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THEORETICAL AND METHODOLOGICAL ASPECTS OF ONTOLOGICAL MODELING OF INFORMATION-ANALYTICAL SYSTEM OF SCIENTIFIC PERSONNEL TRAINING

The development of science and education is now exposed to a huge impact of such civilizational challenges as: climate change, which is due to global warming, excessive and unjustified consumption of material goods, environmental pollution; pandemic COVID 19 and the emergence of new diseases and as the quintessence of human irresponsibility and callousness, activation on a global scale, and in Ukraine in particular, hybrid wars against universal values. This situation causes a massive shift to a remote format of the organization of scientific and educational (research) process, including the training of scientific personnel in higher education institutions and research institutes, using certain networked information and computer technologies and systems.

Therefore, the purpose of the study, the current results of which are presented in the article, is to study the problems of applying the methodology of building information-analytical systems (hereinafter – IAS), in particular digital IAS, and to substantiate the basis and highlight in this context the main aspects of creating an ontological model of scientific personnel training (hereinafter – SPT) system as part of a single information space of scientific education. The author raises the problem of the need to apply transdisciplinary methodology of building digital information-analytical system of scientific personnel training in higher education institutions (hereinafter – HEI) and research institutes (hereinafter – RI) of Ukraine in a distance. Particular attention is paid to the ontological modeling of IAS components of the relevant organization of effective scientific and educational (research) process. Also basic definitions of the ontological approach to the training of scientific personnel disclosed. The article considers certain requirements for the design and functioning of intelligent educational systems and programs that provide adaptive information-analytical support of scientific personnel training on the basis of transdisciplinary, system, competence and ontological approaches. The analysis of a certain base of sources (researches and publications) is given. Thus, the methodological basis for building a digital information-analytical system in the specified context is presented and certain fragments of its ontological model are proposed. The presented approbation of applied aspects of the author's research is in the ascertaining stage. Subsequent results of analytical-synthetic and formative stages of the presented doctoral research are passing into the phase of experimental verification and the obtained data will be made public in the following publications of the author.

Key words: Information-Analytical System, Intelligent Information Technologies, Modeling, Scientific Personnel, Science Education, Ontology

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ТЕОРЕТИКО-МЕТОДОЛОГІЧНІ АСПЕКТИ ОНТОЛОГІЧНОГО МОДЕЛЮВАННЯ ІНФОРМАЦІЙНО-АНАЛІТИЧНОЇ СИСТЕМИ ПІДГОТОВКИ НАУКОВИХ КАДРІВ

Розвиток науки і освіти нині завдається під величезним впливом таких цивілізаційних викликів як: зміна клімату, яка відбувається завдяки глобальному потеплінню, надмірному й невиправданому споживанню матеріальних благ, забрудненню навколишнього середовища; пандемія COVID 19 та поява нових захворювань і, як квінтесенція людської безвідповідальності та бездуховності, активізація у планетарному масштабі, а в Україні зокрема, гібридних війн супроти загальнолюдських цінностей. Такий стан речей зумовлює масовий перехід на віддалений формат організації науково-освітнього (дослідницького) процесу, у тому числі це стосується й підготовки наукових кадрів у закладах вищої освіти та науково-дослідницьких інституціях, з використанням певних мережевих інформаційних і комп'ютерних технологій та систем.

Тому метою дослідження, поточні результати якого представлено у статті, є вивчення проблематики застосування методології побудови інформаційно-аналітичних систем, зокрема цифрових інформаційно-аналітичних систем, та обґрунтування засад та виділення у цьому контексті основних аспектів створення онтологічної моделі системи підготовки наукових кадрів як частини єдиного інформаційного простору наукової освіти.

Автор порушує проблему необхідності застосування трансдисциплінарної методології побудови цифрової інформаційно-аналітичної системи підготовки наукових кадрів у закладах вищої освіти та науково-дослідних інституціях України в умовах дистанту. Певну увагу приділено онтологічному моделюванню складових інформаційно-аналітичної системи релевантної організації ефективного науково-освітнього (дослідницького) процесу. Також розкрито основні дефініції онтологічного підходу щодо підготовки наукових кадрів. У статті розглянуто певні вимоги до проектування й функціонування інтелектуальних освітніх систем і програм, що забезпечують адаптивний інформаційно-аналітичний супровід підготовки наукових кадрів на засадах трансдисциплінарного, системного, компетентнісного та онтологічного підходів. Наведено аналіз певної джерельної бази – досліджень та публікацій. Тим самим представлено методологічні засади побудови цифрової інформаційно-аналітичної системи у зазначеному контексті та запропоновано певні фрагменти її онтологічної моделі. Представлений у статі фрагмент дослідження носить констатуючий аспект. Подальші результати аналітико-синтетичного та формувального етапів представленого докторського дослідження переходять у фазу експериментальних перевірок та отримані дані оприлюднюватимуться у наступних публікаціях автора.

