international collective monograph

INNOVATIONS IN THE EDUCATION OF THE FUTURE: INTEGRATION OF HUMANITIES, TECHNICAL AND NATURAL SCIENCES

PRAGA 2023

FIT CTU in Prague

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Praga – 2023

DOI 10.5281/zenodo.10277355
UDK 37.018(100):005.591.6
I-66

Approved by the Academic Council of FIT CTU in Prague Protocol No. 08 of 01.12.2023

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Innovations in the Education of the Future: Integration of Humanities, Technical and Natural Sciences : International collective monograph, FIT CTU in Prague 2023. – 722 p.

The collective monograph is the result of the generalization of the conceptual work of scientists who consider current topics from such fields of knowledge as: ecology, mathematics, law, psychology, forensics, national security, state security, pedagogy, digital economy, philology, philosophy, road safety, education

For scientists, teachers, post-graduate students, masters of educational institutions, faculties of higher educational institutions, stakeholders, managers and employees of management bodies at various hierarchical levels and for everyone who is interested in current innovations in the education of the future and problems in the fields ecology, mathematics, law, psychology, forensics, national security, state security, pedagogy, digital economy, philology, philosophy, road safety, education.

ISSN 0-745110-169734

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DOI 10.5281/zenodo.10259802
UDC 004.423

CHAPTER 19.

METHOD FOR USING OF PRODUCTION KNOWLEDGE MODEL IN INTELLECTUAL ADAPTIVE SEMANTIC TESTING

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Abstract. Considered the method for using production knowledge model in intellectual adaptive semantic testing that allows to calculate the estimation of knowledge level of educational materials by using indicators of semantic importance of key terms for adaptive test tasks selection in testing. Each test task allows to purposefully check the knowledge level of separate semantic units of educational materials key words and phrases. It is assumed that increasing the depth of learning of educational material semantic content has the effect of learning less semantically important units of educational materials. Semantic terms are related to the semantic structure of educational material in the form of rubricational system. Test tasks are related to elements of educational material content, knowledge level of which they are tested. In the process of testing, the level of knowledge of each of semantic structure elements of the educational material is consistently adaptively determined. Final grade is calculated based on level of knowledge of semantic structure elements results. As a result of adaptive selection of test tasks, their maximum possible diversity in the final set is reached, because following criteria of production rules are considered: relevant fragment of educational content has not been checked, test tasks of corresponding type were used the least, test task has not been used yet, the test task does not contain less important semantic units. The developed method for using production knowledge model in intellectual adaptive semantic testing makes possible to use different algorithms for starting testing (progressive, regressive, medianic, etc.) and different algorithms for knowledge level estimation (absolute limit, average, etc.). In the developed method for using production knowledge model in intellectual adaptive semantic testing, production rules are used both for generating test tasks and for choosing further actions in various situations during adaptive testing. Applied investigations of the developed method effectiveness in comparison with the traditional algorithm for selecting test tasks established, that testing speed increased an average of 20.53% faster test, and to determine the level of knowledge required the use of an average of 19.33% fewer test tasks.

Keywords: adaptive testing, dispersion evaluation, tests generation, key terms, production model, production rules, educational course

Introduction. The production knowledge model suggests using production rules for select responses to complex combinations of input metadata to make intelligent decisions[1]. Considered use of production rules both for generating test tasks and for choosing further actions in various situations during adaptive testing in the task of intellectual adaptive semantic testing.

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One of the most important indicators of a high-quality educational model is the control of knowledge level[2,3]. The control of knowledge level should be based on the content and material of the educational course in which it is conducted. The basis of the course is educational material that reveals its issues and is the basis for the formation of knowledge. The educational material is complex system that has its own structure with specific elements and relations between them[4]. As the basis of the learning process, the educational material includes all the information that is submitted for learning and promotes learning. The educational material is considered as the set of two pieces of information: basic and auxiliary. The ultimate goal of presenting basic information is to turn it into knowledge or skills. Auxiliary information aims to ensure the reliability of learning of basic information[5,6].

The purpose of this research is the developing of method for using production knowledge model in intellectual adaptive semantic testing, which using production rules both for generating test tasks and for choosing further actions in various situations during adaptive testing.

Literature review and methodology The most objective means for estimation of the knowledge level is currently considered testing, which allows to impartially estimating the academic achievements of students. Computer testing makes it possible to implement the basic didactic provisions of learning control: the principle of individual nature of testing and estimation of knowledge; systematic testing and estimation of knowledge; the principle of subjectivity; the rule of differentiated estimation of progress[7]. At the present stage, under conditions of quarantine restrictions and anti-epidemiological measures, distance computer testing and adaptive technologies of distance education become especially important in the learning process.

Computer testing can be performed in various forms, differing in the technology of combining tasks into a test[8]:

– traditional testing – is a random selection to the working sample of a set of test tasks, fixed by the number or estimated time of execution;

– parameterized testing – is author-created templates of test tasks, in which some elements can be changed (parameters);

– adaptive testing – in which the composition of the working sample of test tasks is unknown in advance, and subsequent test tasks are selected automatically depending on the answers to previous.

Traditional testing is the easiest to implement, allows to see the dynamics of testing and does not set significant requirements for the number of test tasks in the base set. However, there are the following problems of computer testing in the traditional form[9]:

– the set of test tasks received by the user may not completely cover the semantic structure of the educational material;

– for fully cover the semantic structure of the educational material requires a large number of test tasks;

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– the estimation does not take into account the growing level of complexity of test tasks due to the use of terms of different levels of semantic significance in the content;

– fixed amount of test tasks is used regardless of the success of the testing process.

The disadvantage of parameterized tests is the labor intensity of manually forming of many test tasks templates. The advantage of the approach is the ability to create a very large number of test tasks by a small number of test tasks templates[10]. That's way he field of application of parameterized tests is mainly automation of formation mathematical tasks. However, much of the content of many educational courses contains mostly textual content, which is characterized by the consistency and semantic coherence of the presentation. Due to the above reasons, adaptive testing is more effective than the traditional approach of random selection of test tasks to check the level of knowledge of educational material.

Adaptive testing allows to accurately determine the level of learning of material, avoids the use of excessive number of test tasks, but requires a very large number of test tasks in the base set. Also, adaptive testing requires the mandatory definition of a number of parameters of each test task (complexity, semantic relation with the educational material) for its adaptive use[11].

The field of application of parameterized tests is mainly automation of formation of mathematical tasks. However, much of the content of many educational courses contains mostly textual content, which is characterized by the consistency and semantic coherence of the presentation. Due to the above reasons, adaptive testing is more effective than the traditional approach of random selection of test tasks to check the level of educational material.

There are several approaches to adaptive testing, which involve adaptive selection of test tasks according to the parameters of expert assessment of their complexity, including the cross-section of structural elements of educational material, such as paragraphs. Problems of existing approaches to adaptive testing are:

– need to create a large number of test tasks that fully cover the educational material;

– selection of the criterion for assessing the complexity of test tasks and its calculation for each test task;

– calculation for each test task of a number of parameters, including parameters of semantic connection with educational material;

– a variety of basic and working sets of test tasks on a number of parameters (type of test task, a fragment of content that is checked, etc.);

– providing semantic coverage of educational material in the testing process.

At the present stage, it is considered promising to create the required set of test tasks automatically. In addition to the use of parameterized tests, there are known methods of generating test tasks by the conceptual-thesis model, by the ontology of the subject area, by the formalization of structured text statements. In general, the existing means of automating the creation of test tasks are focused on methods of artificial intelligence using the theory of ontologies, which makes them cumbersome and inefficient.

It is known that increasing the depth of learning of the semantic content of educational material has the effect of learning less and less semantically important units of educational materials. Semantic units of educational materials are key terms (keywords, key phrases, abbreviations, etc.), which have different indicators of semantic weight or importance. Semantic terms are the lower level of the semantic structure of educational material in the form of a system of rubrication. Therefore, each test task should purposefully check the level of knowledge of specific semantic units of educational materials for a specific fragment of educational material. Depending on the success of the answers, test tasks are offered to check the assimilation of more or less semantically important units of educational material to determine the level of learning of the content of each element of the rubrication of educational material. Based on these results, the final score for the test is calculated.

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[10] M. J. Gierl, H. Lai, L. B. Hogan, D. Matinovic. (2015). A method for generation educational test items that are aligned to the common core state standards, in: Journal of Applied Testing Technology, vol. 16(1). pp. 1–18

[11] D. C. Ince. (1987). The automatic generation of test data, in: The Computer Journal, Vol. 30, Issue 1. pp. 63–69

The Results of the investigation is the developed method for using production knowledge model in intellectual adaptive semantic testing and its components: information model of the semantic structure of the educational course, method of automated formation of the semantic structure of educational materials, method for automated determination of semantic terms sets, method for automated test tasks creation for educational materials and method for adaptive semantic testing of educational materials level of knowledge.

The ***information model of the semantic structure of the educational course*** *C*[12], developed by the author, is a formal representation of the educational course. It covers the complete semantic structure of the educational material *I* and the set of test tasks *T*, contains the relations *R* of these components and their parameters (Fig. 1). The semantic structure of the course *C* is presented as follows:

$$C = I \cup T = H \cup S \cup K \cup Q, \quad (1)$$

$$R = R_1 \cup R_2 \cup R_3 \cup R_4 \cup R_5 \cup R_6, \quad (2)$$

where *H* – the set of headings (rubrics), *S* – the set of fragments (eg sentences) of educational material, *K* – the set of key terms, R_1 – the set of relations between headings, R_2 – the set of relations between headings and fragments, R_3 – the set of occurrences key terms (relations between key terms and fragments), R_4 – the set of relations between headings and key terms, R_5 – the set of relations between test tasks and fragments, R_6 – the set of relations between test tasks and key terms.

