Article

Integrated Control of Students Competencies in Educational Programs. Innovative Modeling Using an Ontology Approach

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Abstract. For comprehensive testing of students' knowledge, it is necessary to have two areas of consideration - this is an ontological model of the subject area and formulated, formalized, and described concept of knowledge. A formalized description of concepts from the subject area of knowledge is quite specific and time-consuming. At the same time, already at this stage in the development of research and the use of relevant ontology results, they make a significant contribution to the problems of managing and controlling the knowledge of students of higher educational institutions. This article is an attempt by the authors to solve creatively the problem of comprehensive control of students' knowledge using ontologies.

The relationship between explicit and implicit knowledge and skills that are used to build the knowledge management system of a higher educational institution was shown. Also, in the process of work, an experimental testing of the ontology construction methodology for the subject field *Economics* was carried out, which is used for testing knowledge of the level of bachelor specialty *Economics*. In addition, the following was developed: the functional structure of the knowledge management system of the Higher Education Institution, a universal repository of ontologies of concepts of various specialties, and a model for comprehensive testing of students based on the repository of many ontologies.

JEL: A22; I20; L86.

Keywords: ontology; knowledge control; methodology; SvitOsvit.

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Introduction

With the growing requirements for the training of specialists, the volume of accumulated knowledge in various subject areas and relevant information resources, the market of information systems and training systems is developing. At the same time, the software product itself acts as a tool for the application of educational technologies, which in turn are based on the so-called educational content. Creating educational content is a rather laborious process. Content created using such systems is usually focused on a group of trainees and does not consider their individual characteristics. Also, after its creation, it is usually available for use only within this system and is not available for reuse by the authors of other courses in other systems.

Many knowledge management systems mainly work with superficial knowledge. This is because now there are no universal methods that allow you to identify deep knowledge structures and work with them. Any learning process ends with a test of the learner's knowledge, including the control of knowledge of the terminology of the discipline being studied, the subject area.

The methods of knowledge engineering are becoming increasingly popular, among which ontologies have a significant place. As it is commonly known, many systems mainly work with surface knowledge, i.e., there are no universal methods for revealing the depth of students' knowledge. An ontology is an explicit formal specification of conditions in an explicit specification of an object and the relationship between them. The need for ontology is since existing methods are not capable of adequate, distinct, and automatic processing of texts in the native language. To be able to obtain high quality text processing, you must have a thorough description of the problem area with a significant number of logical connections that demonstrate the connections between the terms.

The increased requirements for the quality of vocational education required the creation of new forms of training and test materials of high quality commensurate with the level of knowledge of experts in the subject areas [1].

Reuse of existing ontologies may be necessary if the developed system will have to interact with other applications that have already come to an ontology or controlled dictionaries [2]. There are libraries of reusable ontologies on the Internet and in the literature, for example, in the Ontolingua ontology library [3], or the DAML ontology library [4].

This work is devoted to solving such problems:

1) the relationship between explicit and implicit knowledge in the construction of a knowledge management system of a higher educational institution;
2) complex testing of students knowledge when testing is based on a repository of multiple ontologies;
3) the functional structure of the knowledge management system of the Higher Education Institute;
4) finding the universal repository of ontological concepts of various specialties.

1. Literature review

Currently, to control the knowledge of students, there are many testing systems in various fields of knowledge, for example, *PikaTest* [5], *Moodle* [6], *Indigo* [7] and *UniTest* [8]. Most of these tools provide the ability to create multimedia tests, testing for traditional learning and e-learning, saving, and transmitting the results to the teacher to manage users and study groups.

To build the ontology of *Economics*, it is more profitable to understand the need for ontology and some works devoted to ontology based on text analysis.

Ontology is an explicit formal specification of conditions in an explicit specification of the subject and the relations between them [9]. Ontologies can be used to support the sharing and reuse of knowledge [2]. This re-application approach is based on the assumption that the modelling scheme, i.e., the ontology, is specified in detail and mutually agreed upon by the parties, and then it can be shared, reused and disseminated knowledge. Many disciplines are now developing standard ontologies that can be used by experts in this field to share and annotate information in their field. Problem solving methods, domain-independent applications and software agents use ontologies and knowledge bases built on ontology data [2].