Ключові слова: інформаційно-аналітична система, інтелектуальні інформаційні технології, моделювання, наукові кадри, наукова освіта, онтологія

Introduction

The beginning of the 21st century has been marked by significant instability in human life. Scientific and educational space under the influence of globalization, the emergence of new priorities, and, consequently, the demands on the content and quality of education, including scientific engineering education, undergo significant transformational changes. Over the past decades, the main innovations in science and education, provoked by the systemic nature of modernization and reform in these sectors, have led to the rapid development of information technology. This includes digitalization of almost all parts of the country's economy, including the scientific and educational environment of educational institutions and research establishments, the first steps in the application of semantic technologies and the introduction of artificial intelligence technologies in research activities.

In addition, the development of science and education is currently under the enormous influence of such civilizational challenges as: climate change, which occurs due to global warming, excessive and unjustified consumption of material goods, environmental pollution; pandemic COVID-19 and the emergence of new diseases and, as the quintessence of human irresponsibility and callousness, activation on a planetary scale and in Ukraine in particular hybrid wars against universal values. This situation has led to a massive transition to the remote format of the educational process, including the training of scientific personnel, using network information and computer technologies.

According to many researchers, the remote format of scientific and educational (research) activities is becoming increasingly popular, as the digital transformation is very fast, and information technology is an indispensable tool for scientific and educational activities.

In addition, digital information technologies already play a major role in the research process, but their effect on this process is becoming more and more tangible. The introduction of such innovations contributes to the modernization and development of the national education system, as well as improving the quality of scientific training and further convergence between science and education. And, as we can see from the example of other states, the introduction of such technologies in many ways requires revision of the existing approaches to scientific and educational activities. The logical development of the implementation of engineering and software innovations tools into the scientific and educational process is their integration into the environment of information-analytical systems of the respective HEI/RI.

Consequently, one of the problems of remote organization of scientific personnel training is to promote the formation and development of the transdisciplinary component of their information-analytical competence. That is, it becomes important not only to reproduce certain knowledge by applicants for scientific education (master's students, PhD students, etc.), but also to stimulate and motivate them to conduct information-analytical slices on the results of scientific research in the vector of the chosen research topics. Indeed, such approach encourages applicants for scientific education to independently deepen the acquired knowledge and adequately develop their system-critical thinking, which will lead to the acquisition of transdisciplinary competencies in constructing logical relationships and generalizing relevant conclusions, going beyond a particular discipline. In our opinion, this problem is solved through the development of Semantic Web concept and transdisciplinary approach (including adaptive and ontological approaches as its variants).

Let us focus on the ontological approach and note that one of the reasons for its growing popularity to the visualization of knowledge is the prospect of presenting knowledge as a holistic picture, which will prevent the fragmented perception of the world and reflect the cause-and-effect transdisciplinary relationships.

In fact, ontology finds application in the development of various systems, such as integration of business processes and corporate platforms, monitoring and analytical information gathering systems, distance learning systems, etc. They are also used for searching and combining information from different sources and environments. The use of ontologies allows to significantly simplify the construction of individual research trajectory of each applicant of scientific education (including – applicants for a scientific degree), can be the basis for the development of so-called mind maps, contributes to the introduction of elements of artificial intelligence in the scientific and educational process, such as evaluation of achievements, etc.

Thus, the ontological approach becomes one of the most promising methodologies for building an IAS of SPT and needs to be extensively researched and implemented under the conditions of digitalization.

Related Works

The analysis of recent studies and publications has shown that the main approaches to the formation of science education in their research are laid by such scientists as: S.Corneliussen [1], S. Erduran [2], N. Teig [3], J. Yeo and K.C.D. Tan [4], etc.The study of sources has shown that the definition of “science education” (SPT) by scientists is interpreted ambiguously. Thus, the lack of a unified understanding of the concept of science education causes difficulties with its modeling.