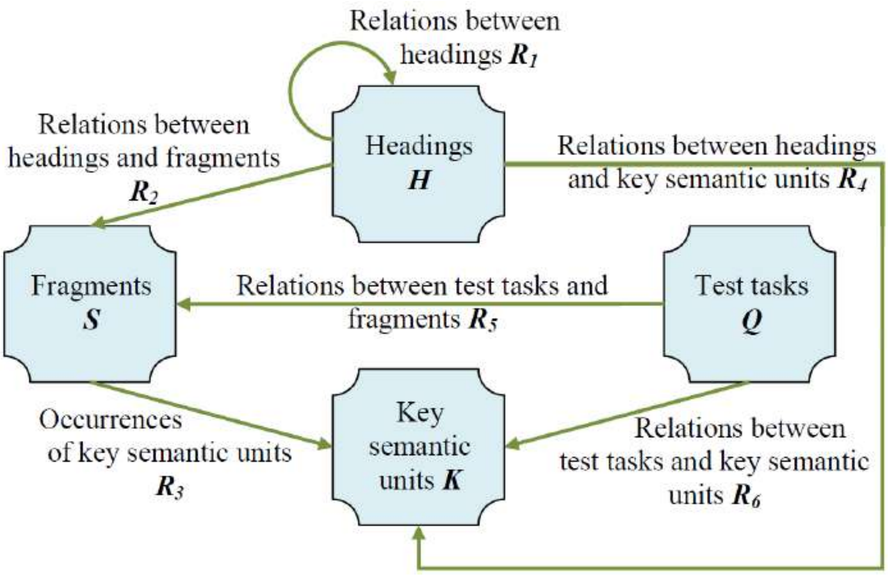

Fig. 1. Relations between model parameters

[12] O. Barmak, I. Krak, O. Mazurets, S. Pavlov, A. Smolarz, W. Wojcik. (2020). Research of efficiency of information technology for creation of semantic structure of educational materials, in: Advances in Intelligent Systems and Computing, vol. 1020, pp. 554–569

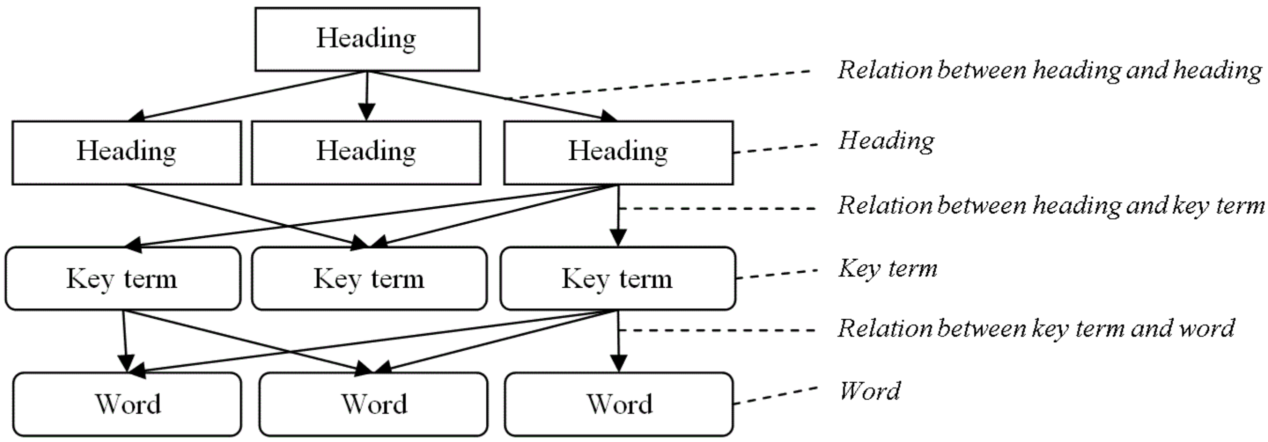

Fig. 2. Example of using elements of the set of entities of the educational material to represent the semantic structure of the educational material

Example of using elements of the set of entities of the educational material to represent the semantic structure of the educational material can be presented in the form Figure 2. Defining of all the elements of this model opens the possibility of adaptive semantic testing of the level of knowledge of educational materials according to the described method.

So, the ***method of automated formation of the semantic structure of educational materials***[13] as a result of parsing of the content of the corresponding digital files, determines the elements of the sets of headers *H*, fragments *S* and the corresponding relations between them:

$$H = (ID, Name, Grade), \quad (3)$$

where the attribute *ID* – a unique identifier of the heading, *Name* – the name of the header, *Grade* – the heading level in the hierarchical structure.

$$S = (ID, Content, Number, Type), \quad (4)$$

where the attribute *ID* – a unique identifier of the fragment, *Content* – fragment content, *Number* – fragment number within the header, *Type* – fragment type.

On the next step of the method, the content of each element of the set of headers *H* is processed to search for lower-level semantic units in the form of key terms. First, a set of all possible candidate-terms is formed, their occurrence in the content is searched, the numerical value of their importance is determined using the method of disperse estimation, their number in the resulting set is limited using the method of limiting keyword density[14]. These operations result in elements of the set of key terms *K* and the corresponding relations:

$$K = (Name, Num), \quad (5)$$

where *Name* – the symbolic name of the term, *Num* – the number of words in the term.

The elements of the semantic structure of educational materials, found by means of the method, allow to carry out purposeful creation of test tasks for the further purposeful check of level of knowledge of concrete semantic units of educational materials, on concrete elements of semantic structure of educational materials. To do this, the method captures the relevant fragments of educational materials and the appearance of key terms in them.

In accordance with the method of automated formation of the semantic structure of educational materials (Fig. 3), it's possible to identify two sequential stages of information transformation. The result of these actions is the filling of all sets of the information model of the semantic structure of the educational materials, which makes it possible to use it to solve the described application problems.

[13] O. Barmak, O. Mazurets, I. Krak, A. Kulias, A. Smolarz, L. Azarova, K. Gromaszek, S. Smailova. (2019). Information technology for creation of semantic structure of educational materials, Photonics Applications in Astronomy, Communications, in: Industry, and High-Energy Physics Experiments, vol. 11176

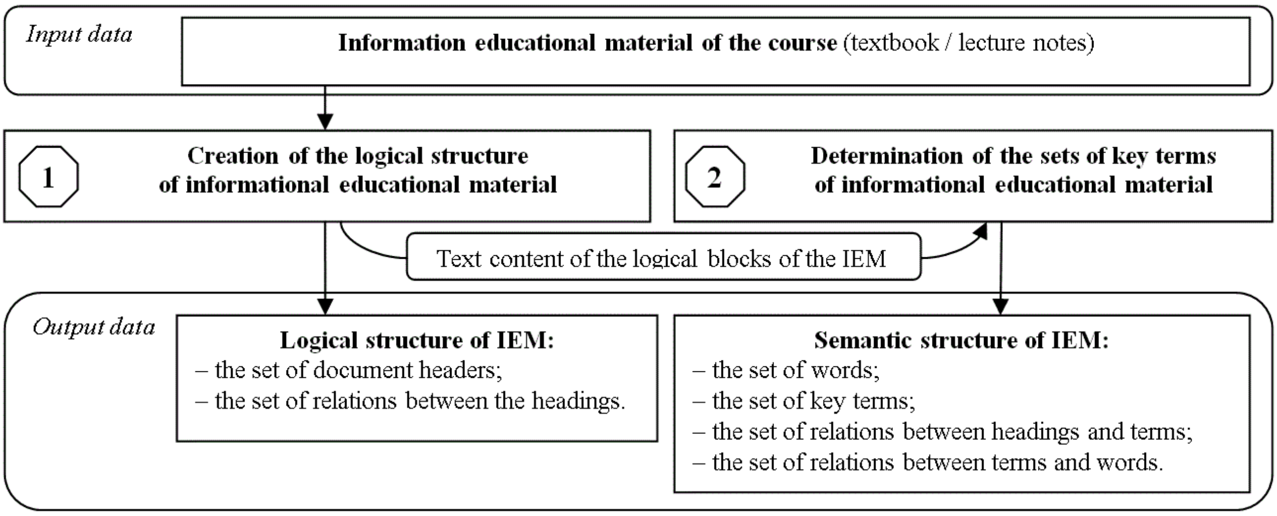

Fig. 3. The general scheme of method of automated formation of the semantic structure of educational materials

The input data of the method of automated formation of the semantic structure of educational materials is the file of the electronic document (for example, .docx format) with poorly structured text content of the educational materials containing the structure of the document in the form of headings, as well as the corresponding text theoretical information.

In the process of execution Block 1 (creation of the logical structure of informational educational material) of method of automated formation of the semantic structure of educational materials, creation of the levels of the logical structure of the educational materials is carried out. These levels correspond to the author's specified hierarchical structure of the educational materials in the form of a system of headings of different levels used in electronic documents with poorly structured text content, and is implemented by determining the set of existing documents headings H and determining their relations by generating the set of unidirectional relations between the headings R_1. Also, in this step, the corresponding texts of the headings are determined automatically for further analysis.

