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DEVELOPMENT OF MODELS AND METHODS FOR CONSTRUCTING MULTIDIMENSIONAL DIDACTIC INSTRUMENTS

The subject *of the study in this article is the synthesis of multifactorial, predominantly eight-factor graphical logical-semantic models for knowledge representation with an open architecture for knowledge bases.* ***The aim*** *is to provide a theoretical description of the stages in developing these models and practical recommendations for their design.* ***Tasks*** *include: analyzing fundamental theoretical and practical principles of didactic multidimensional technology and characteristics of existing multifactorial logical-semantic knowledge representation models, identifying their strengths and weaknesses; defining the research methodology; analyzing theoretical principles for creating multifactorial logical-semantic knowledge representation models and identifying issues requiring solution; examining characteristics of didactic multidimensional instrumental models; researching eight-factor architectures of logical-semantic knowledge representation models; developing a method for designing logical-semantic knowledge representation models; advancing the method for forming two-factor logical-semantic knowledge representation models; practically implementing the logical-semantic physical (first level) knowledge representation model for multifactorial models; and summarizing research results and outlining future research directions in the field of modeling knowledge for open-architecture knowledge bases.* ***The following results were obtained****: Analysis of the literature sources indicates that current information technology implementations mainly focus on artificial intelligence-based tools, such as databases and knowledge bases. However, alternative principles for forming knowledge representation models have also been developed.* ***Conclusions.*** *The scientific novelty of the obtained results lies in the following: establishing the practicality of transitioning from matrices to a tabular form for representing inter-factor (vector) relationships between set elements as a Cartesian product; proposing the use of spreadsheet editors such as Microsoft Excel to form multivector logical-semantic knowledge representation models with any number of factors; determining that the use Microsoft Excel facilitates the implementation of the second and third stages of knowledge base design in the following forms: logical-semantic physical (first level) knowledge representation model; forming logical-semantic physical (second level) knowledge representation model. Additionally, Microsoft Excel supports the administration and management processes for the established knowledge base. However, defining the forms of relationship between elements for Cartesian product operations remains necessary. This issue requires further research and may be the subject of subsequent studies.*

Keywords: *logical model of knowledge representation; logical-semantic model of knowledge representation; open architecture knowledge base; semiotics; tabular representation; factor.*

1. Introduction

The graphical form is one of the primary methods for representing knowledge in the educational process. Various software products, such as Microsoft Office PowerPoint, Microsoft Office Visio, and numerous other applications, are used for creating graphical materials. At the same time, there is a considerable number of graphical models for representing knowledge and data, both in business activities [1, 2] and educational activities [3], which necessitate the development of appropriate methods for constructing knowledge bases using computing tools. In project management, a methodology for multidimensional data representation for managing IT projects has been proposed, defined as follows [4]:

«The project management system can be used practically for any type of project, particularly for managing complex software development projects. Thus, to analyze information processes and manage projects, a multidimensional data representation methodology can be employed, enabling multidimensional visualization and data manipulation. This methodology serves as a means of formulating multidimensional queries and allows processing a large data array to generate queries.

For effective work with large datasets, OLAP programs are most suitable. Most of them have three architectural levels and are known as OLAP cubes. From a mathematical viewpoint, the number of elements in a cube across all dimensions is the same, whereas OLAP cubes do not require such conditions».

It should be noted that OLAP cubes are used for data analysis and are not intended for knowledge representation and analysis. Therefore, it is essential to analyze the applicability of this methodology for multidimensional knowledge representation tasks.

The problem of representing multidimensional knowledge is particularly relevant to the aviation and space industries. These sectors operate with vast quantities of intricate data, encompassing aerodynamic characteristics, flight dynamics, materials, navigation systems, and responses to stress factors. Effective multidimensional knowledge representation methods are therefore essential for developing decision support systems for pilots and air traffic controllers, as well as improving simulation trainers. Implementing such models improves flight safety and the efficiency of space missions.

The problem of multidimensional knowledge representation can be resolved in the following ways:

– developing specialized software to integrate known graphical models of knowledge representation into an appropriate knowledge base. However, there is no specific software identified to handle all management tasks related to such a knowledge base;

– developing a suitable methodology for designing knowledge bases using known software, ensuring integration of existing knowledge representation models, creating new ones, and maintaining open accessibility for users;

– utilizing existing software applications for constructing OLAP cubes to represent knowledge, taking into account the experience gained from developing multidimensional didactic instruments as per [3], strategic thinking models as per [1], and other graphical knowledge representation models as per [2].

1.1. Motivation

One of the main directions in implementing the core principles of Industry 5.0, defined as the Internet of Knowledge, involves developing appropriate methods and models for knowledge representation. Given that knowledge is an essential resource for organizations, the task arises to develop and widely implement methods and models of knowledge representation. These methods and models must meet the following requirements:

– simplicity of graphical knowledge representation models;

– accessibility for users in designing conceptual, logical, and physical models of graphical knowledge representation;

– eliminating the stage of designing graphical knowledge representation models using programming languages.

Further development of the theoretical foundations for logical-semantic graphical knowledge representation models according to [1] has been conducted in work [5].

At the same time, the models of logical-semantic graphical representation of knowledge, which were considered and analyzed in [3], require further improvement through theoretical substantiation of the method of their formation. In addition, methods for designing knowledge bases based on logical-semantic representation models require further development.

Therefore, there is a task of advancing the models and formation methods for multidimensional didactic instruments as outlined in [3].

1.2. State of the art

The development of contemporary technologies in educational practice has been addressed in the work [6].

