) has shown that:

- When the degree of mastering the objects of the educational material thesaurus increases, the degree of correspondence $\delta(G')$ between the educatee's thesaurus graph $G'$ and the educational material thesaurus graph $G$ increases too.

- Increase in complexity of topology of the graph $G'$ caused by expanding conceptual base of the educatee's thesaurus leads to increase in the degree of correspondence $\delta(G')$ between the educatee's thesaurus graph $G'$ and the educational material thesaurus graph $G$.

- The greater the weight of the study course thesaurus objects learned by the educatee, the greater the increment $\Delta \delta$.

Figure: 4
Dynamics of change $\delta(G')$ during expanding the educatee's thesaurus.
These facts allow to conclude that the metric $\delta(G')$ constructed according to the information theory is an objective assessment of the degree of mastering the distance learning course.

**CONCLUSION**

Comparative analysis of metrics of the educational material thesaurus graph has shown that the metric $H'(G)$ (Formula 11) or metric $I(G)$ (Formula 22) can be used for assessing complexity of the distance learning courses. To assess the degree of correspondence between the educational material thesaurus graph and the educatee's thesaurus graph, it is recommended to use the metric $\delta(G')$ (Formula 24) constructed on the basis of the semantic information amount measure since it takes into account the degree of mastering the educational material thesaurus objects by the educatee. The suggested metrics can be used for monitoring the distance learning process.

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**REFERENCES**


Appendix: Dynamics of The Process of Studying Educational Material