To get high-quality text processing, you need to have a detailed description of the problem area with a lot of logical connections that show the connections between the terms. The use of ontologies can process the text in the native language in such a way that it becomes available for automatic processing [10].

Here we consider the control and assessment of knowledge based on the ontology of the subject area *Economics* of the section *Economics Cybernetics* in natural language (Ukrainian). The ontology will be used for automatic comprehensive verification of the learner's answer to a given question. A comprehensive test of knowledge consists in the fact that the answers received from the student are checked by the ontological connections of terms and objects of five disciplines: *System of economic information*; *Model of economics*; *System of acceptance*; *Information systems and technologies in management*.

For a comprehensive examination of students' knowledge, it is necessary to have two areas of consideration - an ontological model of the subject area and a formulated, formalized description of the concept of knowledge. We have reviewed various definitions of the concept of knowledge formulated by different authors. Since knowledge is a complex concept, it can be described and classified in many ways. The most recognized way to classify knowledge is to divide it into explicit (direct answers to questions) and implicit, hidden knowledge (creative and non-standard approaches to solving questions, accumulated experience in solving practical problems). As a definition of a student's knowledge, we will use the following expression: *A student's knowledge is a complex combination of practical experience and information (theoretical base), which are connected through a single structure of concepts used in the subject area*. Problems of knowledge integration are described in Ref. [11].

To date, there are ontologies created for a variety of applications. For example, in WordNet [12], there is a description for each term of the English language, synonyms and general terms are defined. The scale of WordNet is very extensive (the whole English language), while the level of detail is very low (descriptions of terms in natural language, and there are only very simple relationships between terms). Another example of ontology is the system *The Enterprise Ontology* [13] with a wide range of production concepts and terms.

In a formal view, ontology is a sign system O

$$O = \{C, R, L, P_C, P_{LC}, P_{LR}\} \tag{76}$$

in which C represents a finite set of concepts c_i in ontology;
R - a finite set of binary relations r_i between concepts c_i;
L - finite set of lexical labels l_i (dictionary of ontology);
P_C - antisymmetric, transitive, reflexive binary relation;

$$C = \{c_1, c_2, ..., c_n\} \ ; \tag{77}$$

$$R = \{r_1, r_2, ..., r_n\} \ ; \tag{78}$$

$$r_i = \{c_x, c_y\} \ ; \tag{79}$$

$$L = \{l_1, l_2, ..., l_k\} \ ; \tag{80}$$

$$P_C \subseteq C \times C \ ; \tag{81}$$

$$P_C \subset R \ . \tag{82}$$

Actually, P_C is a partial-order relation on a set of concepts with
P_{LC} - binary incidence relation between sets L and C and
P_{LR} - binary incidence relation between sets L and R:

$$P_{LC} \subseteq L \times C \ ; \tag{83}$$

$$P_{LR} \subseteq L \times R \ . \tag{84}$$

Based on the level of generality, three types of ontology are formed.

1. Meta-ontologies - top-level ontologies - describe general concepts, regardless of the tasks of a particular domain (for example, space, time, etc.).
2. Domain ontologies - describe, relatively, general concepts for a specific subject area (for example, such as the electronic industry).
3. Application ontologies - describe concepts that depend on both the domain and the task being solved. Application ontologies include the knowledge necessary for specific applications. An example of an application ontology can be the ontology of Web sites, including concepts such as headings, paragraphs of text, links, etc.

In the literature on working with knowledge, it is not uncommon to assert that the educational environment is not yet ready to use an ontological approach, technologies based on ontologies, that the possibilities of describing knowledge with the help of the field of ontology belongs to the section "the future in knowledge management technologies" [14].

It follows from this that research and development on the development of an ontological approach to the construction of knowledge management systems in educational institutions, on the description of subject areas using ontology, is an urgent scientific problem. At the same time, already at this stage of the development of research and the use of relevant results, ontologies make a significant contribution to the problems of management and control of knowledge of students of higher educational institutions.