This study focuses on «analyzing and summarizing novel approaches to organizing the educational process, aiming not only to describe and analyze current educational trends but also to identify substantial determinants and propose innovative technologies that enhance the effectiveness of professional development for future specialists».

Unfortunately, this study does not address the development of relevant information technologies and practical tools to support the educational process at the university level.

Further advancement of the theoretical foundations for developing multidimensional didactic tools and examples of their practical implementations are presented in work [7]. This study introduces the concept of "design".

The study [8] «discusses the principles and features of technology using multidimensional didactic tools (as cognitive methods for storing and processing educational information and visual aids, facilitating support for various cognitive activities) in the professional training of future educators within modern pedagogical master's programs».

Study [9] «examines contemporary methods proposed for embedding knowledge bases into descriptive logic within vector spaces through the lens of their geometric semantics».

Study [10] «discusses a knowledge-based model for designing and developing educational units and tools. The use of conceptual maps is proposed as a logical and abstract annotation system that can be integrated into learning management systems».

Work [11] is dedicated to specifying requirements for conceptual maps and forms part of a series of standards related to information technologies (ISO/IEC 13250).

An interesting approach is presented in work [12], which discusses the concept of «open architecture in

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educational programs, promoting flexibility and adaptability in the learning process. This approach can be integrated into the development of teachers' knowledge bases to support methodological work».

Unfortunately, the reviewed studies have not paid attention to a crucial aspect of the didactic modeling environment's development, namely, the application of intelligent information technologies to create relevant knowledge bases in the form of automated workplaces for educators, employing logical-semantic models of knowledge representation, as well as the theory and practice of multidimensional didactic technology featuring an open architecture.

1.3. Objectives and tasks

The aim of this article is to develop a theoretical description of the stages involved in creating these models and provide practical recommendations for their design. To achieve this aim, the following objectives must be addressed: conduct an analysis of the characteristics of multidimensional didactic instrument models described in [2]; develop proposals to improve methods for forming multidimensional didactic instruments.

The primary tasks and stages of this research are as follows:

– Stage 1: Analysis of fundamental theoretical and practical aspects of multidimensional didactic technology and the characteristics of existing multifactor logical-semantic knowledge representation models, including identification of their strengths and weaknesses (Section 1);

– Stage 2: Determination of the research methodology (Section 2);

– Stage 3: Analysis of theoretical foundations in forming multifactor logical-semantic knowledge representation models, and identification of unresolved issues (Section 3);

– Stage 4: Analysis of characteristics of multidimensional didactic instrument models (Section 4);

– Stage 5: Investigation of eight-factor architectures of logical-semantic knowledge representation models (Section 5);

– Stage 6: Development of a design method for logical-semantic knowledge representation models (Section 6);

– Stage 7: Enhancement of methods for forming two-factor logical-semantic knowledge representation models;

– Stage 8: Practical implementation of the first-level logical-semantic physical model of knowledge representation for multifactor models;

– Stage 9: Discussion of research results;

– Stage 10: Conclusions and perspectives for further research.

2. Research methodology

The research approach involves developing methods for designing logical-semantic models of knowledge representation based on theoretical foundations and practical results obtained from developing multidimensional didactic technology.

Set theory is proposed as the theoretical foundation. The rationale behind this choice is that all known logical and logical-semantic knowledge models are representative objects within this theory.

3. Materials and methods of research

The basis of multidimensional didactic methodology and the corresponding instruments used to implement this methodology is described as follows [3]:

"The concept of visual multidimensional didactic instruments (MDI) involves the transformation of verbal, textual, or other forms of information representation into a visual, conceptual-imagery form characterized by three parameters: semantic (content-related), logical, and specially graphical. The multidimensionality of the subject displayed by the instrument is ensured by three foundations illustrated in Fig. 1, presenting the content of a coordinate-matrix reference-node system reflecting the three foundations of MDI:

- logical-semantic modeling;
- cognitive representation of knowledge;
- radial-circular organization».

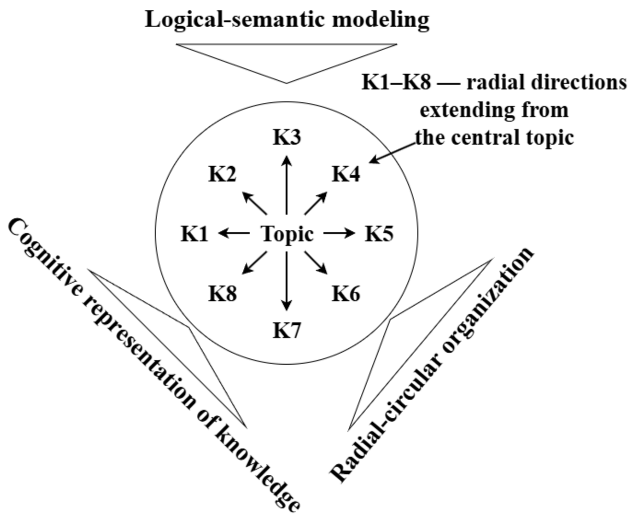

Fig. 1. Triad of MDI foundations

These didactic multidimensional instruments consist of two fundamental components, namely [3]:

– an eight-coordinate node graphical (spatial) representation (Fig. 2, 3);

– a matrix-based inter-coordinate representation of information (Fig. 4, 5).

This form of representation achieves "transformation of verbal, textual, or other forms of information representation into a visual, conceptual-imagery form" [3].