When execution Block 2, the automated determination of the sets of key terms T of the educational materials for the logically separate fragments of the text content of the educational materials, determined in the previous stage, is carried out. As a result of processing, the set of key terms sorted by the semantic value for each of the fragments are determined. The determination of sets of key terms proceed using the dispersion estimation method, filtering according to portraits of key terms, evaluating the semantic importance of key terms, and automatically limiting the sets of key terms. Consequently, the lower, semantic level of the structure of the educational materials corresponds to the set of key terms T, which is matched to elements of the set of headings by means of the corresponding relations R_2, which form the set of relations between the headings and the key terms. Each term is an ordered collection of words, defined by the set of the words and the set of relations between the words and the terms.

Accordingly, the output data of the method are defined elements of all sets of the information model of the semantic structure of the educational materials.

Thus, the method of automated formation of the semantic structure of educational materials developed allows to automate the creation of the logical structure of the informational educational material and to fill all the sets of the information model of the semantic structure of the educational materials. This makes it possible to use it to solve engineering problems.

Developed by the author ***method for automated determination of semantic terms sets*** in the content of educational materials, the input data is the content of the educational material or its defined part in the form of .docx file of any hierarchy of elements[14]; the output data is the set of

[14] Y. Krak, O. Barmak, O. Mazurets. (2018). The practice implementation of the information technology for automated definition of semantic terms sets in the content of educational materials, in: CEUR Workshop Proceedings, vol. 2139. pp. 245–254

semantic terms of the educational material K and the set of relations between headings and key terms R_2; the process of automated determination of the set of semantic terms consists of several stages of the transformation of information.

Digital educational materials .docx files are organized using the open XML format, which stores documents as collections of individual files and folders in a compressed package. To implement software processing of digital documents, it is advisable to use specialized software packages that provide object-oriented tools for software work with the content of the corresponding files, such as Microsoft.Office.Interap.Word.dll, DocumentFormat.OpenXml.dll and Spire.Doc. dll. As part of the developed test software, the Spire.Doc.dll extension was used, which provided both analysis of the levels of the Heading document structure and access to content elements, in particular TextRange, which is the lowest level of the document structure, which defines a text fragment of the same style. Transferring functions of automatic matching of styles of text blocks to their properties from the functional level of the application program code to the functional level of the library made it possible to simplify both the work of the system with a digital document and the programming process.

According to the results of the analysis of more than 1300 elements of educational materials with experts (compilers) representative sets of key terms, it has been established that all elements of the set of sets K correspond to the following regularities:

1. The number of words in the term $n = 1..6$.
2. If the term is a word ($n = 1$), then it is included in the set of the nouns M_N.
3. If the term is a phrase ($n>1$), then it consists of elements of the set M_M. The set M_M consists of sets of semantically meaningful elements (set of nouns M_N and set of adjectives M_A) and semantically binding elements (set of conjunctions M_S, set of numeral M_{Num} and set of prepositions M_P).
4. If $n>1$, then the phrase contains at least one element from the set of nouns M_N.
5. If $n>1$, then the first ($k = 1$) and the last ($k = n$) words are elements of the set of semantically meaningful elements.
6. If $n>1$, there are no punctuation marks between the elements of the phrase (except for the hyphen inside complex nouns, which is part of the word).
7. All elements (symbols, words) of the same term in the text have the identical stylistic properties, so they belong to the same container *TextRange* in the structure of the digital document

As a result of the use of this method, the aim is to create sets of terms M_T, which correspond to the above laws[15].

Fig. 5 provides the sequence of steps for the automated creation of sets of semantic terms in the content of educational materials, which shows the sequence of stages of data transformation to achieve the ultimate goal.

[15] I. Krak, O. Barmak, O. Mazurets. (2016). The practice investigation of the information technology efficiency for automated definition of terms in the semantic content of educational materials, in: CEUR Workshop Proceedings, 1631. pp. 237–245

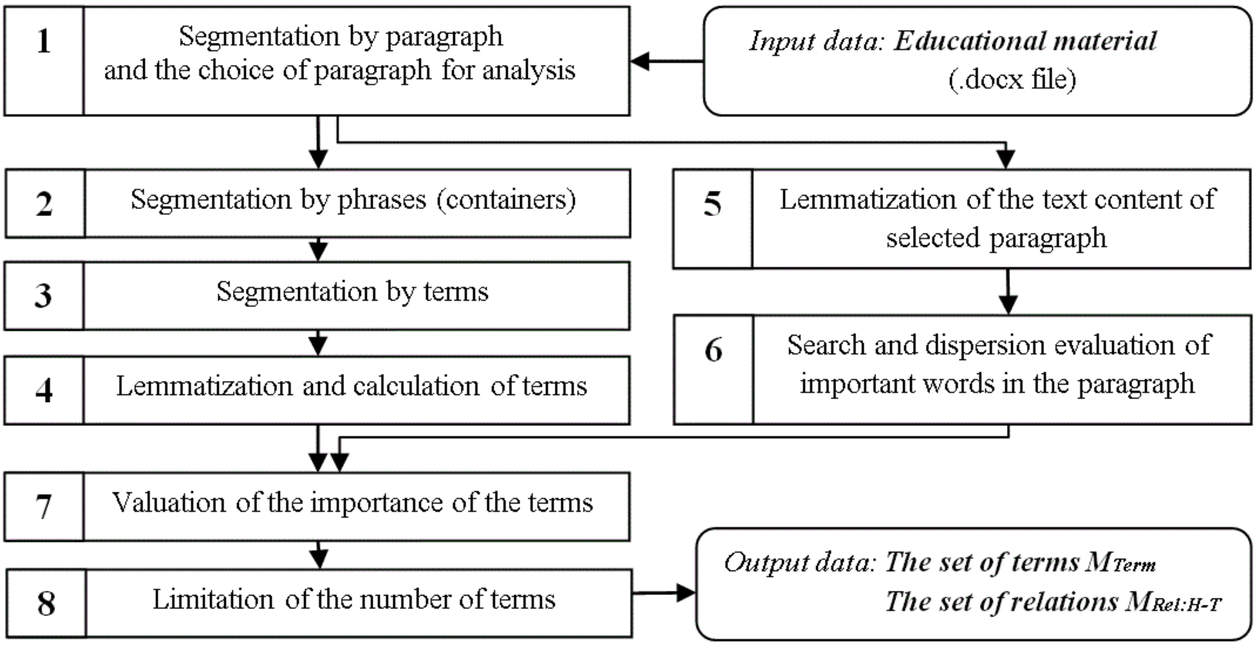

Fig. 5. General scheme of method for automated determination of semantic terms sets

Segmentation by paragraphs and selection of paragraph for analysis (Step 1) consists in analyzing the structure of a digital document. It is based on the natural correspondence of the hierarchical system of headings of educational materials as electronic documents to the upper levels of the logical structure of the educational material of the discipline. For example, the titles of the disciplines correspond to elements of the standard "Heading 1" style, titles of chapters – "Heading 2", topic titles – "Heading 3", etc. Consequently, the structure of educational materials as digital documents is regulated in the languages of marking of digital documents and is implemented through the system of headings. Output data of Step 1 are defined fragments of content of the digital document of the educational material, which will be further processed individually.

Segmentation by phrases (Step 2) is used to split a fragment of content in a digitized document, which is processed, into smaller fragments – phrases, or containers. The phrase is a semantically integral node, distinguished by stylistic text formatting or punctuation, and localizes the location of separate terms. According to the document's object model, MS Office uses *Sections* object to localized parts of the document that have different formatting. The Section objects are contained in the *Document* object (Fig. 6) in the Collection *Selections*. *Sections* contain smaller elements of the structure – *Paragraphs*. And *TextRange* is the lowest level of document structure that defines a text fragment of the identical style within *Paragraph*.

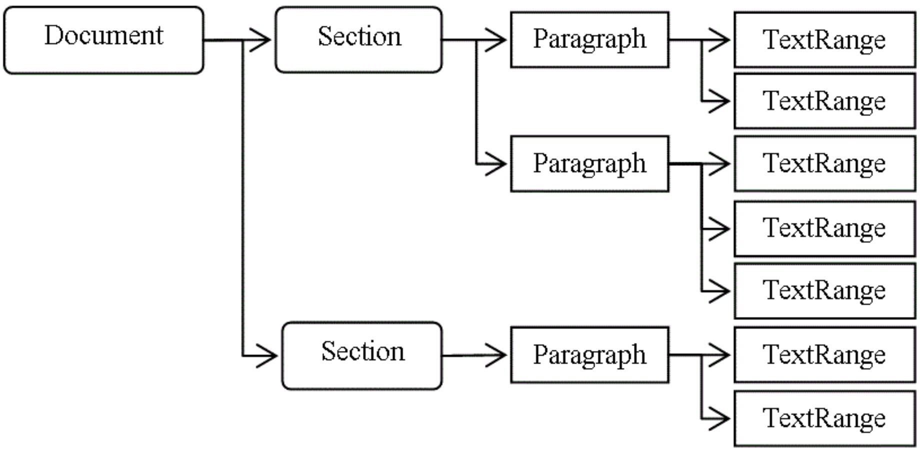

Fig. 6. General structure of the object model of MS Office document

Consequently, the set of phrases include continuous ordered sequences of words that do not extend beyond the limits of the *TextRange* digital document containers and are not interrupted by punctuation marks. Getting as a result of the Step 2 sets of phrases allows to further process each of the phrases separately for the search terms.

