Ontologically-Controlled E-Learning Systems as a Means for Developing Conceptual Thinking of the Individual

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Abstract

The article describes the mission of orderly knowledge in the formation of the personality of a competitive specialist. The technology of building an information system based on the cubic representation of the ontology of the discipline is presented. The presentation of the educational topic in the form of an ontological cube, which consists of three planes: conceptual, informative and stimulating, is characterized. It is proved that such presentation of information in the process of e-learning will promote the development of conceptual thinking and speech, intellectual skills of the future specialist, provides an opportunity to find an unexplored scientific niche in a particular professional field, and, as a result, stimulates the desire to create their own professional image. The essence of the named planes is revealed, the expediency of division of material of planes into chunks is characterized. The technology of construction of information system on the basis of cubic representation of ontology of educational discipline is described. Examples of application of technology for construction of ontology of subject area on discipline "Algorithms and data structures", an ontological cube on a subject: "Psychophysiological bases of creativity" of a course "Psychology of creativity" are resulted.

The results of the introduction of the presented technology in the educational process are described on the example of academic groups of students majoring in "Applied Mathematics" KPI Igor Sikorsky and groups of students majoring in "Psychology" of the Pedagogical Faculty of NPU Drahomanov in 2020-2021. The analysis of the results made it possible to state that the developed ontological system of e-learning is effective and efficient, to state that its implementation allowed to form students' knowledge in the form of flexible systems suitable for use in various educational institutions and life situations.

Keywords [1]

E-learning, information technology; ontological cube, chunk, conceptual plane, informative plane, stimulating plane

1. Introduction

The transformation of Ukraine into a developed European state is associated with the direction of the system of general and higher education for the development of a competitive individual who can think and, as a consequence, create material and spiritual values, adequately assess the results of their own activities. and others. In order to teach a person to think what is important for becoming a competitive professional, it is necessary to radically change the formal education, aimed primarily at assimilating "correct" information or presenting it through information technologies in the form of various presentations, and then checking its assimilation through surveys. and performance of reproductive tasks, for practical education. At the heart of such education is the assimilation of meaningful information within the problem-searching dialogues between the subjects of the educational process and training students to implement it in various bulk and life lessons in general secondary education and students - in various professional situations in seminars and practical classes in

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institutions of higher education. This creates an educational environment in which each subject of knowledge from the consumer of ready-made information becomes a seeker and actor who learns to apply it in practice, and then - to create something fundamentally new in each professional field. Such an environment can be built in the process of e-learning on the basis of ontologically controlled systems. The main mission of such systems is the development of conceptual thinking, which is the basis for the development of divergent, creative thinking and speech. As a result, there is the formation of orderly knowledge. Such knowledge is a tool for cognition of the objective world, various spheres of professional activity, self-education, which must be carried out constantly during conscious life.

Studies by T. Berners-Lee, T. Gruber, and K. Sikar are devoted to the development of a methodology for working with ontologies. The ontological graphs developed and presented by scientists describe a certain set of subjects, between which there is a certain network interaction, due to the set of information processes that make it up. Such subjects can be represented in the form of functional nodes, between which the interaction is realized based on the use of their multiple connectivity [1, 2, 3], which defines it as an open network-centric environment. Ontological models reflect the researcher's conceptual view of a subject area and provide an opportunity to unambiguously define its concept, structure, accumulate and repeatedly use knowledge. The need for such a way of presenting knowledge was strongly felt in many branches of science and, in response to the urgent need, the ontological approach began to be used almost simultaneously in many fields. Currently, we can talk about the formation of a scientific direction related to the development and application of ontological models

O. Strizhak [4] proposed a method of information modeling of subject areas, aimed at ensuring the systematic assimilation by students of large layers of information that indirectly affects the mental development of the individual, in general, and in particular, the development of conceptual thinking. Any information system is a means of developing cognitive processes. For example, George Miller [5] investigated the role of thinking in information processing, the separation of primary and secondary information from the flow of information, the establishment of causal relationships and, consequently, the construction of inferences. However, in our opinion, it is necessary to strengthen the development function of information systems. For example, the development of "cognitive flexibility", namely: the ability to perceive, analyze and interpret information (a certain situation) in different ways according to J. Brown and E. Langer [6]. There is also a lack of information systems that would reflect the developmental educational space, provide an individual trajectory of development of each subject of knowledge, and, at the same time, have a methodological nature, would cover the methodology of the discipline. The purpose of the article: to present an information system that allows you to display, systematize and visualize the conceptual apparatus, phenomena, processes and relationships between them of a particular discipline, which will promote the development of conceptual thinking and speech of the future specialist.

Such systems should become a means of educating the desire to create something fundamentally new in every professional field.