However, there are many works devoted to the application of information technologies and information systems in the SPT, including those by such famous researchers as V. Bykov [5], J. Flotyński [6], T. Hess [7], T. Lynn, P. Rosati, E. Conway, D. Curran, G. Fox, C. O’Gorman [8], I. Voras, M. Orlić and B. Mihaljević [9] and others (digital education, digital competence, open electronic scientific and educational systems, cloud oriented informational and educational systems, digital transformation, etc.); A. Chebanyuk [10], T. Hovorushchenko,

Y. Martynyuk, O. Pavlova and O. Pomorova [11-13], S. Zybin [14] et al. (intelligent technologies and robotics; use of ontologies for evaluating stages of the software lifecycle, software design technologies, information processing and protection systems, software engineering), etc.

Let us focus attention on the fact that the methodology of building IAS is devoted to a number of works of scientists: I. Guitart and J. Conesa [15], M. Steopan, B. Mocan, P. Florin, M. Bucur and V. Ispas [16] et al. (information systems research, the problems of development of intelligent IAS for educational purposes, foundations of designing and creating IAS of educational institution management, UML-modeling of IAS), A. Trofimchuk, A. Nesterenko and I. Netesin (design methodology of analytical information systems of administrative management) [17], etc.

However, ontology modeling and implementation of the ontology approach to the methodology of information and intelligent systems construction, as well as computer ontologies are devoted to the works of such scientists as: Y. Dmitrieva and F. Verbeck [18], A. Katifori, C. Halatsis and G. Lepouras [19], S. Montolo, S. Lieber, B. Meester, A. Dimou and R. Verborgh [20], C.Shimizu, P. Hitzler and A. Krisnadhi [21], etc.

However, the methodological problem of designing and constructing, as well as functioning and supporting, a digital/intellectual IAS of SPT and application of ontological modeling in this context is insufficiently developed in scientific applied engineering and scientific-educational practice.

The purpose of the article

Therefore, the purpose of the article is to present the current results of scientific research aimed at studying the problems of applying the methodology of building IAS (including digital IAS), in particular, the rationale and study of the main aspects of creating an ontological model of SPT system as part of the unified information space of HEI/RI.

Key Message. Results

In view of the fact that the main forms of HEI/RI scientific training are postgraduate, adjunct and doctoral studies, the notion of "scientific training" will imply some kind of scientific and educational process which contributes to the formation of "scientific style of thinking," in particular the ability applicants for scientific education to make decisions based on critical analysis of data, solve complex problems, create innovative solutions, create and take initiative, understand the essence of global and local challenges [9], as well as to have an optimal level of development of transdisciplinary component of information-analytical competence of each potential researcher.

The formation of scientific style of thinking is, first of all, a characteristic of intellectually active personality of a researcher. Therefore, in the process of scientific personnel training it is important not only that applicants of scientific education assimilate knowledge, but also how they master the methodology of their search. In other words, there should be a conscious assimilation of the acquired knowledge. Applicants for scientific education (first of all, potential applicants for scientific degrees) should understand the essence of the studied phenomena, regularities of their development, cause-and-effect relations. They will not only be able to creatively apply the acquired knowledge to solve educational and practical problems, but must acquire the relevant competencies to select the best ways to do so, i.e. be aware of the advantages of certain methods of solving the research problem.

As already noted, the current global trend is the transition to remote forms of education. We will not dwell on the reasons, but note only that this process is inevitable, it should be taken as a given and be based on this fact in our calculations. Remote forms of work require much more effort in terms of the organization and administration of scientific and educational activities than "traditional" education. Automated IAS are being actively implemented in the HEI/RI scientific training system, whose components increasingly include intelligent elements. The main purpose of such systems is to free all participants of the scientific-educational process from routine operations and enable them to focus on the most important aspects of their activities.

For example, in the scientific work "Ontological modeling of learning processes" the authors revealed the requirements for intelligent learning systems and programs, focusing on their attractiveness for use in the educational process. The researchers argue that such systems should be based on ontological models as they "can be used to provide and visualize detailed training information and management information exchanged by subsystems, time and conditions of initialization of subsystems, the state of subsystems, problems and errors in the functioning of computer learning system or its individual subsystems (components)" [22]. Agreeing with this statement, before considering the basics of building the IAS for SPT ontological model, let us give, in our opinion, an adaptation of the most significant of them, which will be characterized by such aspects as:

- intuitive interface (design of individual screen pages applies graphics, color, etc.) with an extensive tooltip system;
- the presence of multiple, multi-level, branching learning-oriented science-education programs, a "linear" mode is possible when reviewing poorly learned material step-by-step;
- the system principle of computer scientific and educational (training-oriented) program construction with a variety of variations in the task setting, possibilities of interaction with the program;
- ensuring adaptation to each applicant of scientific education (taking into account the time and pace of application (training), determining the level of results, psychophysical abilities to perceive the material, etc.);

− possibility of active interference of scientific education applicants in the research process by means of a computer program (reduction/deepening of material, provision of additional content, change of pace, possibility to take breaks for quite a long time, etc.)