Segmentation by terms (Step 3) intended for create the set of all possible terms that are present in the content being analized.

At first, the set of terms of the educational material M_T includes all possible continuous sequences of words that are not beyond the limits of the phrases and are consistent with the condition:

$$M_T = \{\langle x_1, x_2, x_3, x_4, x_5, x_6 \rangle | x_1, x_2, x_3, x_4, x_5, x_6 \in M_M, \langle x_1, x_2, x_3, x_4, x_5, x_6 \rangle \cap M_N \neq \varnothing\}, \quad (6)$$

where M_M – the set of semantically meaningful elements (nouns M_N and adjectives M_A) and semantically binding elements (conjunctions M_S, numeral M_{Num} and prepositions M_P), $M_M = M_N \cup M_A \cup M_S \cup M_{Num} \cup M_P \cup \varnothing$, M_N – set of nouns.

Segmentation by terms is executed using the database of the corpus of words of actual language and as output data forms the set of terms M_T contained in the processed fragment of the digital document of the educational material.

Lematization and calculation of terms (Step 4) allows, on the basis of the set of terms M_T, to form the set of lematic-independent terms M_{T1} and compare each of them the number of occurrences in the text. To do this, at first makes the lematization of each word in each phrase in the set M_T. Under the lematzation, means the translating of words to the infinitive state – for example, the nouns are translated into the singular form. After that, the resulting set is processed and compacted in such the way that all identical duplications of terms is deleted, and for each term, the value K_n is summed up. This value K_n reflects the found number of occurrence of each term *n* in the input set M_T.

Since at the stage of forming the set of terms M_T, all possible variants of the terms from the phrases were added to it, without absorption by smaller words, in this step an analysis of the need for such an absorption is made as follows. If there is a term n_1 in the set M_{T1} (K_{n1} – the amount of occurrence of the term n_1 in the set M_{T1}), which is an ordered set of x_1 words, and the term n_2 (K_{n2} – the number of occurrence of the term n_2 in the set M_{T1}), which is an ordered set of x_2 words, and n_1 is a subset of n_2 and $x_1<x_2$, then, with the correctness of the equation $2x_1>x_2$, the term is deleted from the resulting set. In order to facilitate further processing from the resulting set M_{T1}, it is also advisable to delete all terms in which K_n=1, because the once use of the term excludes the fact of considering the concept of term in this fragment of the educational material.

The resulting set of lematic-independent terms M_{T1} contains terms that at the same time form the set M_{Term}. These are the terms used in the educational material with a quantitative usage indicator, but the importance of these terms has not yet been determined.

Lemmatization of the text content of selected paragraph (Step 5) transfotms the text of a defined content fragment of the digital document with educational material being analyzed to the corresponding sequence of words in the infinitive state, which is the input data of this step. They allow the further evaluation of the word dispersion.

Search and dispersion evaluation of important words in the paragraph (Step 6) is intended to evaluate the importance of each word in the text fragment using the dispersion evaluation method.

This method is an estimate of the discriminant weight of words. The method of dispersion evaluation allows to exclude from the general set of widely used words in the text of word, which are arranged evenly. The method of dispersion evaluation has shown its high efficiency in previous researches. If some word *A* in a text consisting of *N* words is indicated by A_k^n, where the index *k* – the number of the occurrence of the given word in the text, and *n* – the position of the given word in the text, then the interval between successive occurrences words in such notation will be the value $\Delta A_k^m = A_{k+1}^m - A_k^n = m - n$, where the word "*A*", which occurrences *k*+1 and *k* times, is located on the *m*-th and *n*-th positions in the text. Thus, the dispersion evaluation is calculated by the equation

$\sigma = \sqrt{(\Delta A^2) - (\Delta A)^2} \Big/ (\Delta A)$, where (ΔA) – the average value of the sequence ΔA_1, ΔA_2, ΔA_k; (ΔA^2) – sequences A_1^2, A_2^2, A_k^2; K – the number of occurrence of the words A in the text.

The input data of this step is the lemmatized text content of an investigated fragment of the digital document of the educational material; the output data is an ordered set of words, each of which compares the estimation of its dispersion, which is positioned as an estimate of the importance of the given word in the investigated fragment of the educational material.

Valuation of the importance of the terms (Step 7) as the input data has a set of lematic-independent terms M_{T1} with the matching of each of them the number of occurrences in the investigated text, and an ordered set of words with a matching of each of them with an estimate of its importance (dispersion) in the investigated text.

The importance v_n for each term n from the set M_{T1} is calculated by the formula:

$$v_n = \sum_{i=1}^{x_n} \frac{K_n \sigma_n}{k_n} \tag{7}$$

where K_n – the number of occurrences of term n in the set M_{T1}; k_n – the number of occurrences of the i-th word of the term n in the lemmatized text fragment; σ_n – dispersion evaluation of the i-th word of the term n; x_n – the number of words in the term n.

The output data of this step is the set of lematic-independent terms M_{T1} with the matching for each of them the number of occurrences in the investigated text and the value of the importance evaluation, sorted by decreasing the nominal value of the importance evaluation.

Limitation of the number of terms (Step 8) is intended to the creation of the set of key terms by input data – the set of lematic-independent terms M_{T1}. The set of key terms is created on the basis of of lematic-independent terms from the set M_{T1} with the highest values of importance evaluation. The number of key terms is recognized through a well-known semantic text processing knowledges, keyword density. The keyword density D is the ratio of the number of words in the key terms in the text to the total number of words in the text:

$$D = \sum_{i=1}^{n} \frac{K_n x_n}{X_{txt}} \tag{8}$$

where K_n – the number of occurrences of term n in the set M_{T1}; x_n – the number of words in the term n; X_{txt} - the total number of words in the text; n – current number of terms in the set M_{TK}.

The algorithm is based on the fact that the terms from the set M_{T1} with the highest values of importance evaluation are added to the empty resulting set of key terms M_{TK} until the equality is satisfied (for example, for D = 7%): $D \leq 0.07$.

The output data of the step and respectively of the method of keyword density are: a set $M_{TK} = M_{Term}$ of the key terms corresponding to the investigated content fragment of the digital document of the educational material; the set of relations between the headings and the key terms $M_{Rel:H\text{-}T}$, for each element of which the attribute *Feature* = v is defined as the numerical indicator of the importance of this term in this investigated fragment of the educational material.

Thus, the proposed approach allows, on the basis of a digital document of the educational material, to automate the creation of the corresponding set of key terms K and the set of relations between the headings and key terms R_2.

Developed by the author ***method for automated test tasks creation for educational materials*** based on previously obtained data, allows to automatically create test tasks sets that differ in parameters (number of correct answers, type of question, the rule for which the test task is formed, semantic units used in the task, etc.) and can be used for traditional and adaptive testing of the knowledge level acquisition, including with the help of existing learning environments or testing systems[16,17]. The method creates new test tasks using production rules[18,19] and does not require additional formalization of content of educational materials. The production rule as basic constructive element of such model can be represented as follows: *IF <condition> THAN <action>*, so the rule consists of a conditional and an effective part an antecedent and a consequence (Fig. 7)[20].

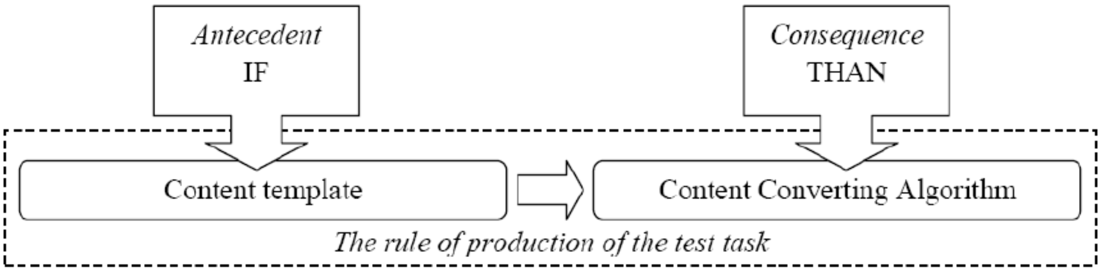

Fig. 7. Example of production rule construction for test tasks creation

The antecedent is some fragment-template, which is searched; and the consequence – the algorithm for converting a content fragment into the content of test task components (Fig. 8).