2. Technology of building an information system based on a cubic representation of the ontology of the discipline

In the construction of conceptual thought, in addition to mental operations, involved such components of consciousness as: sensation, sensory perception, emotional intelligence and certain experiences. Based on the above, electronic coverage of each educational topic should promote the development in tandem of mind, will and emotions. In addition to the hierarchy of conceptual apparatus with coverage of the scope, features of each concept and the relationship between them, the subject must understand the methodology (logic) of a science, namely: methods of scientific knowledge, which are the basis for scientific approaches, patterns, principles of theoretical and practical activities, their mutual enrichment. The main methods of study, knowledge of the content and essence of any discipline in higher education include:

- general, philosophical method - dialectical method. The implementation of this method means the disclosure of the genesis, evolution, features, content and history of a particular science, theoretical approaches to the disclosure of the content of concepts;

- system method (system analysis method). The implementation of this method involves the consideration of a particular science as a single system of relationship between theory and practice (professional activity);
- structural method, the implementation of which involves the creation of a system of concepts of the discipline, their division into types and subspecies;
- functional method, the implementation of which involves the disclosure of the meaning of certain theoretical provisions, which are the basis of existing achievements. It is important that these achievements evoke in the future specialist intellectual feelings (admiration, surprise, etc.), which would cause a desire to create something new;
- psychological and pedagogical methods, including testing, questionnaires, surveys, observations, psychological and pedagogical experiment. They are a means of testing the effectiveness of mental development of the individual, the quality of learning the course.

The main means of meaningful assimilation of information in higher education institutions is a lecture. In order for each lecture to promote the development of conceptual and divergent thinking, intellectual skills, education of the desire to think, the pursuit of achievement, it is necessary to present educational material, using information technologies, in the form of an ontology.

The ontology of the discipline is based on the ontological system [7].

The proposed ontological system consists of a meta-ontology of the discipline, which in turn consists of two parts [8]:

$$O^{Meta} =< O^{Didactic}, O^{Content} > \quad (1)$$

where $O^{Didactic}$ – didactic ontology of the discipline;
$O^{Content}$ – content ontology of the discipline.

In turn, the didactic ontology of the discipline is represented by three:

$$O^{Didactics} =< Ch, L, R >, \quad (2)$$

where $Ch = \{ch_i\}$ – is the set of chunk names that make up the didactic ontology;
$L_i = \{l_{1_i}, \dots, l_{m_i}\}$ – set of links to content elements;
R is the set of relations, and two relations R_1 and R_2 are considered:
$R_1 \subset Ch \times Ch$ – the relationship is "studied after";
$R_2 \subset Ch \times L$ – the ratio "chunk is related to the content element".

It is advisable to divide the material into chunks. Chunk points to a set of logically connected learning material generalized to a topic presented to a student [8].

$$O^{Cube} =< Ch, DChI, L, R > \quad (3)$$

where $Ch = \{ch_i\}$ – is the set of chunk names that make up the conceptual plane;
$DChI = \{DChI_i\}$ – is the set of test tasks that make up the stimulus plane;
$L_i = \{l_{1_i}, \dots, l_{m_i}\}$ – set of references to the information plane;
R is the set of relations, and two relations R_1, R_2 and an additional relation R_3 are considered:
$R_1 \subset Ch \times Ch$ – the relationship is "studied after";
$R_2 \subset Ch \times L$ – the ratio "chunk is associated with a content element";
$R_3 \subset Ch \times DChI$ – the ratio "chunk is related to the test task".

The conceptual plane of the lecture material presents the key chunks of the topic, the relationships between them, the links with the chunks of previous and subsequent topics. In order to form a cognitive interest in the perception of factual material contained in the information plane, it is advisable, in our opinion, in the conceptual plane to offer a problem to solve which students do not yet have enough knowledge. Therefore, in the conceptual plane, the future specialist places certain assumptions, and after understanding the material of the informative plane, the final decision. The problem task, for example, can be in the form of a certain judgment, where it is necessary to determine and then prove its truth. This can be a task related to professional activities.

The informative plane reveals the content of the presented concepts, characterizes the methodology (logic) of a particular educational topic, namely: reveals the implementation of certain methods of study, knowledge of the content of the presented topic, which we have described above. In the information plane certain facts concerning use of the theory in practice, in concrete professional activity are characterized, certain achievements, certain scientific researches and their results are resulted; topics of possible scientific researches, developments are offered. Examples of certain achievements and possible research and development can stimulate students' desire to create their own professional image (unique image of “I”), to find their professional niche.