2. Prototype of ontological system

Let's consider the model of comprehensive knowledge control of a student of a higher educational institution - see Fig.1. In this model, the main elements are the "Analyzer of the response text", "Interpreter of the ontological model" and "Repository of many ontologies". In the "Repository of many ontologies" there are ontologies

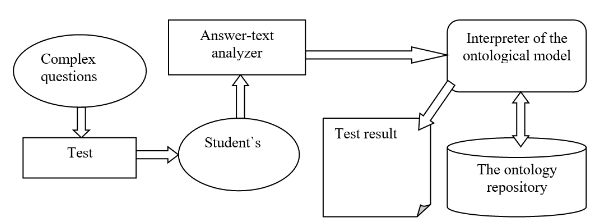

Fig. 1. Model of integrated knowledge control.

Table 1. Sections of the ontology *Economic cybernetics* and elements for their description

N	Ontology Section	Number of elements
1	Economic Information Processing Systems	51
2	Modeling the economy	31
3	Decision-making systems	14
4	Information systems and technologies in management	93
	Total concepts:	189

of those areas of knowledge that have been accumulated and described in the university and, accordingly, can be used both for teaching and for monitoring students. Depending on the degree of expressiveness and formality of the presentation, there is the following classification of ontology [15].

1. Controlled dictionary - is a periodically updated list of terms.
2. Thesaurus - contains elementary connections (most often lexical) between terms, such as synonyms.
3. Informal taxonomy - some explicit hierarchy in which there is no strict inheritance (an instance of a subclass is not necessarily also an instance of a superclass).
4. Formal taxonomy - a set of terms between which strict inheritance is defined.
5. Frames - descriptions of concepts in the form of a set of properties that are inherited by subclasses and instances.
6. A model that implements value constraints — when describing concepts, restrictions are imposed on the values of their properties.
7. A model that implements general logical constraints - the values of the properties of concepts are limited by logical or mathematical formulas using the values of other properties of this or another concept.
8. A model that implements constraints using first-order logic - expressive ontology languages such as *Ontolingua* allow you to set constraints in the form of first-order logic formulas, as well as using more detailed relationships such as disjunct covers, inverse relations, part-whole relations, etc.

What is the contribution of ontology to the knowledge management of a higher educational institution? The main components of this contribution in our opinion are presented as follows.

1. Fixation, categorization, transformation of unstructured and poorly structured data and information into new, valuable knowledge assets for the educational process.
2. Formation of an integrated model of the subject area of the university and in the form of a systemically structured knowledge network, which is essentially a new important knowledge.
3. Improving the language of professional communication based on deepening the joint understanding of terms, concepts, objects, processes of disciplines and training courses achieved in the process of ontology construction and its use.
4. Creation of an environment and tools for conceptual modeling using the apparatus of discretionary logics (solvable logics of the first order).
5. Providing opportunities for the use of modern and promising new standards in the field of programming languages (XML, RDF/RDFS, OWL).
6. Development of intellectual functions of the interface between a person and a computer, simplification on this basis of access to knowledge (explicit and implicit), increasing the productivity and effectiveness of such communications.
7. Expansion of the field of attainability of knowledge to computer networks of the university, expansion of communications between a person and a computer, between autonomous and interacting groups of students and teachers.
8. Integration of data and information about curricula, teachers, students, documents, resources, technologies to ensure and improve the effectiveness of the educational process.

It should be noted that the construction of complete and detailed ontologies is a very time-consuming process. Ontologies of the *Economy* type, if we consider not even all spheres of economic activity that can be covered, not all types of elements, nodes, devices, and systems with which it can be carried out, as well as their superpositions can contain tens of thousands of concepts. Therefore, further the process of building an ontology will be localized in one of the fields of knowledge actively used in the educational process and knowledge control, namely in the field of *Economic cybernetics* - see Table 1. An idea of these possibilities is given by the general heading of the ontology of a higher educational institution (HEI) as presented in Table 2.

The transition from the taxonomy of concepts in the listed rubricators to the basic ontology is associated with the definition of relations between concepts. The relations obtained as a result of the decomposition of "Sources of knowledge about ..." are intended to fix the relationship of concepts in the knowledge management system of a higher educational institution with the concepts of the subject area. The domain and domain of the values of the relations obtained because of the decomposition "Has to do with ..." are the concepts of the section "Concepts of the subject area" (*Economic cybernetics*, for example). For the relations "Consists of ...", "Uses ...", the inverse relations "Is part of ..." and "Is used ..." are defined, respectively. In relation to the object under study, two main types of associative relations were identified: a) "Related to ..."; b) "Source of knowledge about ...".