In constructing MDIs, information is transformed according to these foundations based on several specialized principles [3]:

– the principle of systemic multidimensionality in selecting and aggregating content;

– the principle of splitting-combining and the related principle of complementarity in constructing and utilizing MDIs;

– the principle of triadic structure in forming semantic groups that enhance psychological stability."

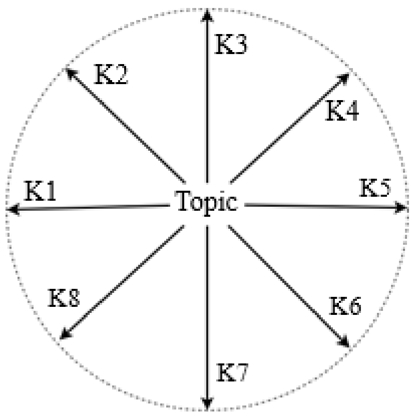

Fig. 2. Multidimensional semantic space, K1...K8 – Coordinates – directions of measuring the topic being studied

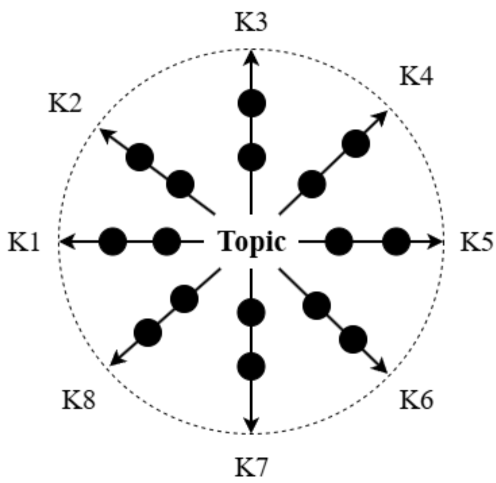

Fig. 3. Coordinates and reference nodes

4. Analysis of the characteristics of multidimensional didactic instrument models

The characteristics of the models discussed in this paper for respective factors (vectors) are summarized in Tables 1 and 2. Future research should focus on providing a theoretical justification for the formation methods of these graphical structures and determining the directions for further development of the respective models. As a starting point for analysis, the eight-factor knowledge representation model architecture is proposed.

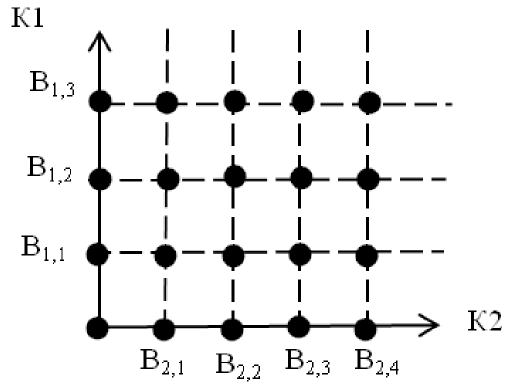

Fig. 4. Inter-coordinate matrix

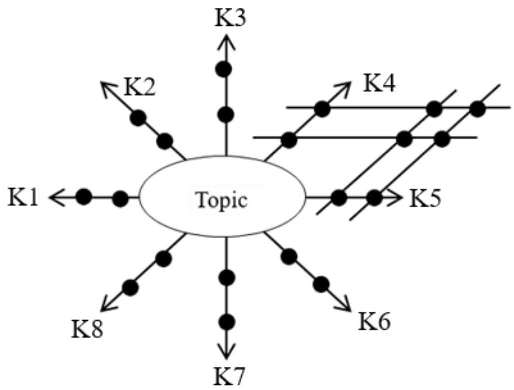

Fig. 5. Coordinates, reference nodes, and inter-coordinate matrices

5. Investigation of eight-factor architectures of logical-semantic knowledge representation models

The investigation begins with the model of a multidimensional semantic space (see Fig. 1). This model is constructed using eight coordinates, where the elements of set K are formed as a set of characteristic attributes relevant to knowledge in a given subject domain (or topic). These attributes originate from the element that denotes the topic, or more precisely, the subject domain for which this model is developed. In other words, the coordinates in terms of content are the elements of set **K**.

In general, each coordinate to be elaborated is further divided into dimensions (nodes) $B_{1.1}$, $B_{1.2}$, and so on (see Fig. 4).

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Table 1

Characteristics of multidimensional didactic instrument models (one to five factors)

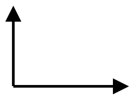
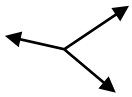
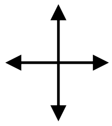
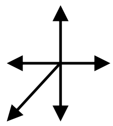
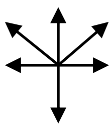
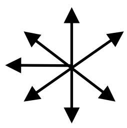
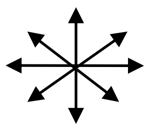
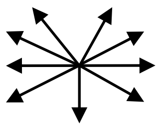
Model Characteristics	Number of factors in models					Total
	One factor	Two factors	Three factors	Four factors	Five factors	
Number of models	4	8	2	3	8	25
Number of matrices	1 matrix	8	2	0 matrix	8, one matrix per model	19
Graphical architecture of models						

Table 2

Characteristics of multidimensional didactic instrument models (six to nine factors)

Model Characteristics	Number of factors in models				Total
	Six factors	Seven factors	Eight factors	Nine factors	
Number of models	6	3	40	1	50
Number of matrices	6 matrix 2 matrices per model	0	0	6, one matrix per model	12
Number of spiral models	1 – spiral				1
Number of circular models			3		3
Number of models with inter-coordinate links			2 relations		3
Number of quadrant models	1 model (3 quadrants)				1
Graphical architecture of models					

The first question that arises here concerns the nature of relationships between adjacent elements in set K, for example between K1 and K2. Are they semantically related to one another or not? If they are unrelated, then the order of elements within set K can be arbitrary. If relationships do exist, then an additional task emerges: to uncover the form and meaning of these relationships.