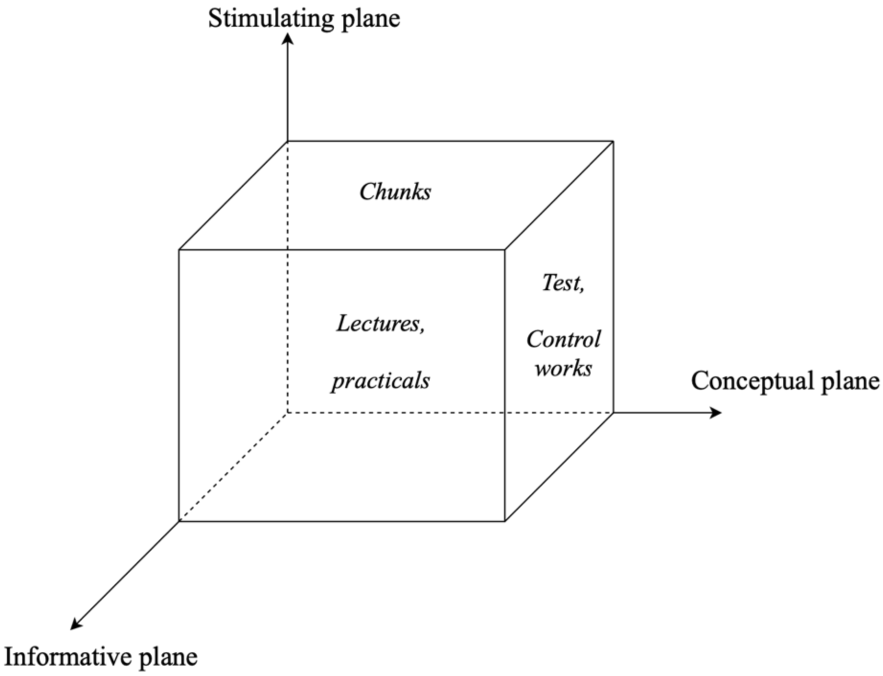

Figure 1: General representation of the ontological cube

Another component of the information system - the stimulating plane should be aimed at developing the ability to use the knowledge of the course in certain educational and professional situations. Based on the above, a system of tasks of different levels of complexity should be presented: reproductive, problem-solving and creative. In order to develop conceptual thinking among reproductive tasks, we recommend offering tasks with a logical load, activating the knowledge of formal logic. For example, to find an error in the proposed definition of the concept, to put in this definition the closest generic concept; graphically, with the help of Euler's circles, show the relationship between the volumes of concepts and make a general, partial and negative judgment with the proposed concepts. It is expedient to offer tasks for drawing inferences, using the offered concepts. Thus, it is possible to offer students to build the following inferences: categorical syllogism, conditionally categorical, divisive-categorical. We believe that problem-solving tasks should be a means of self-education. This is a task to prove the truth of certain statements based on the course material. Sometimes it is necessary to look for additional information from the course to build a proof. In order to develop intellectualized speech (clear, concise, evidential), it is advisable to use quantifiers of generality or existence in the proposed statements. In order to develop students' ability to work in a team among the creative, it is advisable to offer tasks for designing, combining, creating certain projects, which provides for the mission of each project participant.

3. Application of technology to build an ontology of the discipline

In the course of the research, an ontology of the subject area for the discipline "Algorithms and Data Structures" and with the help of the editor Protégé 5 was built.

In figure 2 presents a generalized principle of constructing an ontology of the subject area.

The Protégé 5 ontology editor has a downward or pyramidal ontology design strategy.

To build an ontology in the Protégé environment, you need to perform the following steps:

An example of numbered list is as following.

1. to analyze the subject area of ontology - to select classes;
2. organize classes in the hierarchy of the base class - subclass;
3. determine the properties and their allowable values;

4. fill in the property values for the instances of the class.

Table 1 shows an example of classes, relationships and instances for the ontology of the subject area in the discipline “Algorithms and data structures”.

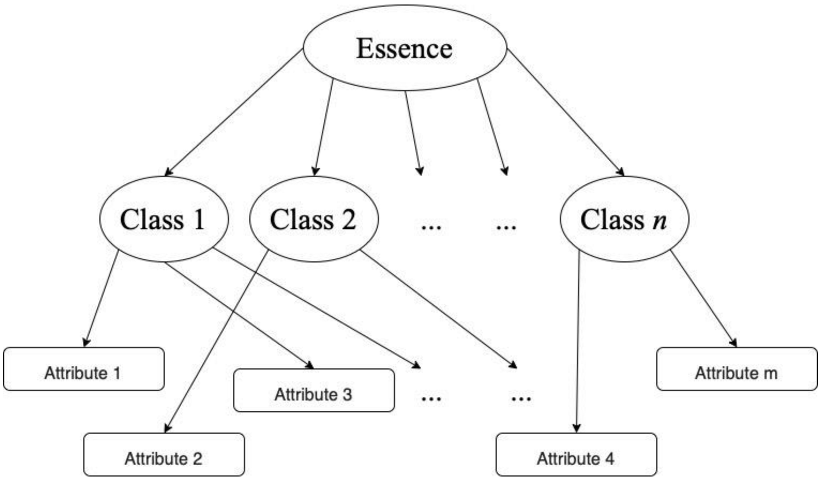

Figure 2: The general principle of constructing the ontology of the subject area

Table 1

Subject area ontology of the discipline "Algorithms and data structures"

Classes	Relations	Instances
Prloblems		Computing the convex hull
		…
Solving methods of the algorithmic problems	has	Brute force
	is	Divide and conquer
	is resolved	…
Time complexity	class-subclass	Exponential
	uses structure	Polynomial
	…	Logarithmic
		…
Data structures		Arrays
		Lists
		…

By default, classes can intersect. In order to divide groups of classes, each individual will not be able to be an instance of more than one class, you need to make the groups of classes non-intersecting (Disjoint Classes).