The developed ontology should not be considered as a set of static, unchanging concepts and terms in time. Over time, the meaning of the terms of the subject area may change, the terms may receive a new meaning due to the emergence of new and the development of existing technologies. To effectively perform its functions, the domain ontology must be kept up to date. In this regard, there is a need to make changes to the sections of ontology. The main types of changes in ontology are presented as follows: i) changing the meaning of ontology elements; b) removing unnecessary items;

Table 2. The main elements for building a knowledge base of a Higher Educational Institution (HEI).

N	Subject	Explanation
1	Areas of knowledge	The composition of the main areas of knowledge of a HEI
2	Automation objects	Objects whose automation is carried out within the framework of completed, ongoing and planned projects
3	Modules, blocks, systems	List of disciplines, specialties developed, developed and produced by a HEI
4	Projects	Types and composition of projects carried out and planned to be carried out by the faculties of a HEI
5	Product creation processes	Classification of processes and stages into which the implementation of training courses in a HEI is divided
6	Participants in the processes	Teachers, departments and faculties that directly/indirectly participate in the implementation of the educational process
7	Structural divisions	Classification and composition of structural divisions of a HEI
8	Consumers of products	Students studying at a HEI

c) adding new elements.

The evolution of ontology, in turn, requires special solutions for updating annotations and knowledge base structures that depend on ontology. The information that enters the knowledge management system is annotated and these annotations must adapt over time to the new meaning of terms and relationships.

Maintenance and development of the knowledge model is mainly an organizational task. Those responsible for the various processes of ontology maintenance should be explicitly identified. The knowledge officer should collect feedback from teachers and students on their experience with the system and regularly improve the ontology based on them.

Experience shows that the development and maintenance of ontology should be considered as a cyclical process. In this regard, the maintenance scenario should provide feedback and close integration between using the ontology and making changes to its structure. It is even possible to add new conceptual structures to the ontology used to perform the tasks of annotating knowledge and structuring the knowledge base.

The exchange of implicit (hidden) knowledge includes the transfer of unpublished ideas, personal experience, best practical solutions, etc., and this is a valuable component in the chain of knowledge transfer, and a more difficult task, from the point of view of implementation in the learning process, than the exchange of explicit knowledge. Knowledge is exchanged not only through the knowledge management system of a higher educational institution, but also because of personal communication, using traditional technologies such as e-mail, discussion forums, videoconferences, etc.

Description and modeling of knowledge based on ontologies is a new approach that has been developing rapidly in recent years, opening new opportunities for professional communication. This is largely due to the fact that strict ontological foundations for knowledge representation lead to better methodologies for conceptual modeling of data and knowledge bases that facilitate the exchange and reuse of knowledge in higher education [16].

There is no doubt that the description (modeling) of teachers of a higher educational institution is a very difficult task and can only be carried out in a certain respect at the general conceptual level.

Identifying the most significant characteristics of teachers relevant to the context of the knowledge management system of a higher educational institution is the most interesting and important problem with a comprehensive approach to the educational process. These characteristics will be described in terms of concepts and attributes. They are the basis for the conceptualization of the teacher's competence model.

3. Characteristics of system

The model of a teacher's competence is the following set of indicators MC,

$$MC = \{O, K, P\} \tag{85}$$

where O - general characteristics of the teacher;
K - indicators of the teacher's competence in the relevant fields of knowledge of the university;
P - characteristics of the teacher's behavior in the knowledge management system of the university.
The general characteristics of the teacher include such indicators as presented below:

a) last name, first name, patronymic;
b) location (physical location, building and room);
c) contact information (phone, E-Mail, etc.);
d) basic education: document, higher education institution, date of receipt, type of education received, faculty, direction, specialization;
e) academic titles: document, time of completion, date of receipt, whether the courses were planned, courses were attended voluntarily or not;
f) advanced training: document, time of passage, date of receipt;
g) is an expert, etc.

The competence of a specialist K

$$K = \{K_o, K_s\} \tag{86}$$

includes indicators of the teacher's competence in the fields of knowledge of the K_o and their semantic description of the K_s based on the ontology of subject areas of knowledge.