Let us first consider the case where no relationships exist between adjacent elements of set K. In that case, the following structure of set K for the multidimensional semantic space model is valid:

$$K = (K1, K2, K3, K4, K5, K6, K7, K8).$$

Under this condition, the model architecture depicted in Fig. 3 is justified. Without violating the internal logic of this model, we can propose its reformatted graphical representation (Fig. 6). In this representation, each element of set K (K1…K8) corresponds to a vertical coordinate, on which reference nodes $B_{1.1}$ through $B_{8.3}$ are marked. These vertical coordinates are the components of a future grid. The nodes along these coordinates represent specific knowledge elements. First and foremost, it is important to note that for the elements of set K, the following inclusion conditions are possible.

The content of all elements in set K is independent from one another, and their inclusion in set K is determined by the content of the subject domain (educational topic for the model) (see Fig. 6).

The content of certain elements (nodes) within sets K1…K8 (from the set $B_{1.1}…B_{8.3}$) for adjacent vectors may be interdependent (Fig. 7). At the same time, such relationships may also be established between non-adjacent vectors (Fig. 8).

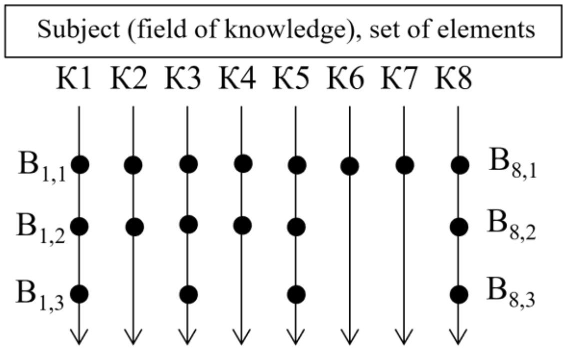


Fig. 6. Graphical Representation
of the Logical-Semantic Model

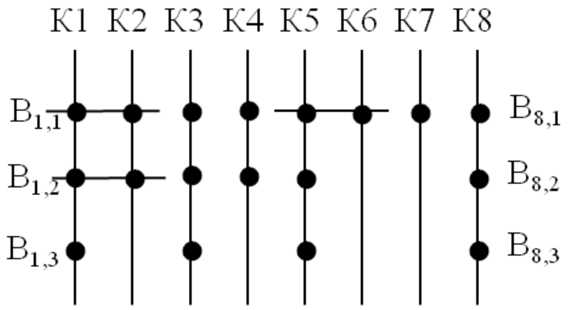


Fig. 7. Logical-semantic model with dependencies between adjacent vectors

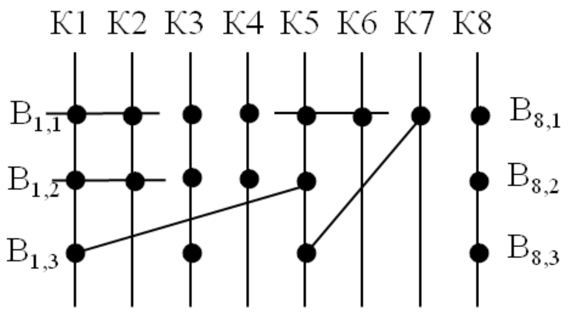


Fig. 8. Logical-semantic model with dependencies between non-adjacent vectors

In the following research, it is assumed that relationships can be established only between adjacent elements of the set K, such as K1 and K2. This allows the formation of an additional two-factor knowledge representation model. Such a model can either be part of a larger multifactorial model—of which there may be several—or exist as an independent two-factor model.

From this point on, the overall eight-factor model will be visualized as a grid model in the following form (Fig. 9).

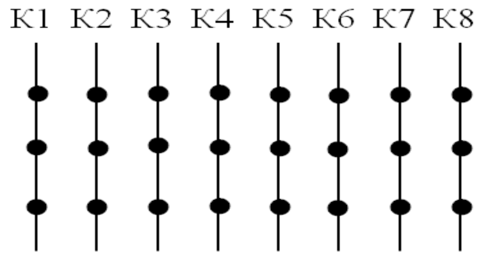


Fig. 9. Grid representation
of the eight-factor logical-semantic model

It should be noted that a specific configuration of content is possible for vectors K1...K8, where the contents of all first nodes, all second nodes, and so on across all vectors correspond to a unified condition. In this case, the following form of the grid model is feasible (Fig. 10).

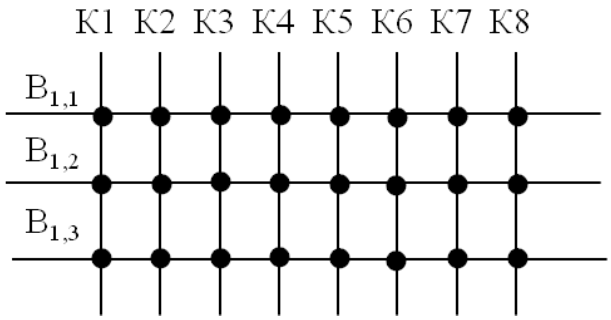


Fig. 10. Grid model with semantically unified nodes across vectors

In the case where the knowledge contents of two adjacent vectors in set K (e.g., K1 and K2 as shown in Fig. 4) are dependent on one another, this results in the emergence of relationships between adjacent elements of sets $B_{1,1} \ldots B_{1,4}$ and $B_{2,1} \ldots . B_{2,4}$. In such instances, it becomes crucial to define the nature of relationships between the concepts represented by those elements. One possible form of such a relationship is the Cartesian product of sets, for example, K1 × K2.

