Categorical-ontological approach to information support of educational activities

Oleksandr Tarasov1,∗, Pavlo Sahaida1,∗∗, Sergey Podlesny1,∗∗∗, and Liudmyla Vasylieva1,∗∗∗∗

1Donbass State Engineering Academy, 72 Akademichna Str., Kramatorsk, 84313, Ukraine

Abstract. An important basis for information support of educational activities is the effective presentation of knowledge and standardization of training tasks based on ontological models of learned subject areas. The competence approach to the organization of the educational process and the requirements for the training of specialists from the point view of enterprises and organizations, in which they will carry out their professional activities, requires the development of a comprehensive model of educational processes and objects that are participating in them, based on high-level abstractions. On the basis of the results obtained in this work, the methodology of informational support of educational activities was further developed on the basis of: organizing the educational process and standardization of education based on a categorical-ontological approach; construction and use of relevant ontologies and knowledge bases; automation of data processing by forming and executing queries to the content of ontological models. The use of the results of categorical-ontological modeling allowed to reconcile the interests of active agents of the organization-technical systems, the subjects of educational activity and the ability of students to acquire the necessary knowledge and skills.

1 Introduction

The speed of renovation of engineering and technical knowledge and competencies is steadily increasing. In most industry sectors there is a decrease in the time of the innovation cycle – the time between scientific development and the introduction of technology in production. This is especially true in the field of information technology (IT) education. Technical skills are also rapidly evolving. Many students currently studying in university will eventually work for professions that do not yet exist, and the skills they will have to possess are not yet defined. For many students, re-training will become a common practice, as we enter into an era of continuing education. At the same time, engineering problems and tasks themselves change in connection with the penetration of technology into all spheres of life and economy. Technical systems become more complex and interconnected. Solving these problems and managing such systems requires new approaches that take into account not only their technical component but also their impact on social, environmental, economic and other aspects.

At present, educational strategies for the development of STEM-STEAM-STREAM education [1] have been developed in technologically developed countries and include various specialized programs for different levels of education, designed as a set of interdisciplinary integration approaches for each STEM discipline. STEM-based teaching methods are aimed at addressing the challenges of multidisciplinary education through deeper understanding of subjects related to different natural sciences, united in one educational program.

In order for students to learn to take non-standard, creative decisions, it is necessary to include the components of STEAM (Science, Technology, Engineering, Arts and Mathematics) in education. This is especially important when using multidisciplinary training programs combining natural sciences and other disciplines [2]. The international educational project ERASMUS+ “Innovative Multidisciplinary Curriculum in Artificial Implants for Bio-Engineering BSc/MSc Degrees” is carried out at the Department of Computer Information Technologies of the Donbass State Engineering Academy (DSEA). ERASMUS + project “BIOART”, which also includes a four-party contract and cooperation between DSEA, Zaporizhzhia National Technical University, the state institute “Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine” and PJSC “Motor Sich” (Zaporizhzhia) in the field of improving of medical products design and education.

The agreement on cooperation with the Donetsk Physical-Technical Institute of the National Academy of Sciences of Ukraine (Kyiv) and the PJSC “Motor Sich” have been concluded for the expansion of cooperation with the scientific institutions and universities of Ukraine, the development of creative connections and the implementation of joint work. Such cooperation fully corresponds to STREAM technology and allows complex formation of key professional, social and personal competences of young people.

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
It is known that STEAM technologies determine the educational organization’s strategy and determine the educational process, as well as the technologies used in its organization. For the effective implementation of the principles of STEAM and enhancement of students' motivation, a continuous improvement of the structure of the educational process is required, based on the development of e-learning methods using modern information and communication technologies and global networks [3, 4]. It is also necessary to improve the content of disciplines that provide the knowledge, skills and competence of graduates.

The totality of knowledge and skills that a student receives in the process of learning taking into account applied technologies forms a model of the learning process that more or less corresponds to the model of future professional activity. Therefore, the development and improvement of the content of education should be based on an analysis of the directions of technology development in the subject area of expertise. The time of replacement of standards should correspond to the time of the life cycle of existing concepts and technologies at the time of its adoption, taking into account the prospects for the development of this subject area. The complexity of performing these tasks requires constant research in this area, which results in recommendations for improving the content of the educational process of training specialists in the field of information technologies [5, 6], as well as new technologies for training and knowledge control [7, 8].

The competent approach to the organization of the educational process and the mandatory consideration of requirements for the training of specialists from the enterprises and organizations in which they will carry out their professional activities, requires the development of a comprehensive model of processes taking place during training, and objects taking in their participation, based on high-level abstractions.

An important basis for the information support of engineering activities is the effective presentation of knowledge about the work of the subject area (SA) and the standardization of tasks and educational process based on ontological models of investigated SAs. In the process of learning, students acquire knowledge in the field of future professional activities. Some of them are fundamental, and some are aimed at the development of modern technologies and tools for professional work. Providing the necessary correlation between these parts determines the effectiveness of learning. Both parts change in time, the field of activity of the corresponding specialty expands [5, 6].