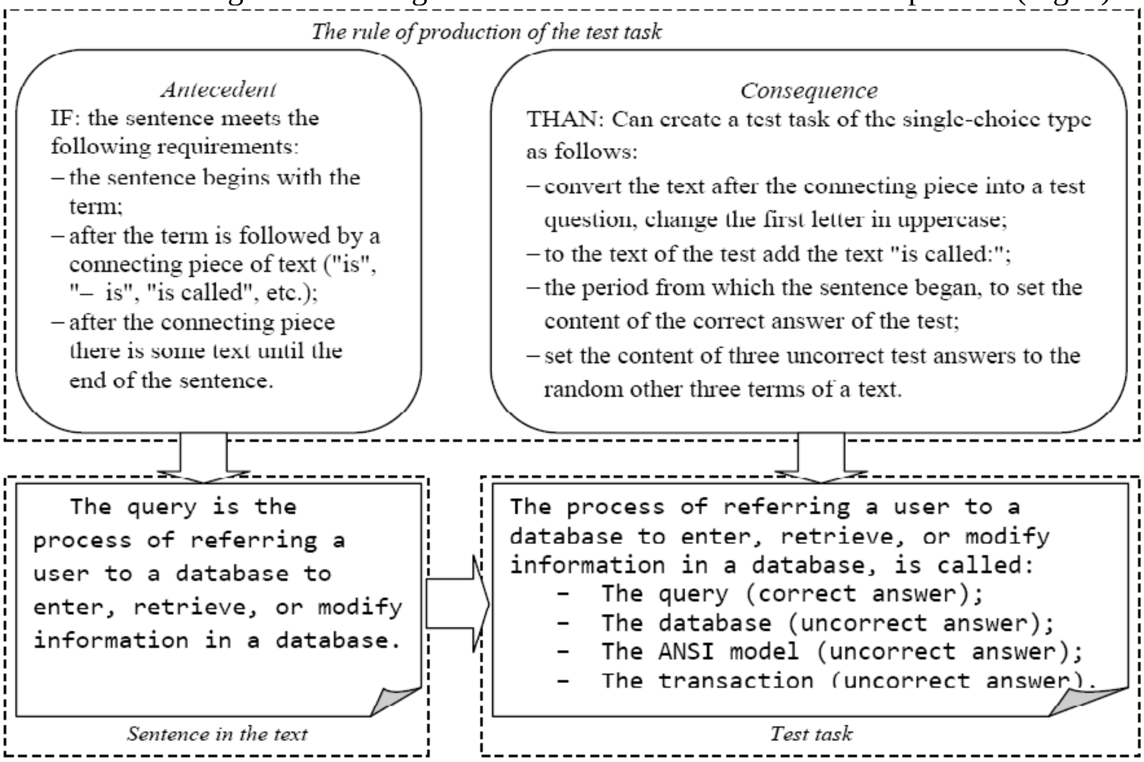

Fig. 8. An example of the production rule for creating of test task prototype

To create a set of test tasks, each fragment $s \in S$ from each heading $h \in H$ of the document $i \in I$ is checked for the presence $p \in P$ of each key term $k \in K$, compared to this heading h. If the

[16] O. Barmak, O. Mazurets, I. Krak, A. Kulias. (2020). Method for automated test tasks creation for educational materials, in: CEUR Workshop Proceedings, vol. 2711. pp. 309–320

[17] O. Mazurets, O. Barmak, I. Krak, M. Molchanova, O. Sobko. (2021). Information Technology for Adaptive Semantic Testing of Knowledge Level of Educational Materials. Conference Paper. Proceedings of the 11th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2021, vol. 1, pp. 160–165

[18] H. Liu, A. Gegov, M. Cocea. (2016). Rule-based systems: a granular computing perspective, in: Granular Computing, vol. 4. pp. 259–274

[19] I. Baki, H. Sahraoui. (2016). Multi-step learning and adaptive search for learning complex model transformations for examples, in: ACM Transaction on Software Engineering and Methodology, vol. 25(3). pp. 1–37

O. Mazurets, O. Barmak, I. Krak, E. Manziuk, R. Bahrii. (2022). Method for Adaptive Semantic Testing of Educational Materials Level of Knowledge. Book Chapter. Lecture Notes on Data Engineering and Communications Technologies. Vol. 77. pp. 491–506 term k is present in the fragment s, then the search of product rules for compliance with the antecedence of the rule. Each case of correspondence results in the automatic creation of a new test task $q \in Q$. The consequence determines the algorithm for converting the content of the fragment p into a test task q. Thus creating the elements of the set of test tasks Q and the corresponding relations:

$$Q = (ID, Type, TEContent, Answers), \tag{9}$$

where ID – unique identifier of the test task, $Type$ – type of question, $TEContent$ – content of the test task including answers, $Answers$ – number of answers.

Respecting to the set of relations R between the elements of the considered sets, the general structure is:

$$R = (TypeRel, Obj1, Obj2, Feature), \tag{10}$$

where $TypeRel$ – the integer indicating the type of relation; $Obj1$ – the first entity of the relation; $Obj2$ – the second entity of the relation; $Feature$ – the attribute that indicates the relation property.

Depending on the attributes of the $Obj1$ and $Obj2$ belonging to separate sets, the $TypeRel$ attribute accepts the values given in Table 1.

Table1. List of values of the *TypeRel* attribute for the elements of the set R

TypeRel **value**	**Affiliation Obj1**	**Affiliation Obj2**	***Feature*** **value**
1 (R_1)	$h \in H$	$h \in H$	non-available (Null)
2 (R_2)	$h \in H$	$s \in S$	position of the fragment within the heading
3 (R_3)	$k \in K$	$s \in S$	position of the key term within the fragment
4 (R_4)	$h \in H$	$k \in K$	numerical indicator of the importance of the key term
5 (R_5)	$q \in Q$	$s \in S$	place of content use (task or answer)
6 (R_6)	$q \in Q$	$k \in K$	place of term use (task or answer)

As a result of using the method, for each occurrence of each key term, a number of different test tasks are created, which provides complete semantic and content coverage of educational material by a set of automatically created test tasks. In addition, the method provides storage of metadata for positioning each test task and its components in the semantic structure of the educational material, which is necessary for further adaptive testing of the knowledge level.

The developed ***method for adaptive semantic testing of educational materials level of knowledge*** makes it possible to determine the assessment of the level of knowledge of educational materials by using indicators of semantic importance of key terms for adaptive selection of test tasks in testing (Fig. 9) [23].

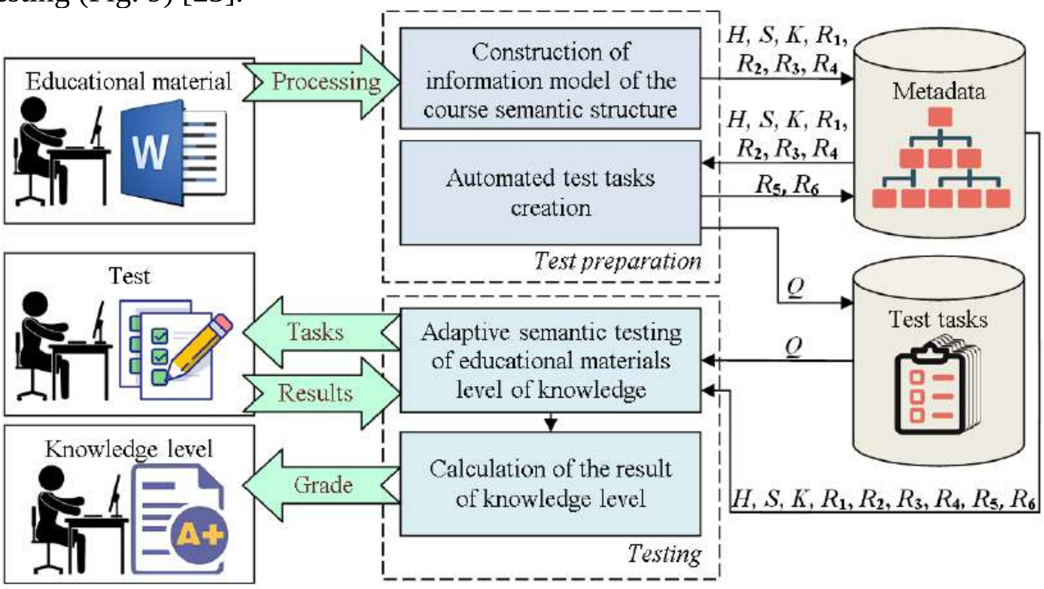

Fig. 9. Scheme of implementation of adaptive semantic testing of the level of knowledge

The *input data* of the developed method are elements of information model of semantic structure of educational course C, in particular set of test tasks Q and metadata for adaptive semantic testing of knowledge level: set of headings *H*, set of fragments of educational material *S*, set of key terms *K*, set of relations between headings R_1, set of relations between headers and fragments R_2, set of occurrences of key terms R_3, set of relations between headers and key terms R_4, set of relations between test tasks and fragments R_5, set of relations between test tasks and key terms R_6. The method also requires parameters: the element of semantic structure selected for testing, the algorithm for starting testing and the algorithm for assessing the level of knowledge (Fig. 10).