Figure 3 presents the classes in the construction of the ontology of the subject area of the discipline "Algorithms and data structures" in the editor Protégé 5, which are non-intersecting.

Properties (rdf: Property) in OWL (RDF (s), XML) represent the relationships between classes or their objects [9]. In Protégé 5 there are two main types of properties:

- object property (owl: ObjectProperty), which is a relationship between two classes or individuals;
- data type property (owl: DataTypeProperty), which associates the individual with the data type value of the RDF scheme, ie defines the relationships between the individual and the data values.

Similar to the Thing class, the Protégé 5 editor automatically creates a TopObjectProperty property by default, to make it easier to combine ontologies. Therefore, all object properties are TopObjectProperty subproperties. Protégé 5 implements the ability to visualize the created ontology using an ontograph. An ontograph is an information model of a subject area in the form of an oriented graph [10], the vertices of which are classes, and the arcs are connections that connect these vertices.

In fig. Figure 4 presents the ontograph of the discipline "Algorithms and data structures" for 4 entities, obtained by constructing an ontology of the subject area of the discipline in the environment Protégé 5.

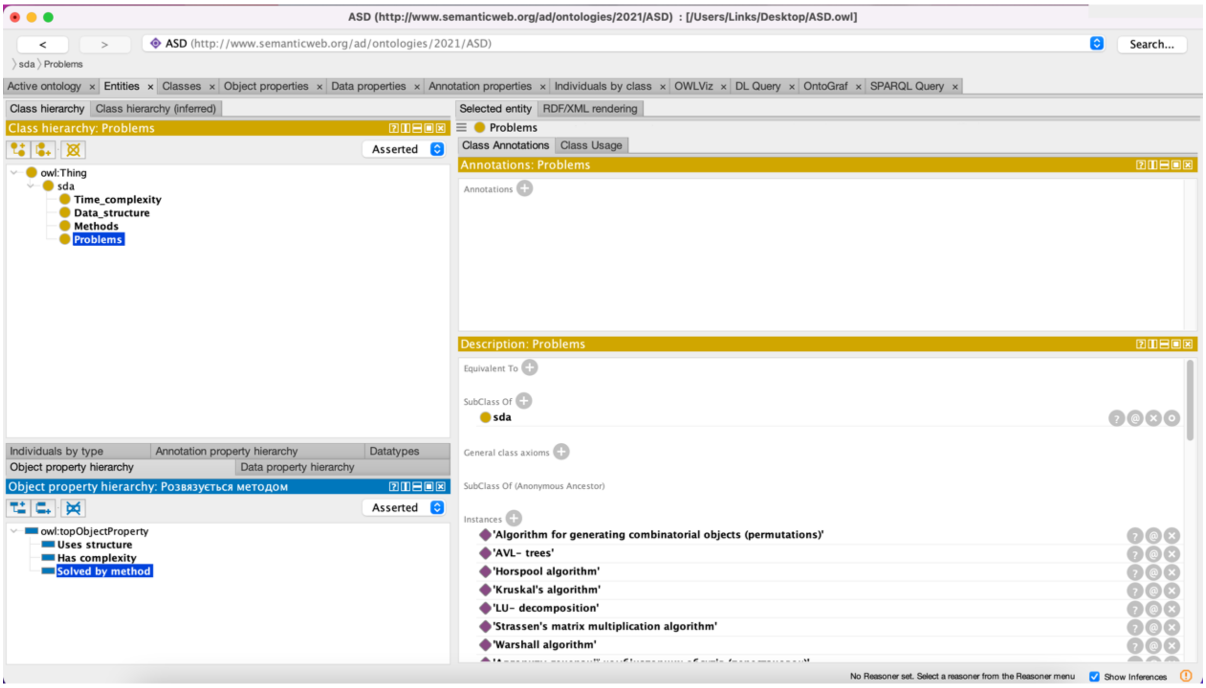

Figure 3: Classes of ontology of the subject area of the discipline "Algorithms and data structures"