In these conditions, it is necessary to constantly clarify the boundaries of the field of specialists, the allocation of new branches of knowledge. All this requires constant replenishment of knowledge and skills of the graduate in the subject area and adjustment of the educational process. The solution to this problem will improve the competitiveness of graduates in the labor market. Taking into account these tasks, the future of higher education is connected with the processes: integration of education, science and innovations; the use of technologies based on the participation of students in innovation activities, research works, etc., which provides a competent approach to education [5], the growth of knowledge and skills through the active participation of students in the process of education.

An important basis for informational support of engineering activities is the effective presentation of knowledge about the work of SA and standardization of tasks and educational process on the basis of ontological models of investigated SAs [9]. This approach allows formalizing the available knowledge for each, including complex, organizational-technical system (OTS). The advantage is the ability to separate models of knowledge from algorithmic and software that uses these models in the process of data acquisition and processing. The use of ontology editors and ontology model exchange formats allows to adjust and scale such models in manual and automated mode, in the process of changing goals and tasks of data processing or the conditions of the OTS [10, 11]. An ontology can be used for automatic deduction in axioms and application of methods of artificial intelligence. An important feature of ontology is the presentation in one model of not only generalized, conceptualized knowledge, but also actual information, results of operational accounting in the SA [12].

High-level SA modeling allows to reconcile the interests of active OTS agents, subjects of educational activity and the ability of students to master the necessary knowledge and skills. However, an ontological model, which is constructed in general terms on the basis of accumulated data on the work of SA, has a number of significant disadvantages. When designing it, an analyst should not be guided by formal rules and restrictions. Ability to perform verification of the ontological model provides categorically-ontological (CO) modeling [13–15]. Its essence is to use the method of verification of ontological models in the process of knowledge engineering on the basis of objects of the category theory and their relations. The application of such a method introduces the mathematical foundations into the process of knowledge engineering, provides verification of the results of conceptual modeling based on the evidentiary power of topological design patterns [16, 17].

In the process of learning, students acquire knowledge in the field of future professional activities. Some of them are fundamental, and some are aimed at the development of modern technologies and tools for professional work, as well as taking into account the specifics of a specialist within the framework of SA. Providing the necessary correlation between these parts determines the effectiveness of learning. Both parts change in time, the field of activity of the corresponding specialty expands.

The purpose of the work is to use an ontological approach to formalizing knowledge about the educational process during the formation of multidisciplinary educational programs for the education of bachelors and masters in the field of information technologies with different training specializations.
2 Categorical-ontological modeling of the subject area of the formation of multidisciplinary educational programs

The methodology for choosing information support for the structure and content of educational and professional programs is based on the following main components: world-class documents aimed at improving the education system as a whole, in particular [6]; laws and documents regulating the educational process in the state [18, 19]; educational standards and recommendations of professional associations (ASME, ACM, AIS, IEEE, ABET, etc.) [20, 21], which reflect the state of development of science, technology, and industry in this area of professional activity. For the information content of the program and disciplines, these documents are of particular importance so that the disciplines of educational programs include the study of advanced technologies in the field of professional activity of students and can be adapted following the development trends of this subject area.

The taxonomy of educational activity developed on this basis with selected features and their meanings is shown in figure 1. Concepts and relationships between them, shown in this figure, reflect the structure of educational activity. The department is part of the university and prepares students for a specialty corresponding to its profile, scientific, personnel and material and technical resources. The specialty of training specialists and masters allows future employees who have received the required qualification level to participate in the implementation of a certain type of economic activity, performing professional duties in accordance with the job description of their workplace. Using their professional skills, employees perform various work functions, which are generally distributed by type (research, control, design, technological, forecasting, organizational) and levels (stereotyped, operational, technological, research).

In the process of implementing the work functions, the workers (bachelors and masters) perform various tasks of activity, which also differ in types (professional, social, production, social, etc.). Qualitative performance of such tasks must be ensured by appropriate knowledge and understanding of production and scientific tasks and algorithms for their solution. From the viewpoint of educational activity, the functions and tasks of future employees should be ensured by the formation of students of different competencies. Competences are accordingly supported by the skills formed during the study of disciplines of different cycles.

The formed skills determine the volume and content of educational disciplines and vary by type (subject-practical, subject-intellectual, sign-practical, sign-mental) and the level of formation (the ability to perform actions on the basis of material media, at the expense of constant mental control, automatically on skills levels, etc.) [5, 6].

Thus, the development of the content of masters training in the field of IT requires the consistent implementation of the following tasks:

- the formation of typical production functions in accordance with the classifier of occupations and types of economic activity;
- determining the preparation level of bachelors or masters for the fulfillment of these functions and key competencies for this educational-qualification level;
- development of these competences for the field of professional activity;
- the formation of skills that differ from the requirements for bachelor’s “level of formation” abilities;
- development of the composition and content of disciplines, within which formed the necessary knowledge and skills.