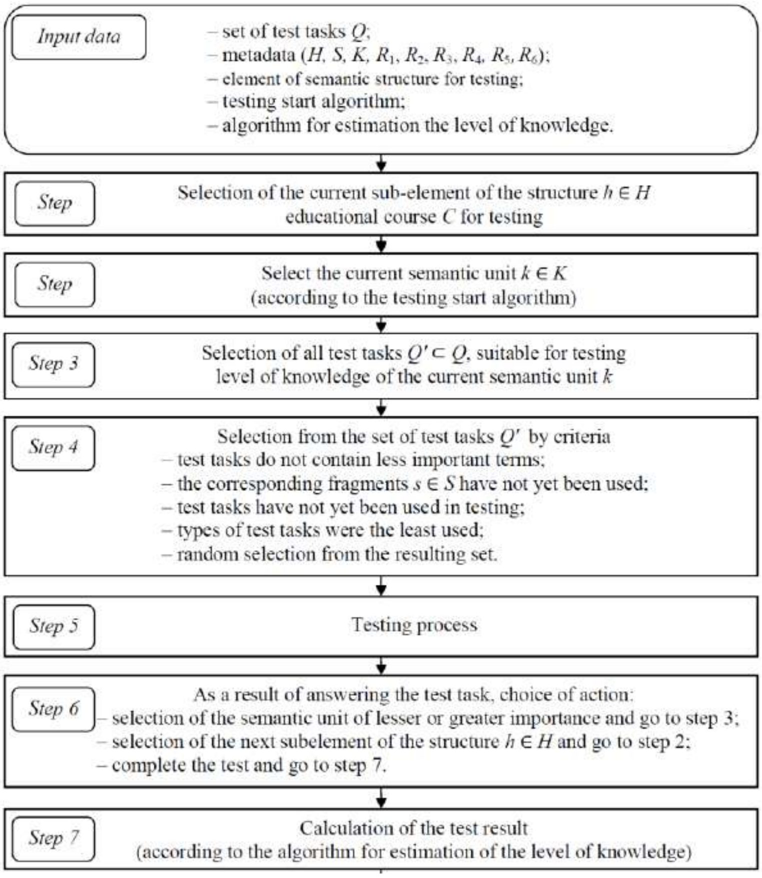

Fig. 10. Scheme of method for adaptive semantic testing of educational materials level of knowledge

In *Step* 1, within the content of the selected element of the semantic structure for testing, the current subelement $h \in H$ of the educational course *C* is selected for further testing.

In *Step* 2, from the set of semantic units $k \in K$ of the current subelement $h \in H$ of the educational course, the current semantic unit $k \in K$ is selected, the learning of which will be checked in this iteration. The selection of the current semantic unit *k* is carried out according to the specified test start algorithm. Next, in *Step* 3, is created a sample of all test tasks $Q' \subset Q$, suitable for checking the level of knowledge of the current semantic unit *k*.

In *Step* 4, irrelevant test tasks are removed from the obtained set Q'. Namely, remain (or receive a positive rating) test tasks that accord the criteria:

– test tasks do not contain less important terms;

– the corresponding fragments $s \in S$ of the educational material have not been used yet;

– test tasks have not yet been used in this testing;

– types of test tasks were the least used.

If in obtained result in set of actual test tasks $Q'' \subset Q'$ there are several test tasks, then a random selection of a test task from Q'' will be applied.

In *Step* 5, is directly the testing process: the test task is provided to the user and the received answer is recorded. Depending on the correctness of the answers to the test tasks, in *Step* 6 the following action is selected:

– applies the selection of the semantic unit k ∈ K of lesser or greater importance and go to Step 3 – if the data for estimation the knowledge level of current sub-element h ∈ H of the course is still insufficient;

– applies the selection of the next subelement of structure h ∈ H and go to Step 2 – if the data to estimation the level of knowledge of current sub-element h ∈ H of the educational course is sufficient, but there are other untested subelements h ∈ H;

– test is completed and go to Step 7 – if the data to estimation the level of knowledge of current subelement of the educational course is sufficient and all subelements h ∈ H are checked.

The production rules for choice of further action depends both on the correctness of the answer to the last test task, and on the general dynamics of the testing process (Table 2). In addition to the usual approach *A* (rapid testing), when the level of knowledge of each semantic unit is checked only once, testing with confirmation *B* is possible. In the case of confirmation testing, each change in the level of knowledge of semantic units requires confirmation the specified number of times, and after this number of iterations, option *A* is selected.

Table 2. Production rules for action choice in adaptive semantic testing

Local test result	**Additional condition**	**Action**
Test task solved	Exist less important semantic units	Less important semantic unit is selected as the current
Test task solved	No exist less important semantic units	A. The level of knowledge is fixed (maximal) B. Performing a repeat (for the current semantic unit)
Test task not solved	Exist more important semantic units. A more important semantic unit was not considered	The more important semantic unit is chosen as the current
Test task not solved	Exist more important semantic units. A more important semantic unit has already been considered	A. The level of knowledge (current) is fixed B. Performing a repeat (the more important semantic unit is selected as the current)
Test task not solved	No exist more important semantic unit	A. The level of knowledge is fixed (absent) B. Performing a repeat (for the current semantic unit)

In S*tep* 7, the calculation of the test result is performed according to the selected algorithm for estimation of the level of knowledge. The calculated estimation of the level of knowledge of the educational material is the output data of the method.

Experiment, Results and Discussions For investigation the effectiveness of the developed method, this practice implementation as special software was developed, that provides the ability to conduct traditional and adaptive testing (Figure 11). According to the developed auxiliary elements (method for automated formation of educational materials semantic structure and method for automated test tasks creation) and the scheme of information technology for adaptive semantic testing of educational materials knowledge level, in the developed information system the only obligatory user function is the choice of the file of informational educational material document for processing. The next steps, leading to the formation of test tasks set and the corresponding metadata, the system is able to perform independently. Other user functions are optional (settings and selection options) or observational (to understand the process of obtaining intermediate and source data).

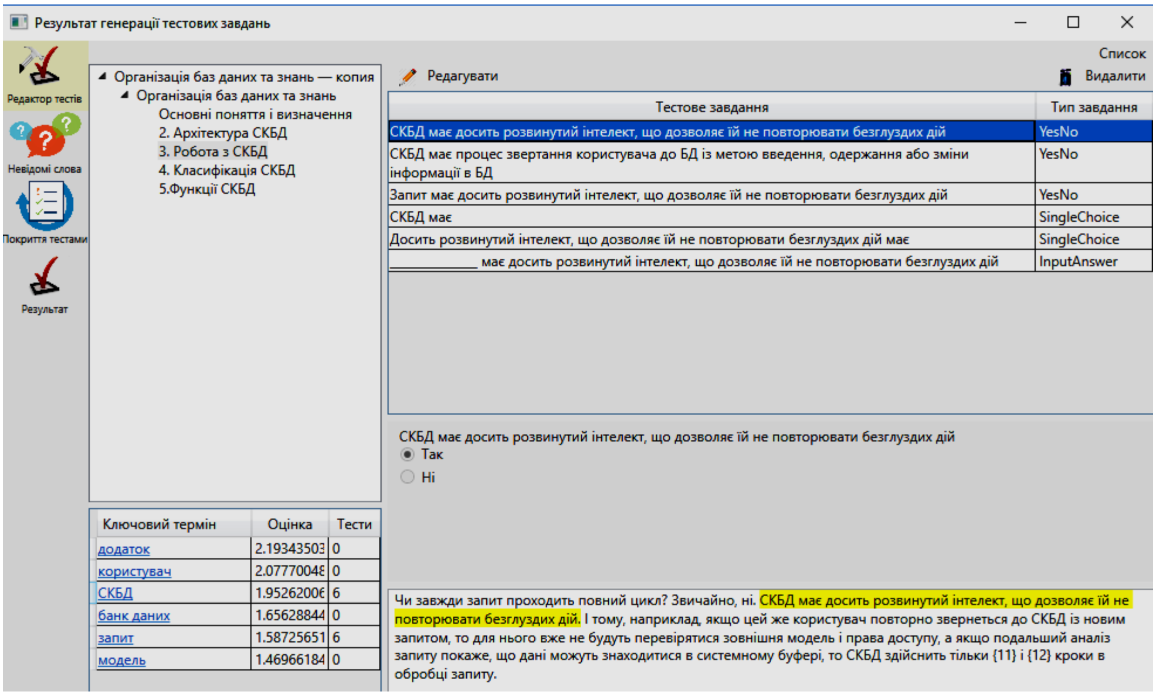

Fig. 11. Using the developed information system for working with automatic created test tasks

The process of knowledge level testing is similar to testing in well-known learning environments, only the total number of questions in advance is unknown to the user.

Investigation of searching for key semantic units effectiveness in the content of informational educational material elements confirmed the ability to effectively automatically create sets of key semantic units for the content of informational educational material elements with search precision up to 92.9% and search recall up to 100.0%. It was found that for the value of the density index of 11%, the key semantic units from the automatically obtained set are contained in an average of 89.1% of sentences, which make up 91.4% of text content (Fig. 12). This gives grounds to consider the automatically generated key semantic units sets as the level of semantic structure of informational educational material, which correctly conveys the meaning of educational material and requires the creation of test tasks sets to verify the level of knowledge of these key semantic units.