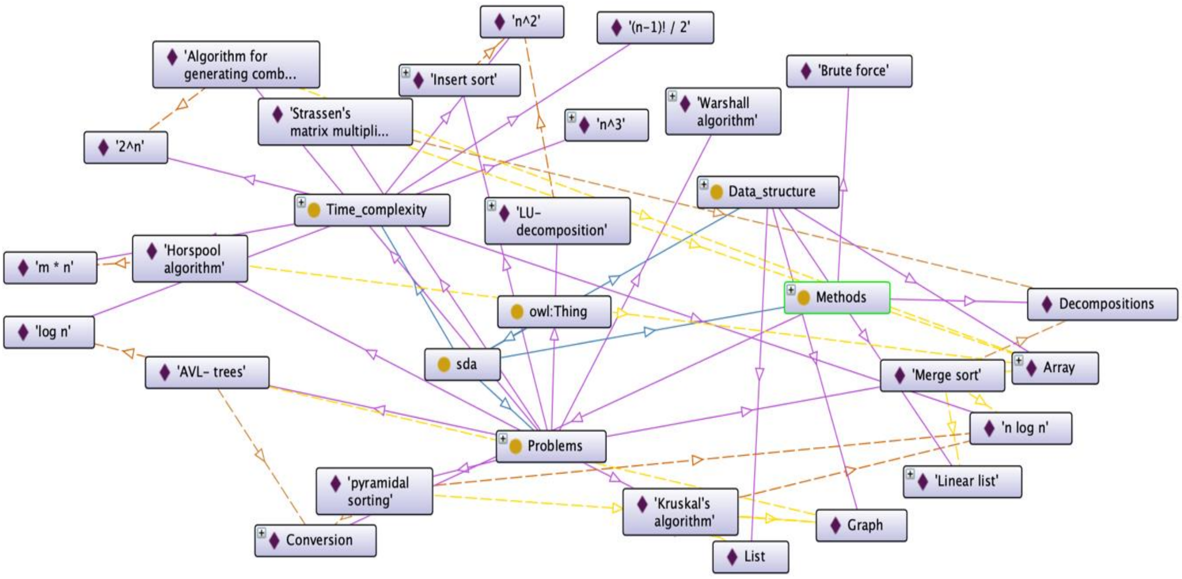

Figure 4: A part of ontograph of the discipline "Algorithms and data structures"

The resulting ontology of the subject area with the increase in the number of entities becomes very big. The generally accepted principle of constructing an ontology of the subject area has advantages, such as: the presence of structure and the ability to acquire new knowledge. In turn, the disadvantages of this approach are: the dependence of the structure of the ontology on the subject area and cumbersomeness. Classes, subclasses, and instances may be different in nature for each subject area. Therefore, the developed information technology should work equally with different subject areas.

In order to develop such information technology, it is proposed to work with the ontology of the discipline (course), as all courses have a similar structure.

Here is an example of the reflection of each of these areas of the presentation of the topic: "Psychophysiological foundations of creativity" course "Psychology of Creativity" for students majoring in "Psychology" - future practical psychologists of educational institutions.

Conceptual plane

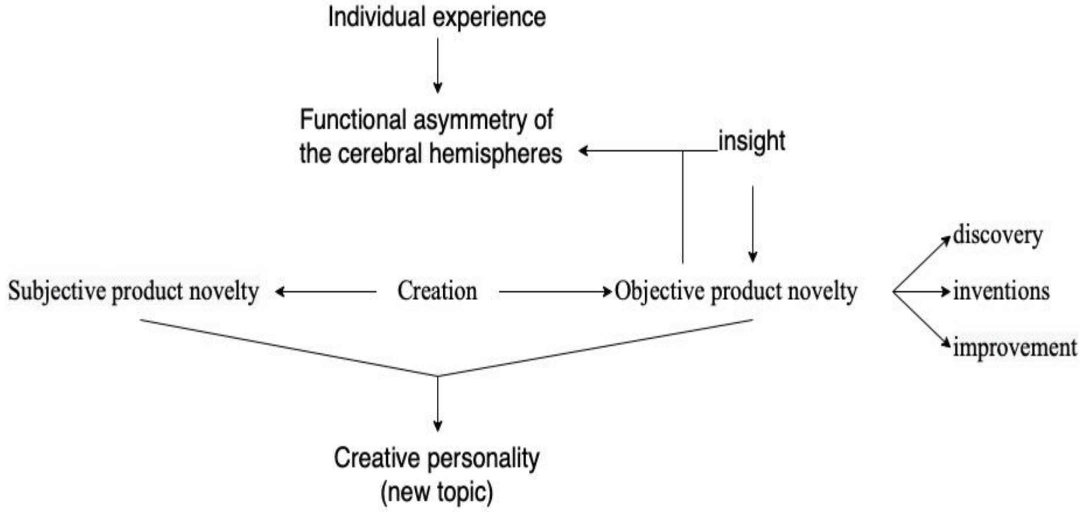

Figure 5: Conceptual plane

The informative plane reveals the content of these concepts and examples of their implementation in the professional sphere. It is advisable to divide the material of the planes into chunks. Chunk points to a set of logically connected learning material generalized to a topic presented to a student. Here is an example of chunks from the proposed topic in each plane. For example, in the conceptual plane will be:

Objective product novelty: discovery, inventions,improvement.