Fig. 2 represents the visual representation of the ontology.

Application of our research was realized in the developed automated system of educational process support *SvitOsvit* [17]. In the sub-system of "testing students" with the modular system of knowledge management, ontological modeling is used for comprehensive control of students' competencies. Fig.3 represents the working interface of *SvitOsvit*. Using this software product in the educational process, we can conduct a comprehensive survey and control of students' knowledge based on a repository of multiple ontologies.

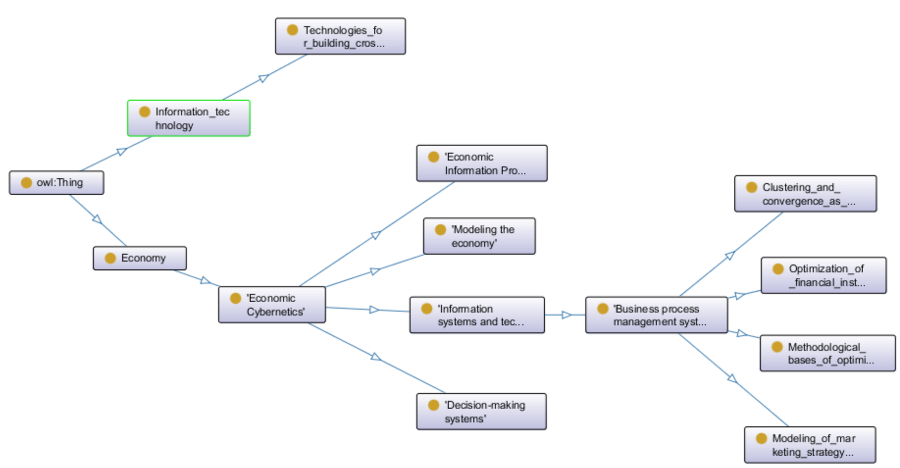

Fig. 2. Visual representation of the ontology.

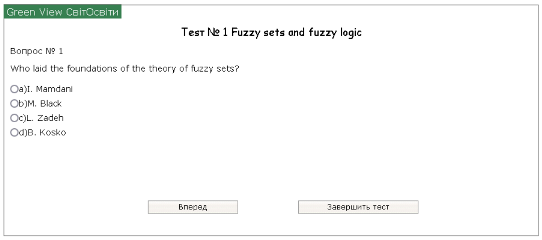

Fig. 3. Interface of the program SvitOsvit [17].

Conclusions

In the process of research, the following main scientific and practical results were obtained as presented below.

1. The interrelation of explicit and implicit knowledge in the construction of a knowledge management system of a higher educational institution is shown.
2. A model of comprehensive testing of students based on a repository of multiple ontologies has been developed.
3. An experimental approbation of the methodology of ontology construction for the subject area *Economics* used in testing knowledge of the bachelor's degree in the specialty *Economics* was carried out.
4. The functional structure of the knowledge management system of a higher educational institution has been developed.
5. A universal repository of ontologies of concepts of various specialties has been developed.

The developed models, algorithms and knowledge base schemes for comprehensive testing of students and teachers' competence will allow us to further develop software for their implementation, including methods of working with ontological models, methods of working with semantic meta-descriptions, as well as an ontological knowledge base and a semantic web portal. This will allow us to create a large class of software systems for working with data and information at the university in the future, which will allow us to move to the level of knowledge management systems of a higher educational institution. In addition, these methods and software can be used by university students in the educational process to complete term papers and theses, as well as during the study of such disciplines as knowledge management, systems modeling, artificial intelligence and business process reengineering.

Abbreviations

HEI	-	Higher Educational Institution
OWL	-	Web Ontology Language
RDF	-	Resource Description Framework
RDFS	-	Resource Description Framework Schema
XML	-	Extensible Markup Language

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Authors' contributions

Julia O. Maksymova initiated research on concept and design. Oleksandr S. Maksymov collected and analysed, interpreted data. Oleksandr O. Maksymov prepared the manuscript. Julia O. Maksymova and Oleksandr S. Maksymov wrote the theoretical overview whilst both authors prepared other parts of the manuscript. All authors reviewed and approved the final manuscript.

Conflicts of interest

All authors declared at they have no conflicts of interest.

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