Multidimensional semantic space models in the form of eight-coordinate radiant representations (see Figs. 2, 3) as well as two-coordinate matrix (grid) representations (see Fig. 4) provide a clear and visual way of presenting knowledge elements.

Based on the analysis, the following advantages (features) of the models investigated can be identified:

– clear and unambiguous representation format – eight-coordinate semantic space;

– formation of reference nodes along each coordinate, which are linked with semantic knowledge units;

– possibility of establishing various types of relationships between reference nodes on different coordinates;

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– capability to form inter-coordinate matrices (grids).

The disadvantages of the investigated models include:

– impracticality or inconvenience in associating defined coordinate-axis nodes with concrete knowledge elements;

– undefined nature of relationships between adjacent nodes (i.e., between corresponding knowledge units) within matrix (grid) representations (see Fig. 7);

– absence of dedicated software (applications) for forming the studied models as digital representations;

– inability to include knowledge carriers (e.g., books, journals, articles, regulations) in electronic form as part of the model's structure;

– in none of the seventy-five studied models was time included as a coordinate. As a result, the knowledge represented in these models pertains only to the static existence of objects from the animate and inanimate world.

6. Development of a design method for logical-semantic knowledge representation models

This raises the issue of further improving the method for constructing knowledge representation models. It is proposed to apply a well-known method from relational database design theory, which is based on a hierarchical project model with the following stages of data model representation [13]: conceptual data model; logical data model; physical data model.

Based on this approach, it is proposed that the development of multivector logical-semantic knowledge representation models follow the same sequence.

At the first stage, a conceptual graphical (paper-based) model is created to represent primary knowledge about the subject area (domain knowledge), which will later be represented in the form of grid models using formats shown in Fig. 6 –10. It should be noted that at this stage, the essential knowledge components to be included in the model are identified. These components define the content of the elements in set K (K1…K8) as well as the sub-elements that determine their content, for example, in K1: ($B_{1.1}$ … $B_{8.3}$) (see Fig. 6).

At the second stage, it is proposed to transform the previously designed model into one implemented in a software application such as Microsoft Excel, as shown in Table 3, i.e., in tabular form. The transition from a grid model to a logical physical tabular form enables the fixation and visualization of knowledge elements corresponding to the elements of set K, as well as the elements of sets K1…K8 ($B_{1.1}$ … $B_{8.3}$).

This stage in the design of logical-semantic knowledge representation models is defined as the formation of the logical-semantic physical knowledge representation model (first level). At the third stage, the model undergoes further transformation by creating a set of folders in which knowledge carriers in electronic form can be stored. The content of these folders corresponds to the Cartesian product elements of sets K × A. This leads to the formation of a complete logical-semantic physical knowledge base model (second level) for a specific subject domain, consisting of a structured folder system (Fig. 11). To establish links between non-adjacent elements of set K (see Fig. 6), hyperlinks must be created between corresponding cells in the logical model (at the second design stage).

Table 3

Tabular representation of set **K**

K1	K2	K3	K4	K5	K6	K7	K8
$B_{1,1}$							$B_{8,1}$
$B_{1,2}$				$B_{5,2}$			$B_{8,2}$
$B_{1,3}$							$B_{8,3}$

Advantages of the proposed method for designing logical-semantic physical multifactor knowledge representation models include:

– the existence of two interconnected logical-semantic physical models of knowledge representation;

– open architecture of the logical-semantic physical model (spreadsheet) accessible to the user;

– direct access to the original knowledge sources—folders created in File Explorer and linked to cells in the logical-physical model (spreadsheet) via hyperlinks.

Disadvantages: all of the studied models lack a time vector!

7. Advancement of the Method for Constructing Two-Factor Logical-Semantic Knowledge Representation Models

In cases where a multifactor model includes connections between adjacent elements of the set K (see Figs. 7, 8), the application of the proposed method for knowledge base formation enables the creation of a local knowledge base for a specific pair of elements from set K – for example, elements K1 and K2 – in the form of a table (see Fig. 11).

According to [3], in order to define the content of knowledge associated with a specific node that represents an inter-coordinate link (see Fig. 7), the Cartesian product operation (direct product) is applied (Table 4).

Another possible representation is a standard table format (see Table 5). In this case, relationships arise between elements of sets K and A, for example in the form of a Cartesian product K × A, which may result in a value such as the pair v, K4. Thus, this operation—and more