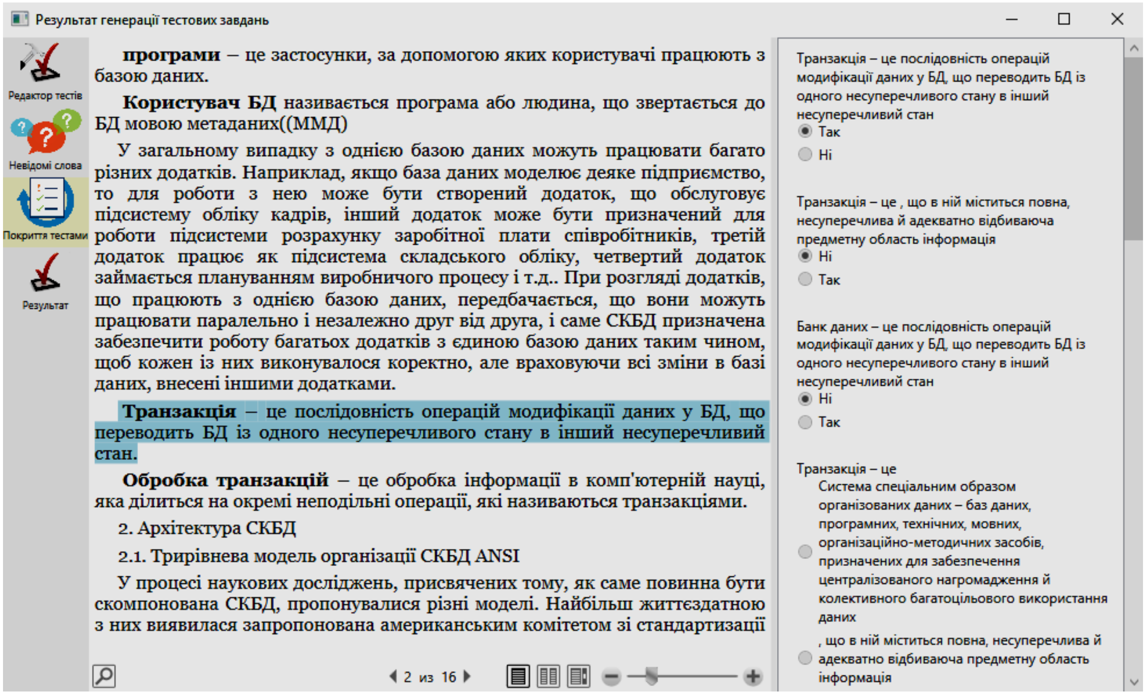

Fig. 12. Using the developed information system to determine the coverage of educational material content

Efficiency of practical applying of method for automated determination of semantic terms sets can be estimated by using values precision and recall (Fig. 13).

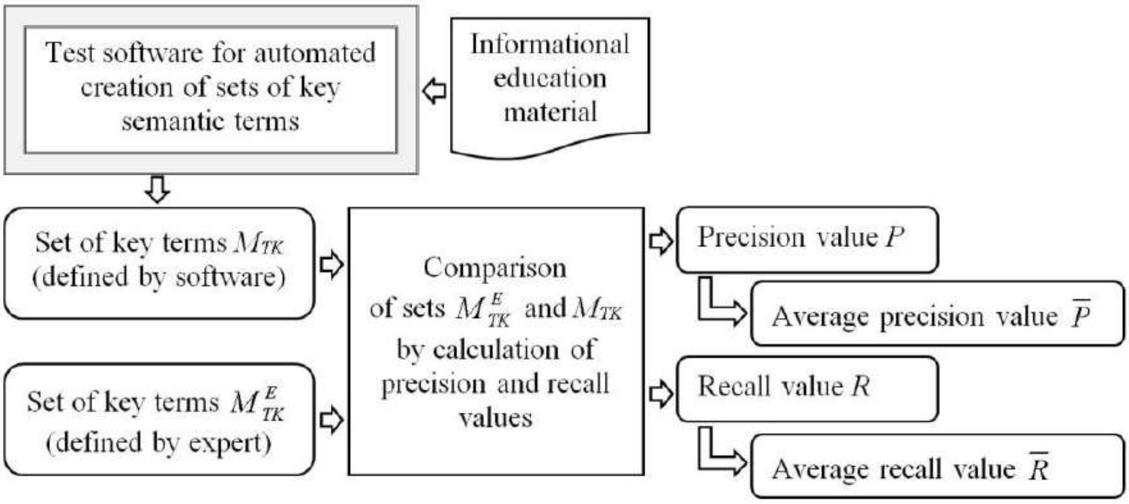

Fig. 13. Shema of research of efficiency of method for automated determination of semantic terms sets

In order to check the effectiveness of method for automated determination of semantic terms sets, was conducted the comparison of the automated creation of sets of key semantic terms with sets of experts (authors) for a test samples of digital documents of educational materials.

Efficiency of practical applying of the considered information technology can be estimated by using values precision and recall [**Ошибка! Источник ссылки не найден.**].

The precision *P* (the ratio of the number of relevant key terms found automatically to the total number of key terms found in the text under investigation) and the recall *R* (the ratio of the number of relevant key terms found automatically to the total number of relevant key terms in the text under investigation) are calculated as follows:

$$P = \frac{\left|M_{TK}^{E} \cap M_{TK}\right|}{\left|M_{TK}\right|}, R = \frac{\left|M_{TK}^{E} \cap M_{TK}\right|}{\left|M_{TK}^{E}\right|}, \tag{1}$$

where M_{TK}^{E} – the set of relevant key terms generated by the expert; M_{TK} – the set of automatically found key terms.

Accordingly, the average search precision $\overline{P}$ and the average search recall $\overline{R}$ are calculated using the following formulas:

$$\overline{P} = \frac{\sum_{i=1}^{k} P_k}{k}, \overline{R} = \frac{\sum_{i=1}^{k} R_k}{k}, \tag{2}$$

where *k* – the number of educational materials in the test sample.

In general, result of method efficiency investigation was next. The average precision was 0.732, the average recall was 0.697. The minimum precision was 0.512, the minimum recall was 0.581; the maximum precision was 0.929, the maximum recall was 1.000 (Fig. 14).

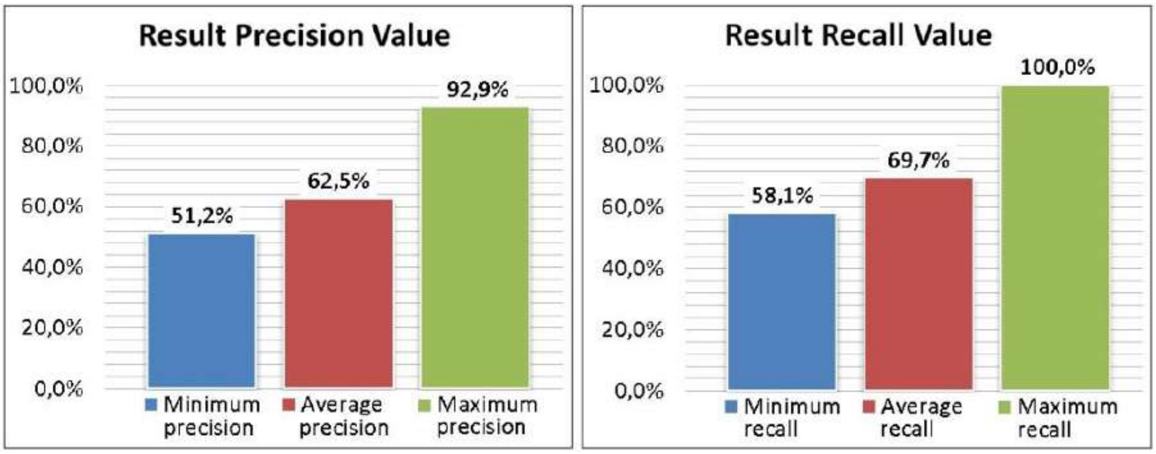

Fig. 14. Final results of method efficiency, values precision and recall

Analysis of the results revealed that the absence of the terms found by the program in the author's set does not always characterize the disadvantage of this information technology. Some semantically important terms are ignored by the experts subjectively. Another category is the terms on which the experts accent excessive attention, but they are semantically secondary in the educational material.

The use of developed method for automated test tasks creation allows in 100% of cases to achieve the goal of creation of test tasks sets in less time (on average by 60.25%) compared to the manual creation of test tasks. At the same time, 46.56% of the test tasks accepted for work does not require adjustment or change. The obtained results showed that on average adaptive testing provides faster passing of the test and the test requires fewer tasks. For example, for the median start algorithm and the average knowledge estimation algorithm, adaptive testing compared to traditional testing provided an average of 20.53% faster test.

At the same time, to determine the level of knowledge, it was necessary to use an average of 19.33% fewer tasks. In particular, when using the same set of test tasks, the adaptive testing algorithm reduced the average time required to pass the test: for the assessment of "F/FX" by 47.92%, for the assessment of "D/E" by 42.99%, for the assessment of "B/C" by 16.71%, to assess "A" by 2.89% (Fig. 15).

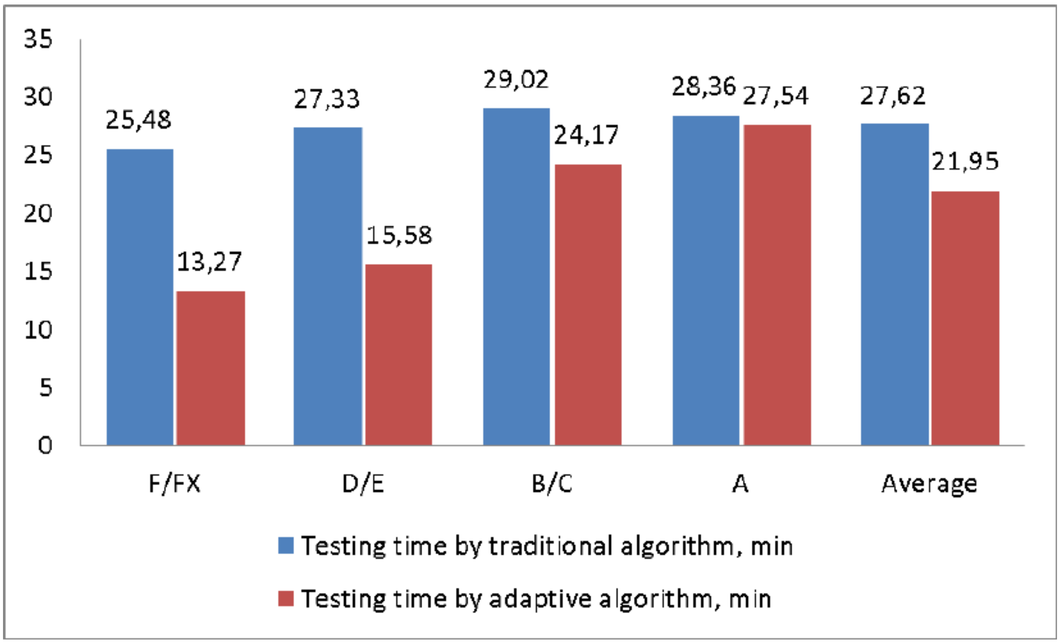

Fig. 15. Average time of tests, min

The average number of test tasks obtained using the traditional testing algorithm was 15.22 units, while using adaptive testing - 11.95 units (Fig. 16).