In the informative plane the characteristic of the named concepts is given. The discovery is fundamentally new: something that did not exist in a certain professional field. Inventions - a certain modernization (addition) of the existing. Improvement - the creation of certain tools for optimal (with minimal time and effort) awareness of the new. There are also examples of discoveries, inventions, improvements in various professional fields. Thus, in pedagogy, the discovery, for example, the creation of pedagogical concepts, technologies, author's schools: author's school Guzyka M.; V.O. Sukhomlynsky's educational system, developmental training according to O. Dusavytsky, etc.; inventions: methods, techniques of teaching and education: "whispering in the ear", "pedagogical error" by Sh.O. Amonashvili; lessons of open thoughts from V. Shatalov, "commented management" by SM Lysenkova, etc .; improvement: creation of a certain system of clarity: drawings, diagrams, tables, etc. And, as a result, students have a desire to work on building their own professional image (unique image of "I"). The image construction algorithm is also presented in this plane.

A system of tasks is presented in the stimulating plane. We offer an example of a research task.

Determine whether each of the proposed theses is true or false. Prove your opinion.

- Each individual can become creative in the learning process.
- The left hemisphere of the brain is responsible for the development of creative thinking.

After students get acquainted with the essence of the presented concepts in the informative plane, they can determine that the first statement is true, the second - false.

4. The results of technology implementation

On the basis of ontologies of academic disciplines in the form of cubes and generated control measures with the help of a test task generator [11] an ontologically controlled e-learning system was created. The use of the developed ontologically controlled e-learning system in the study groups of students majoring in applied mathematics KPI Igor Sikorsky and in the study groups of students majoring in "Psychology" ("Practical Psychology" of the Pedagogical Faculty of NPU Drahomanov in 2020-2021 demonstrated the effectiveness and efficiency of the developed ontological control system of e-learning [12] and allowed to form knowledge in the form of flexible systems suitable for use in various educational and life situations

Lectures, practical classes and laboratory classes for filling courses in ontologically controlled e-learning system (OCELS) were developed and created by the authors of the course, and the bank of test questions and tests was generated automatically using the developed information technology and tools to automate the creation of test questions and computational tasks.

An example of integration of an ontologically controlled engine into existing e-learning systems [13], on the example of an e-course created with the help of developed tools, is presented in Fig. 6.