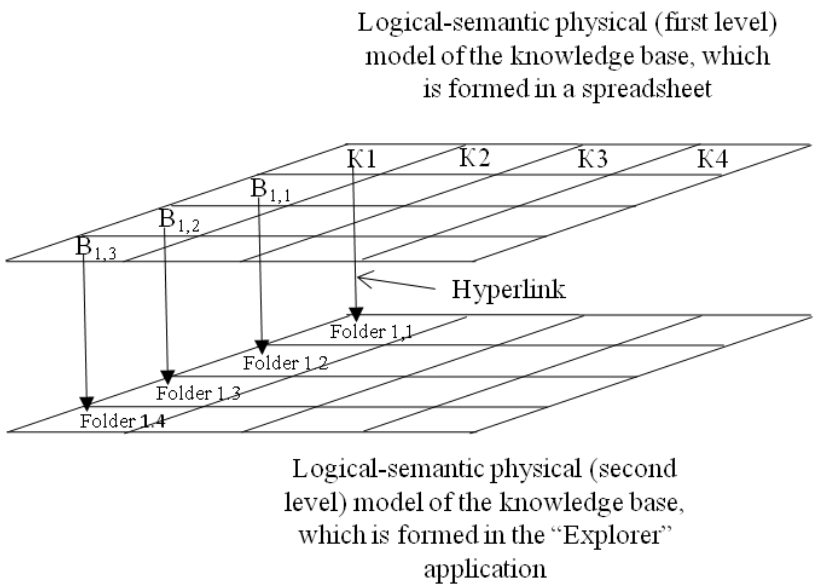

Fig. 11. Logical-semantic physical knowledge base model (second level)

Table 4

Representation of the Cartesian product operation

K1 \ K2	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8
2,1								
2,2				1,4:2,2				
2,3								

broadly, other forms of binary relations—can be regarded as the first stage of knowledge processing within this knowledge representation model, supporting the formation of primary knowledge. Alternatively, the Cartesian product may also be expressed using a different combination format. According to [9], the Cartesian (direct) product of two sets is defined as follows:

"In set theory, the Cartesian product (direct product) of two sets X and Y is the set of all possible ordered pairs in which the first component belongs to set X and the second to set Y. The term is named after the French mathematician René Descartes. The Cartesian product of two sets X and Y is denoted as X × Y." ». Furthermore, [10] presents another visualization of the Cartesian product (Table 6).

Table 5

Representation of the Cartesian product operation for elements of sets **K** and **A**

K \ A	K1	K2	K3	K4	K5	K6	K7	K8
X								
Y				Y,K4				
Z								

In previous examples (Table 4 and Table 5), the result of the Cartesian product is a pair of elements such as B, K4 or 1.4, 2.2. However, in this new example, the elements (letters) change color. What does that mean?

Consider, for example, the Cartesian product of two sets of numerical series ranging from 1 to 6. Here, we apply the Cartesian product in the form of a “Cartesian algebraic product” of table elements. As a result, we obtain a multiplication table. In this case, the outcomes of the Cartesian product are not pairs of numbers. Therefore, the meaning of the Cartesian product operation may vary.

Table 6

Alternative representation of the Cartesian product operation

Index	Colors						
	purple	dark blue	blue	green	yellow	orange	red
B	B	B	B	B	B	B	B
I	I	I	I	I	I	I	I
K	K	K	K	K	K	K	K

In the examined examples (Table 6 and Table 7), the cells of the table contain not just pairs of elements, but also the outcomes of combining those elements. In the first example, this combination results in colored letters; in the second, it is a mathematical combination—the product of two numbers.

From a mathematical standpoint, in addition to multiplication, other operations can also be implemented: addition, subtraction, division, exponentiation, square root extraction, and others.

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Table 7

Cartesian product of two sets
as numerical series from 1 to 6

	1	**2**	**3**	**4**	**5**	**6**
1	1	2	3	4	5	6
2	2	4	6	8	10	12
3	3	6	9	12	15	16
4	4	8	12	16	20	24
5	5	10	15	20	25	30
6	6	12	18	24	30	36

With regard to the example in Table 5, the following explanation of the pairing mechanism may be proposed. If we consider the concepts of "color" and "letter" as results of cognitive processes in the human brain, then—according to G. Hegel’s Science of Logic—these concepts can be associated with the philosophical categories of “universal” → “color” and “particular” → “letter”, establishing a dialectical unity between them:

– « universal » ⊳ « particular »;

– « color » ⊳ « letter».

Thus, this form of Cartesian product can be described as a "Cartesian dialectical unity." From this, it follows that the elements of the sets used to construct such a table need not be limited to numbers or letters; they may also include terms, concepts, or meaningful expressions.

In such cases, it becomes possible to generate new knowledge based on the pairs formed.

8. Practical Implementation of the Logical-Semantic Physical Knowledge Representation Model (First Level) for Multifactor Models

According to the data from Tables 1 and 2, two-factor logical-semantic models in matrix form are used as standalone models in eight cases.

In other multifactor models, inter-factor matrices are generally applied in twenty models. Notably, the unique nine-factor model includes six such matrices. Based on these observations, there arises the task of developing a design method for the logical-semantic physical knowledge representation model (first level) that allows for any number of factors and inter-coordinate tables.

Considering the conclusions of the previous section, the term "inter-coordinate table" is proposed instead of "inter-coordinate matrix."

Fig. 12 presents an example of architecture of such a model for eight factors. This model can be used to construct knowledge representations ranging from a single factor up to eight factors. Not all adjacent factor pairs require a corresponding table. The maximum number of tables in this model is eight.

A question arises: is it possible to construct such a model for more than eight factors? According to Fig. 13, by applying the same logic used for generating individual tables in Fig. 12, any required number of factors and inter-factor tables can be developed.

Once the content of the factor set K, as well as the content of each individual factor’s elements, is defined, it becomes possible to proceed to the third stage of the design process – namely, the logical-semantic physical knowledge base model (second level) for the specified subject domain (see Fig. 12). To accomplish this, an appropriate number of folders is created, and hyperlinks are established from the cells of the first-level model to the respective folders.

Afterward, relevant electronic documents can be placed into the corresponding folders, with their content defined based on the results of applying the Cartesian product operation – taking into account the considerations discussed in Section 6.