Also in the context of the problem of ontological modeling, let us define its basic definitions: **subject domain**, **ontology.**

In various literary sources it is possible to meet the name “subject sphere”, i.e. some set of objects of the real or supposed world considered within the given context, information which will be the object of formalization, preservation and processing.

In scientific and engineering circles concerned with the theory and practice of automated information systems (hereinafter – AIS) subject domain is a systematized set of objects, the properties of objects, the relationships between objects, and functions resulting from the objects, whose activities are the subject of automation through the AIS.

We know that “ontologies, as sets of concepts and their interrelations in a specific domain, have proven to be a useful tool in the areas of digital libraries, the semantic web, and personalized information management” [19]. By **ontology** we will understand a certain structure describing the meaning of the elements of some system, an attempt to structure the world around, to describe some specific subject domain in the form of concepts and rules, statements about these concepts, with which one can form relations, concepts, classes, functions, etc. Subject domain ontologies are limited to describing the world within its specific limits [24-25]. Ontology allows us to specify a complex structure that can contain data of different types, provides a simple understanding of the representation of structured knowledge, allows its automatic analysis, identification and addition of missing logical entanglements and relatively uncomplicated sharing and updating.

The formal description of ontology in the form of triplets [23-25] :

$$\mathbf{O = \langle X, R, F \rangle}, \tag{1}$$

where $\boldsymbol{O}$ is ontology in itself; $\boldsymbol{X} = \{\mathbf{x_1}, \mathbf{x_2}, \dots \mathbf{x_n}\}$ is the finite set of concepts of the domain, $\boldsymbol{n}$ is the number of elements of this set; $\boldsymbol{R} = \{\mathbf{r_1}, \mathbf{r_2}, \dots \mathbf{r_m}\}$ is a finite set of relations between the concepts of the domain, $\boldsymbol{m}$ is the number of significant relations; $\boldsymbol{F}$ is a finite set of interpretation functions defined on concepts and relations of ontology $\boldsymbol{O}$ ($\boldsymbol{F}$ is the Cartesian product ***of XxR*** is a finite set of interpretation functions defined on concepts and/or relations).

In a general sense, relations can be conventionally divided into general-valued relations (including partial-order relations, as a rule, are distinguished) and specific relations of a given subject domain. In fact, a relation $\boldsymbol{R}$ is an interpretation of properties of concepts, i.e. there is a transformation that assigns a certain property to each relation.

The complexity of the ontological modeling task of the IAS is determined, in particular, by the presence of countless individual elements of the domain – in our case, the system of knowledge, which should be obtained by scientific education applicants, the complexity of grouping them into separate sets of objects (concepts proper), the complexity of developing rules for such grouping, establishing interdisciplinary and transdisciplinary links between concepts, different goals of end users. The result of ontological modeling will be a certain formalization of the subject area, which can be represented graphically in the form of some graph.

For example, in developing an ontological model of distance learning system researchers offer an ontological representation of knowledge in the form of a set of concepts, depicted using ontograph (combination of content concepts (vertices, nodes) and the relationships between these concepts). They have built an ontological model of the distance learning system, which captures and structures the knowledge common to the domain. The authors have developed information hierarchies to build an intellectual model of distance learning process using the elements of object-oriented approach methodology. They based their work on the methodology of automating the design of information and technological processes and systems. Researchers applied ontological modeling of information systems based on multidimensional models. In this sense, this methodology can be adapted to build any “infological model” of the information system, including IAS for SPT, fully reflecting the pragmatics of the system under study [18, 23-26]. It should also be noted that recently the use of ontological approach to model building in education is becoming more widespread. Most often, this approach is used to model intelligent systems, in particular, those designed to function on the Internet. This is due to the fact that the ontological model allows creating an appropriate metadata model, which significantly increases the efficiency of using the system by a wide range of users in terms of organizing interaction.