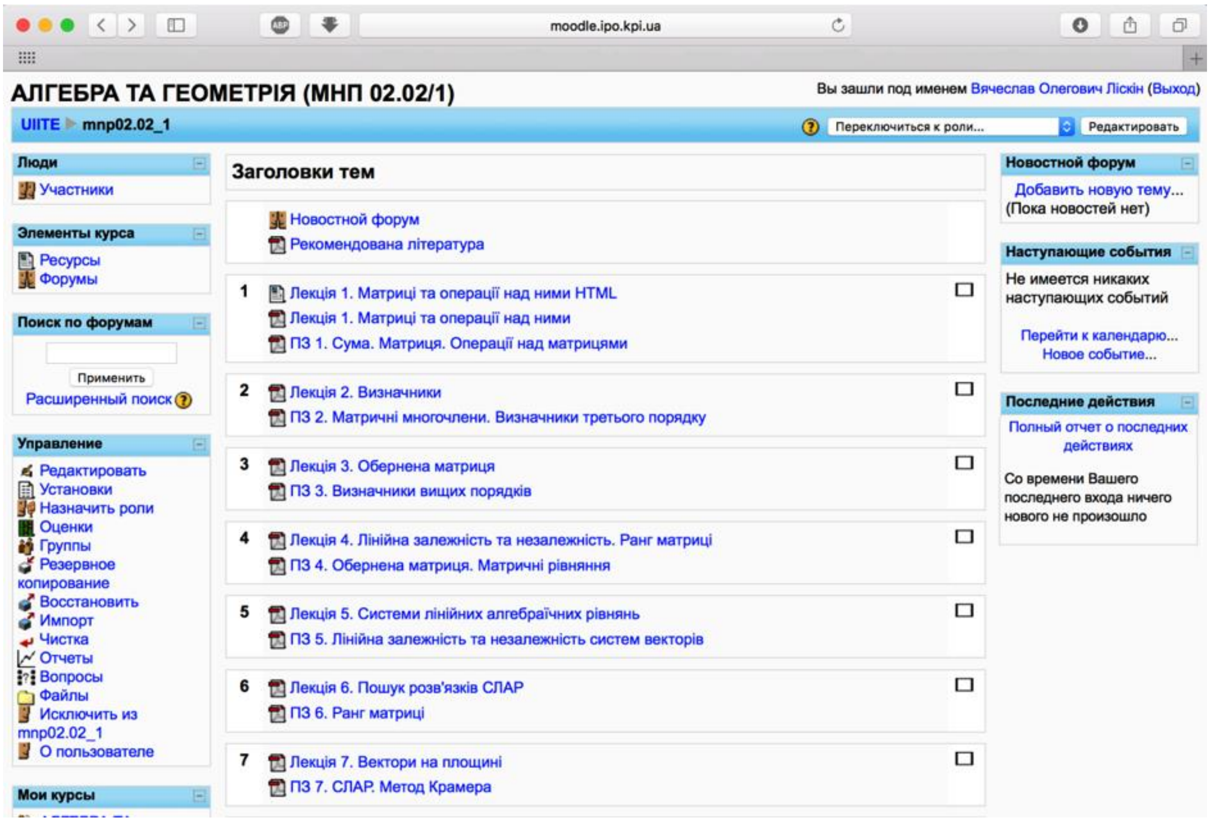

Figure 6: Integration of OCELS with the system "Moodle" on the example of the discipline "Algebra and Geometry"

In the main page of each student, the educational content is distributed by modules and topics of the discipline and is presented in several formats. The student independently chooses a convenient time for processing materials and format. In order to consolidate the skills after studying each topic, the student is asked to take a test, which consists of questions from the catalog of questions arranged by DChI. Based on the results of the student's answers, a grade for the module or recommendations are given, an individual learning trajectory is created for repeating certain topics (chunks), answers to questions about which were incorrect. To determine the number of students to participate in the experiment, which ensures the representativeness of the sample, the formula was used:

$$n = \frac{N*t^2*\sigma^2}{N*\Delta^2+t^2*\sigma^2}, \tag{4}$$

where n is the size of the representative sample;
N is the size of the general sample;
Δ - marginal error of sample representativeness;
σ is the mean square of the deviations;
t is the confidence factor, which depends on the probability of determining the marginal error.

Consider the flow of academic groups of students, which is a general sample, so $N = 83$. The marginal error of representativeness of the sample, which characterizes its accuracy or the level of significance was chosen to be 5%, in order to maximize the accuracy of the experiment. For $\Delta = 0.05$ the confidence factor or the Student's coefficient will be $t = 1.96$. Thus we obtain:

$$n = \frac{83 * 1{,}96^2 * 0{,}5^2}{83 * 0{,}05^2 + 1{,}96^2 * 0{,}5^2} \approx 45$$

To increase the representativeness and in accordance with the study groups of students, each about 25 students, the value obtained was rounded to $n = 50$.

In total, 4 study groups and 83 students were involved in the experiment. The sample of students is divided into two groups: control group (group A) and experimental group (group B). About 50 students took part in the experiment in each discipline, which ensures the representativeness of the data (according to formula 4), in addition, the volumes of the experimental and control groups are almost the same (table 2).

Table 2

Distribution of students by groups and disciplines

Disciplines	Control group		Experimental group	
Algebra and geometry	29	29	28	29
Algorithms and data structures	24	27	26	28

Table 3 shows the results of educational achievements for the control and experimental groups before the experiment in the discipline “Algebra and Geometry”.

Table 3

Distribution of the level of academic achievements before the experiment

Group	Total students	A	B/C	D/E	F/Fx	Success rate in %
Group A	27	4	12	9	2	92,6
Group B	28	5	11	10	2	92,9

As can be seen from table 3, the success rate in the control and experimental groups is almost the same. At the beginning, it is necessary to establish whether there is a difference in the initial levels of knowledge of group A and group B (before the experiment).

Let's compare hypotheses (hypothesis H_0 - the level of knowledge in groups is the same, H_1 - the level of knowledge in groups is not the same) by Pearson's criterion:

$$\chi^2 = \frac{1}{n_1 * n_2} * \sum_{i=1}^{4} \frac{(n_1 * q_{2i} - n_2 * q_{1i})^2}{q_{1i} + q_{2i}}, \quad (5)$$

where n_1 is the number of students in group A;
n_2 - number of students in group B;
q_{1i} - the number of assessments of group A in the category;
q_{2i} - the number of assessments of group B in the category.

The value of the criterion $\chi_A^2 = 0.39$ calculated by formula 5 and $\chi_B^2 = 11.345$. Since the inequality $\chi_A^2 < \chi_B^2$, so H_0 is accepted and H_1 is rejected.

Thus, two samples of students belong to the same general population, we have the same distribution law, they are randomly selected and have the same level of success.

To evaluate the results of electronic testing and identify students with a dishonest attitude to learning, the calculations of the following indicators were used formula 6 and 7.

Number of points obtained for the test work:

$$TS = \sum_{i=1}^{k} Q_i, \quad (6)$$

where Q_i - points obtained for the i-th question;
k is the number of questions asked.

The number of points obtained for the studied chunk:

$$ChR_i = \frac{\sum_{i=1}^{k} DChI_i * m}{n}, \tag{7}$$

where $DChI_i$ - questions related to the i-th chunk;
m is the number of correct answers;
n is the number of questions asked.