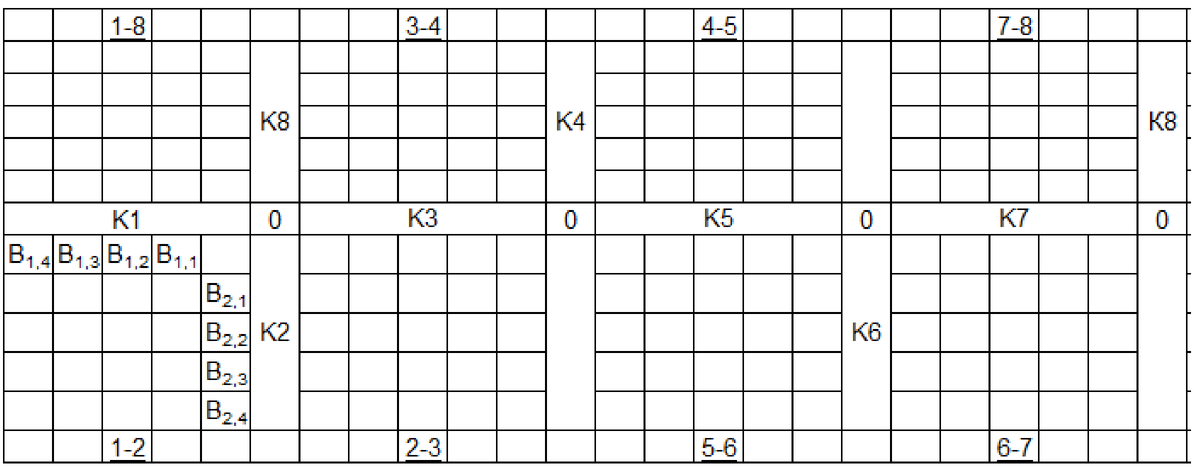

Fig. 12. Example of model architecture for eight factors

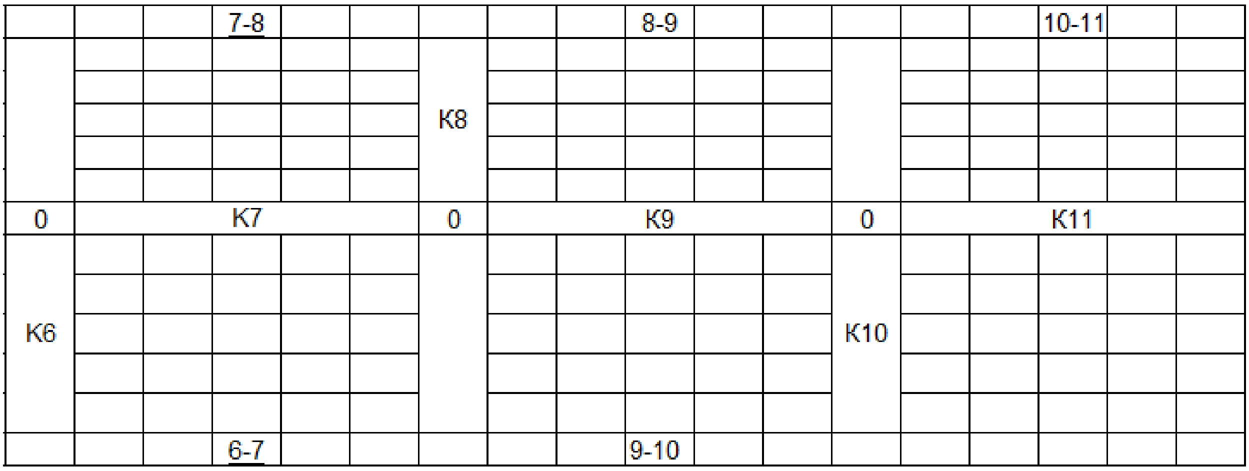

Fig. 13. Example of model architecture for eleven factors

9. Discussion of Research Results

From the analysis of literature sources, it follows that currently the primary focus in the implementation of information technologies is on tools based on artificial intelligence theory, including databases and knowledge bases. On the other hand, alternative models and methods of knowledge representation that utilize different principles for constructing knowledge models have also seen development.

As part of our investigation, we considered the work by Różycki et al. [14], which explores the use of multilayer fuzzy ontologies for semantic knowledge modeling in Industry 4.0 environments. This study provided valuable insights into integrating semantic models into intelligent decision-support systems. It supported our assumption that logical-semantic models, particularly those with open architectures, can be effectively applied in complex industrial systems where semiotic layers of interpretation are essential.

Additionally, we reviewed the application of formal ontologies in knowledge-intensive environments as presented by Dell'Anna et al. [16].

Their use of semantic agents for interoperability reaffirmed the necessity of standardized and modular approaches in knowledge representation.

This reinforced our conclusion that logical-semantic models, such as the ones developed in this paper, can be adapted for use in diverse semiotic systems, ranging from academic knowledge bases to organizational process modeling.

In [17] is proposed the novel method, which introduces historical information completion strategy and pretrained language model to conduct explainable inductive reasoning over temporal knowledge graphs. Moreover, the semantic similarity between the query quadruples and the extracted paths is evaluated to simultaneously optimize the representations of entities and relations.

A novel framework that combines emotion learning and logical semantic representation is proposed for video paragraph captioning in [18]. And it also could be used as didactic instruments.

The knowledge organization provides theoretical support for the study of semantic knowledge organization and representation, among which knowledge organization system is the important tool of semantic organization and it is focused in [19]. The model and method proposed in this paper is independent of the specific type of knowledge organization system, so it is innovative and universal. The methodology is also applicable to other fields of conceptual system modeling, metadata standard construction, and data model modeling.