For this purpose on the basis of descriptive logics the language of Web-ontologies OWL was developed, which is one of the main components of semantic Web. It should be noted that OWL language is a result of RDF technology development based on XML and allows combining specific forms and formats of objects and processes representations in such subject domains as knowledge visualization, natural language information processing, decision making, expert systems, etc. based on the formats of Internet technologies. The basic structural unit of RDF is the triplet “subject – object – predicate”, called RDF-graph. Subjects and objects act as vertices, predicates act as arcs. Mathematically, a triplet is an instance of an element of some binary relation. The language of first-order predicate logic looks capacious and neat if we imagine that tables are predicates.

One of the most well-known tools to work with ontological models, which allows to create their graph mappings, is Protege [27]. It is in this format that researchers use RDF/XML syntax as the ontology representation language. Of course, the most effective way to automate the management of research training in HEI/RIs is to create a unified information research space. The solution to this problem comes down to the construction of a unified automated HEI/RI information system. The ontology fragment presented in Figure 1 can become one of the basic components of building the ontology model of the digital IAS of SPT, which will ensure the scientific and educational process in HEI/RI on a remote basis.

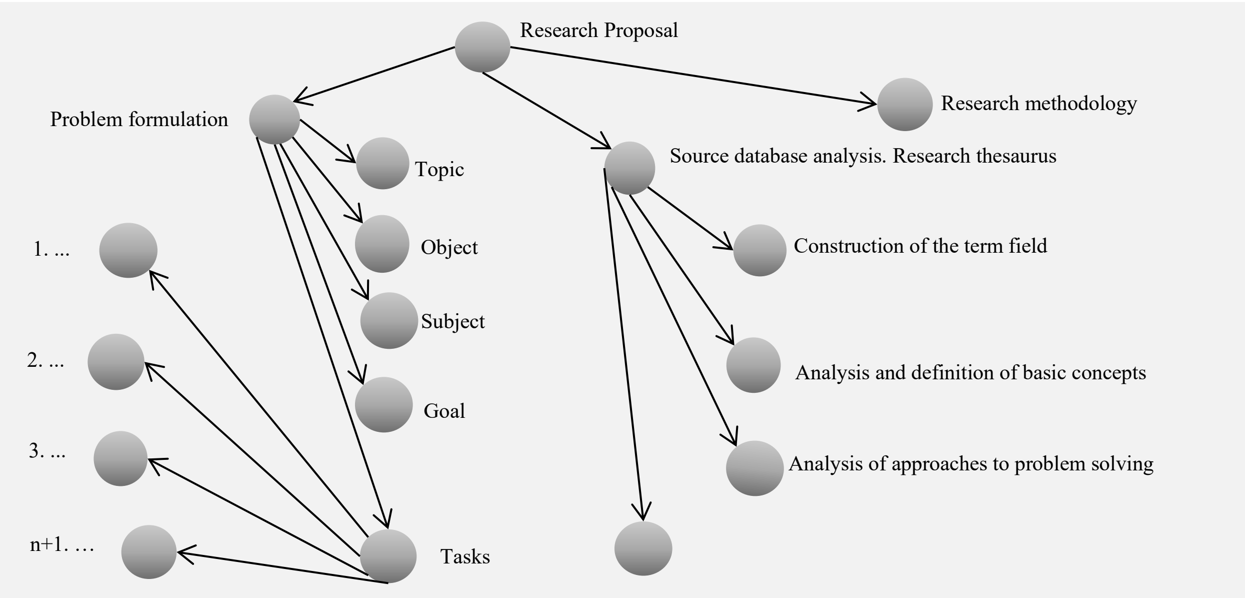

Fig. 3. Ontograph of the IAS for SPT module "Preparatory Information Analysis of Research Problem. Research proposal" (fragment developed by the author)

In general, the definition "information-analytical system of scientific personnel training" will be understood as a transdisciplinary network environment, which in its overall structure logically has two main components – information and analytical blocks, and also includes a technical and technological complex of software developed according to the methodology of system analysis, mathematical reasoning and ontological modeling to ensure automation and optimization of information and analytical activities of educational process participants. In our opinion, this definition can still be clarified in the research process.

That is, IAS for SPT is an information-analytical system aimed at ensuring the functioning and support of scientific education. As it was mentioned above, the task of designing such a system is quite complicated. IAS for SPT should take into account all processes of information collection and processing using the latest information technologies, validation of obtained analytical data, generalization of expert evaluations, maintenance of knowledge bases, use of software and hardware tools and creation of authoring programs and systems, formation of ramified transdisciplinary environment of information and analytical resource centers and many other things.