In the context of the COVID-19 pandemic, all groups studied in a mixed mode, mainly learning using e-learning systems. Each control group studied according to the traditional methodology, which includes conducting lectures, practical, laboratory classes and modular tests throughout the course and credit or exam at the end of the course. Each experimental group studied according to a mixed methodology, based on a chunk-oriented approach to learning, which also includes lectures, practicals, laboratory classes and modular tests throughout the course and credit or exam at the end of the course.

The purpose of the experiment was to prove or disprove the hypothesis of the effectiveness of the integration of the chunk-oriented approach to learning, as well as to study the rationality of the use of algorithms for creating test tasks and tests. In the 2020-2021 academic year, 7 tests were conducted in the discipline of "Algebra and Geometry". Each test work consisted of questions that were generated using the developed tool. During the 1st semester of the 1st year, 3 tests in the discipline "Algebra and Geometry" were conducted for the control and experimental groups, and 4 in the 2nd semester.

Figure 7 and table 4 shows the results of groups A and B of 7 tests, as well as the result and general statistics.

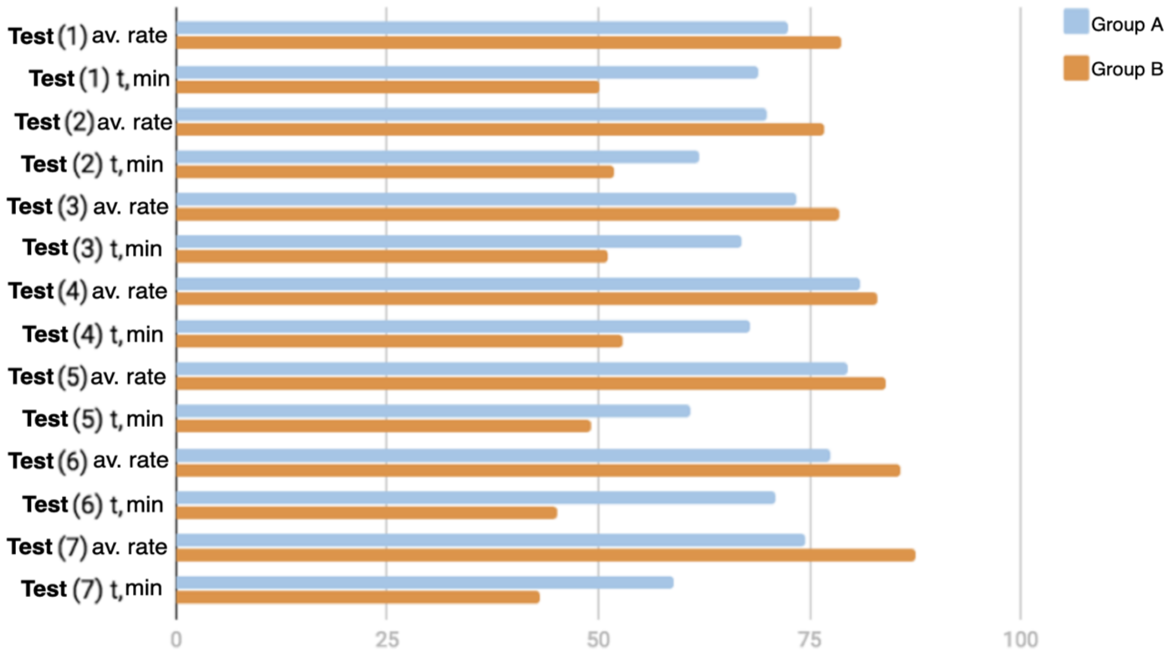

Figure 7: Diagram of test results in the discipline "Algebra and Geometry"

At first glance, on figure 7 it can be seen that from the beginning of the experiment the average score of group B increased and the time of work decreased, at the same time both of these indicators in group A changed without visible patterns, indicating possible cases of dishonest attitude to learning or deterioration of overall success in group, which can be caused by many factors.

Table 4
The average value of test results in the discipline "Algebra and Geometry"

Group	Efficiency indicators	
	Average rate	Average time (minutes)
Group A	~ 75	~ 65
Group B	~ 82	~ 49

After analyzing the data shown on figure 7 and calculating the average rate on tests and the average time of work, we can conclude that for the discipline "Algebra and Geometry" the average percentage of correct answers in group B is 7% higher than the result of group A, and the time of work in group B is less than group A for 16 minutes.

Thus, the control group and the experimental group differ in the results of learning success in favor of the experimental group. This allows us to make conclusions about the effectiveness of the developed information technology and chunk-oriented approach to learning. It also provides a person-centered approach to monitoring student knowledge that eliminates subjective relationships.

5. Conclusion

Such information systems help individuals to systematize large layers of information, get achievements in a particular field of knowledge and, as a consequence, to find their, not yet explored, professional niche, on the one hand - have a strong developmental character - are means of becoming a competitive specialist. Presentation of the educational topic in the form of an ontological cube provides an opportunity to systematize knowledge and use it in different educational and life situations.

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