For instance, works [1–8] propose various graphical knowledge representation models using vector coordinate systems. In works [1, 2, 5], particular attention is given to using a four-vector Cartesian coordinate system as the graphical foundation for knowledge models. In [1], other vector-based models are also used, such as two-vector representations. Works [3, 7] focus on multivector (primarily eight-vector) knowledge representation models, which, according to the principles of semiotics, are classified as logical-semantic models.

The main shortcoming of all the examined models, as noted in [1] and [3], is the lack of developed information technologies and software applications for building such models. This issue stems from the absence of general theoretical foundations for designing such applications, as well as limited application of existing tools.

It is important to emphasize that both the four-factor models described in [1] and the eight-factor models in [3], as well as the models developed in this study, do not provide a theoretical justification for the construction logic of two-factor models in matrix form. Therefore, based on [5] and the results of this research, the use of the term "table" is proposed for two-factor models.

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As demonstrated in Section 6, the use of tables enables the formation of multifactor models with any number of factors and a corresponding number of inter-factor tables. Replacing the term "vector" with "factor" emphasizes the fact that the contents of the matrix elements A and K (see Table 5) carry specific semantic meaning.

10. Conclusions and Future Research Perspectives

The main outcomes of this study are as follows:

– the justification for transitioning from the use of matrices to describe inter-factor (vector) relationships between set elements to a tabular form of representation, based on the Cartesian product;

– the use of spreadsheet editors, such as Microsoft Excel, enables the construction of multivector logical-semantic knowledge representation models with any number of factors;

– the use of Microsoft Excel also supports the implementation of the second and third stages of knowledge base design in the following forms: logical-semantic physical model (first level) of knowledge representation; logical-semantic physical model (second level) of knowledge representation;

– the use of Microsoft Excel also facilitates administration and management of the developed knowledge base.

At the same time, there arises the need to define the types of relationships between the elements for which the Cartesian product operation is applied within the table. This issue requires further study and may serve as the foundation for future research.

Contribution of authors: conceptualization, methodology, and task formulation – **Serhii Dotsenko, Karina Trubchaninova**; model and algorithm development, validation, result analysis, visualization, writing, and original draft preparation – **Dmytro Nor**; literature search – **Olga Morozova**; review and editing – **Serhii Dotsenko, Karina Trubchaninova, Olga Morozova**.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, author ship or otherwise, that could affect the research and its results presented in this paper.

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Data Availability

The manuscript contains no associated data.

Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence methods while creating the presented work.

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РОЗВИТОК МОДЕЛЕЙ ТА МЕТОДІВ ФОРМУВАННЯ ДИДАКТИЧНИХ БАГАТОМІРНИХ ІНСТРУМЕНТІВ

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Предметом вивчення в статті є процеси синтезу багатофакторних, переважно восьми факторних, графічних логіко-смислових моделей представлення знань з відкритою архітектурою для бази знань. **Метою статті** є формування теоретичного опису етапів розробки цих моделей й формування практичних рекомендацій з їх проектування. **Завдання:** аналіз основних положень теорії та практики дидактичної багатомірної технології та характеристик багатофакторних існуючих логіко-семантичних моделей подання знань та виявлення їх сильних і слабких сторін; визначення методології дослідження); аналіз теоретичних положень формування багатофакторних логіко-семантичних моделей подання знань, визначення проблем, які потребують вирішення. знань; аналіз характеристик моделей дидактичних багатомірних інструментів; дослідження восьми факторних архітектур логіко-семантичних моделей подання знань; розробка методу проектування логіко-семантичних моделей подання знань; розвиток методу формування двох факторних логіко-семантичних

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моделей подання знань; практична реалізація логіко-семантичної фізичної (перший рівень) моделі подання знань для багатофакторних моделей; узагальнення результатів дослідження та окреслення майбутніх напрямків розвитку в галузі моделювання знань для баз знань з відкритою архітектурою **Отримані такі результати.** З аналізу літературних джерел слідує, що на цей час основна увага при впровадженні інформаційних технологій приділяється інструментам на основі теорії штучного інтелекту, в тому числі базам даних та базам знань. З іншого боку, отримали розвиток моделі й методи подання знань в яких застосовуються альтернативні принципи формування моделей представлення знань. **Висновки.** Наукова новизна отриманих результатів полягає в наступному: встановлена доцільність переходу від застосування матриць при формуванні між факторних (векторних) взаємовідносин елементів множин, які їх формують, до табличної форми представлення цих відношень у формі декартового добутку; запропоновано застосування табличного редактора, наприклад Microsoft Excel, що забезпечує формування багатовекторних логіко-семантичних моделей представлення знань з будь-якою кількістю факторів; встановлено, що застосування табличного редактора Microsoft Excel забезпечує реалізацію другого та третього етапів проектування бази знань у наступних формах: логіко-семантичної фізичної (перший рівень) моделі подання знань; формування логіко-семантичної фізичної (другий рівень) моделі подання знань; в той же час, застосування табличного редактора Microsoft Excel забезпечує реалізацію процесів адміністрування та управління сформованою базою знань. При цьому, для таблиці виникає необхідність визначення форм відношень поміж елементами, для яких реалізується операція декартового добутку. Ця проблема потребує додаткового дослідження і може бути темою для подальших досліджень.

Ключові слова: логічна модель представлення знань; логіко-смислова модель представлення знань; база знань з відкритою архітектурою; семіотика, табличне подання; фактор.

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