It should only be noted that the management of information processing processes in the IAS for SPT ecoenvironment will be implemented based on the use of certain hierarchies reflecting the properties of the information processes involved. It is these processes that constitute the operational environment. In the existing intelligent systems knowledge is represented by means of ontologies and inference rules, which allow to obtain new knowledge, not yet placed in explicit form in the knowledge base. Such a system will have a modular character, and the capabilities of functional modules should be determined by the purpose of the system. Thus, IAS for SPT will necessarily include those modules that will be responsible for the development of scientific thinking, acquisition of competencies in exploratory analytical activities, methods of organizing and conducting scientific research, etc. The main task of IAS for SPT is to support the educational and research management functions of HEI/RI. For example, the ontograph of one of the IAS-SPT modules "Preparatory Information Analysis of Research Problem. Research proposal" in the context of scientific research apparatus formation can alternatively be represented as shown in Figure 1. Thus, the given ontograph is only a fragment of the functional module "Preparatory Information Analysis of Research Problem. Research proposal" of digital IAS-SPT. However, the creation of such a system in its entirety is a complex and cumbersome task, because its implementation can raise the system of scientific personnel training to an optimally high quality level of providing both scientific and educational and research processes. Also note that in IAS-SPT each of the nodes of such ontograf should be associated with a certain software (Table 1).

Table 1.

General description of the ontology fragment of the IAS for SPT functional module "Preparatory information analysis of a scientific research problem. Research proposal"

Processes of scientific activity	Subprocess	Information and analytical support tools
Research proposal. An informative analysis of the research problem	1.1. Information analysis of the problem study. 1.1.1. Analysis of existing research topics and publications. Formulation of the topic. 1.1.2. Analytical processing of information and definition of the object and subject 1.1.3. Summary of information and analytical data and formulation of research objectives. 1.1.4. Use of current results of information analytics and definition of tasks.	Web-technologies for joint work of IAS of SPT subjects in the Internet (for example, Collaboration Platforms). Internet search engines (Microsoft Bing, Google, Swisscows, DuckDuckGo, Wiki.com, Wayback Machine, WolframAlpha, etc). Microsoft Office applications. Electronic open access systems, software platforms for the creation of digital libraries (for example, Open Access Same-Time Information System (OASIS).
	1.2. Analysis of the source and instrumental base of the research problem. 1.2.2. Structural-semantic (definitive) analysis of basic concepts of the problem under study. 1.2.3. Analysis of methodological approaches to the problem under study. 1.2.4. Analysis of tools and software to support applied research tasks.	Web technologies for collaborative work of SPT subjects on the Internet (for example, Flowdock, GoToMeeting, Slack, Cisco WebEx, Asana etc). Internet search engines (Microsoft Bing, Google, Swisscows, DuckDuckGo, Wiki.com, Boardreader, SlideShare, Wayback Machine, WolframAlpha, etc). Microsoft Office applications.
	1.3 Analysis of existing methodologies and techniques for the organization of applied research in the field of "Information Technology" and justification of a more adequate methodology for solving this problem of scientific research.	Internet search engines (Microsoft Bing, Google, Wiki.com, WolframAlpha, etc). Open access electronic systems (for example, Open methodologies – Open-design movement, Open Design, etc.). Microsoft Office programs. Other specific application software.

Conclusions

So, in the process of research it was found that the ontological approach is currently one of the least studied and promising methodologies for building information systems, including digital information-analytical systems

Over the last decade, attention to ontological modeling has been attracted by an increasing number of strategic thinkers.

In turn, ontological modeling in the considered context proceeds from the natural ability of people to think logically and creatively, to define events and establish relationships between them.

Also ontology as a semantic model reflects the elements of the domain, reveals the relationship between them, along with a fully formalized phenomenon, and the reflection of the ontological model in the form of ontograph makes visible (visualizes) the processes occurring in the domain.

Thus, we consider it expedient to state the fact that the results of research presented in the article allow drawing a general conclusion: the need and necessity to create a unified digital/intellectual IAS of SPT based on ontological modeling will ensure the efficiency of scientific-educational process in this vector. It should be noted that this becomes a particularly important factor in times of force majeure (pandemic, martial law, etc.), which entail remote mode of both educational training and research process.

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