The developed method for adaptive semantic testing of educational materials knowledge level provides realization of the basic properties of adaptive testing, in particular selection of test tasks at testing depending on result of the answer to previous test tasks, and support of various algorithms of start, dynamics and estimation of testing. It is assumed that increasing the depth of learning of educational material semantic content has the effect of learning less semantically important units of educational materials. Accordingly, the method allows to calculate the estimation of knowledge level of educational materials by using indicators of semantic importance of key terms for adaptive selection of test tasks in testing. Semantic terms are related to the semantic structure of educational material in the form of rubricational system. Test tasks are related to fragments of educational material content, the knowledge level of which they test. In the process of testing, the level of knowledge of each of semantic structure elements of the educational material is consistently adaptively determined, and the final grade is calculated based on these results.

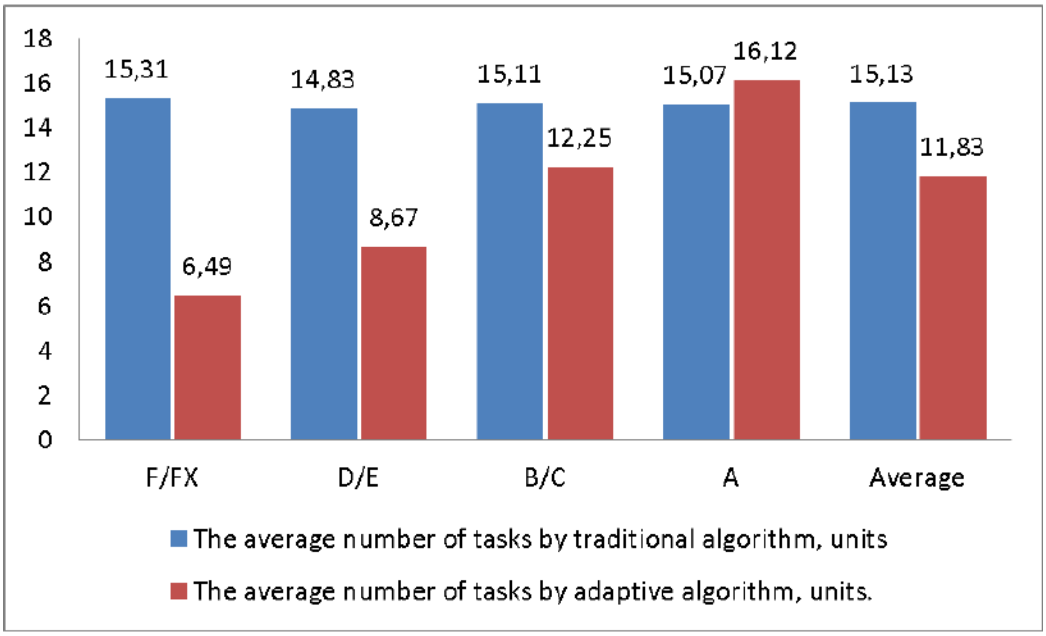

Fig. 16. The average number of received test tasks, units

Under the described conditions, the algorithms of the test start determine from which level of semantically important units of educational materials the check of the knowledge level of each of the elements of the semantic structure of the educational material begins. In particular, it is possible to use the following algorithms to start testing:

– regressive (testing begins with the semantically most important units);

– progressive (testing begins with the semantically least important units);

– median (testing begins with semantic units of medium importance).

Algorithms of testing dynamics determine the need to repeat each check of the level of knowledge of each semantically important unit, which greatly affects the speed of testing. In particular, it is possible to use the following algorithms for testing dynamics:

– rapid testing (the level of knowledge of each semantic unit is checked only once);

– confirmation testing (each change in the level of knowledge of semantic units requires confirmation the specified number of times).

Algorithms for estimation of the knowledge level provide different approaches to the formation of conclusions about the test. Their choice depends on the characteristics of the test and the conditions of its applying. In particular, it is possible to use the following algorithms for estimation of the knowledge level:

– average (final estimation is calculated as the average for estimations of all elements of the semantic structure of the educational material);

– absolute limited (to pass the test it is necessary to show the level of knowledge of each of the elements of the semantic structure of the educational material is not lower than specified).

Most of the described algorithms for starting, dynamics and estimation of testing are possible only for adaptive testing, which makes it impossible to compare the results with traditional testing.

According to the method for adaptive semantic testing of educational materials level of knowledge, as a result of adaptive selection of test tasks, their maximum possible diversity in the final set is reached, because following criteria are considered: test task has not been used yet, relevant fragment of educational content has not been checked, test tasks of corresponding type were used the least, the test task does not contain less important semantic units.

According to the results of practice implementation, on average, to estimation of the level of knowledge in adaptive testing required the use of 17.28% fewer test tasks. The higher the level of knowledge of the user, the more test tasks were needed to determine the level of knowledge in adaptive testing. Moreover, if for the assessment of "F/FX" this number was significantly less than the traditional algorithm (57.61%), then for the assessment of "A" the number of obtained test tasks was even slightly higher (-6.97%), which was due to the need to deepen the test in each element of the structure of the educational material.

Regarding testing time, on average the developed method provided 20.53% faster test than traditional testing. The higher the level of knowledge of the user, the more tasks were needed to determine the level of knowledge in adaptive testing, and accordingly the more time was spent on their solution – if the assessment is "F/FX" 47.92%, then for the assessment of "A" 2.89%. While in traditional testing, these figures differ insignificantly.

On average, compared to traditional testing, a larger number of test tasks was required to assess "A", but their processing took less time. This can be explained by the fact that during adaptive testing test tasks were presented in a logically consistent order, which allowed users to process them more focused and reduced the time to "switch" between different semantic blocks.

With a correctly formed set of test tasks, the developed method allows to more accurately determine the uniformity of the level of knowledge and identify gaps in the understanding of the studied material.

Although key terms are considered in the paper under semantically important units of educational materials, processing of special objects (formula, figure, scheme, etc.) in the content of educational materials is also quite possible, by considering their position in the text as separate semantically important units, along with terms. Their signatures (for example, geometric and disk dimensions of formulas) are used to determine the positions of identical special objects. Like special objects, in addition to inserted objects, also consider semantically significant classes (for example: surnames, years, centuries), to build tests to verify them, it is possible to include them in set of semantically important units. In the case when, on the contrary, it is necessary to exclude from the process the content of certain special elements (tables, program codes, etc.), it is possible to do so by using design styles other than heading styles and main text, which is natural when working with lowstructured text documents. The above determines the directions of further research.

Conclusions and suggestions. The results of research allow to conclude, that the developed method provides a full-fledged tool for adaptive semantic testing of educational materials level of knowledge, which provides a complete semantic and structural coverage of educational material in testing. In combination with the described previous auxiliary methods (method for automated formation of semantic structure of educational materials, method for automated test tasks creation for educational materials), all sections of automated testing of knowledge level from loading of the document of educational material till the calculation of an estimation of level of its studying are provided. Applied investigations of the effectiveness of the developed method in comparison with the traditional algorithm for selecting test tasks established, that testing speed increased an average of 20.53% faster test, and to determine the level of knowledge required the use of an average of 19.33% fewer test tasks.

The developed method of adaptive semantic testing of knowledge level of educational materials makes possible to use different algorithms for starting testing (regressive, progressive, medianic, etc.) and different algorithms for knowledge level estimation (average, absolute limit, etc.). As a result of adaptive selection of test tasks, their maximum possible diversity in the final set is reached, because following criteria are considered: test task has not been used yet, relevant fragment of educational content has not been checked, test tasks of corresponding type were used the least, the test task does not contain less important semantic units.

Especially effective is the use of adaptive testing according to the developed method for testing the level of knowledge of educational material, which contains mainly textual content. In this case, each test task allows to purposefully check the level of knowledge of separate semantic units of educational materials, which related to the semantic structure of educational material in the form of rubricational system. Test tasks are related to fragments of educational material content, the knowledge level of which they test. In the process of testing, the level of knowledge of each of semantic structure elements of the educational material is consistently adaptively determined, and the final grade is calculated based on these results. In the developed method production rules are used both for generating test tasks and for choosing further actions in various situations during adaptive testing.

Thus, the paper considers a complex approach to the automation of adaptive testing of the knowledge level, which includes steps of automated formation of semantic structure of educational materials, automated test tasks creation and adaptive semantic testing of educational materials knowledge level.

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CONTENTS

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DOI 10.5281/zenodo.10277355
UDK 37.018(100):005.591.6
I-66
ISSN 0-745110-169734

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IČ: 27662101, DIČ: CZ2766210