Consider the mathematical apparatus and methodology for modeling the subject area, which were used in this study. Today conceptual models based on category theory (CT) are actively introduced for solving practical tasks in physics, biology and what is more important for the subject in hand in computer science. Category theory provides means to implement knowledge engineering and to support life circle of knowledge bases on mathematical basis using objects, morphisms and their solutions. Such objects and solutions that form commutative diagrams [17, 22] can be used as typological design patterns for conceptual models. Thereby using this approach an analyst can justify the correctness of modeling results, when knowledge is formalized in the form of ontological models as one of the closest in type to diagrams of category theory. Apart from that the approach enables to find missing objects or morphisms in a particular ontological model as well as ontology alignment using rigorous mathematical tools.

Sketch theory is a logical development of category theory [23–25]. When the two theories are used together analysts can develop mathematical constructions using such a descriptive picture format as graphic charts. At the same time correctness and adequacy of categorical models are established on the basis of axioms and theorems of category theory.

When such an approach is implemented in the form of verification technique of a particular ontological model, analyst formalized concepts, relations and restrictions are presented as rigorously mathematical. It is implemented through placing restrictions of category theory on elements of an ontological model. The restrictions of category theory are described by axioms and theorems of the theory. Let us consider the developed technique on a simple example from a subject area “Task modeling of intellectual processing and data analysis”. Concepts and relations between them that characterize a IDP task description aspect and manipulations with data according to the IDP aim and expected systemic impact are provided in figure 2. Let us call a model free of any restrictions on relations between class samples presented by utilized concepts as a particular ontological model. It presents a particular piece of knowledge of an analyst in terms of a considered aspect of a subject area and one of the options of possible formalization (the extent to which it is correct
depends on many circumstances and the result can not be mathematically verified).

The diagram in figure 3 has been obtained as a result of application of the verification technique based on category theory. The diagram is a category theory commutative diagram constructed in accordance with the graph in sketch theory [22, 25]. Arrows used in the diagram represent morphing objects in category theory. Commutative property means equal ways (composition of morphisms) that are used to display some concept samples in others.

When a particular ontological model is developed no restrictions on types of relations between concepts except for subject area semantics (according to the way the analyst understands it) are placed. Thanks to commutativity and using category theory notions the analyst has managed to put aside some relations and either reconsider or add other relations. Diagram presented in figure 3 has been developed on the basis of “pushout” typological pattern marked on the diagram with “PO”. In category theory it is described mathematically and its properties are substantiated including the so called universal property. The application of the property has enabled to discover “achieved-through” morphism that makes the whole diagram commutative. The morphism is very important for the seman-
The SA model reflects the requirements of educational standards to the assimilated amounts of knowledge and the results of mastering skills in the process of acquiring the competencies required by the OTS for the implementation of various types and tasks of economic activity by students. However, this model also includes a factor limiting the learning process to learner’s ability to perceive knowledge and skills, as well as methodological and organizational capabilities of the educational process (represented by the object “Student image in the education system”) in the process of achieving the required qualification level.

Consider based on the ontological approach the requirements for the content of education and the process of developing a multidisciplinary educational curriculum for masters in the field of information technology. Such analysis allows to structure the information about the educational process and provide a coherent image of ensuring its quality. The advantage of ontological models is also the flexibility in the process of their development and modification [10–12].

Data for the ontology design during the formation of higher education standards for various specialties and levels of training are contained in the requirements of the Ministry of Education and Science of Ukraine (MESU) for the development of standards and other documents regulating the process of education in higher educational institutions [27]. The high-level ontology of concepts was developed that describe the essence of the educational process and the relationship between them. The fragment diagram of such ontology is shown in figure 5.

The developed models of SA standardization of educational process based on the competence approach was used in the formation of the Education Standard for the preparation of masters of the specialty “Design Information Technologies” (DIT; now “Computer Sciences”) in the course of the work of the relevant commission of the MESU. The ontology for the information support of the developed standard, verified with this categorical-ontological model, was also developed. In the process of forming and agreeing sections of this standard, the primary positions at which magistrates may work, the competencies that are expected from employees at such positions, and the skills displayed by such competencies are defined.

On the basis of the ontological approach to the modelling of business processes taking place in the subject area
"Master's training in the field of DIT", and using the developed taxonomy of educational activities, the content development of the disciplines of the specialty DIT was completed. In accordance with the proposed methodology, on the basis of economic activity types supported by the specialty and the work duties of the corresponding qualification level, a list of competencies to be formed for students in the framework of the educational process was determined. Subsequently, for the necessary competencies, skills were identified which should be formed when studying the topics (sections) of the relevant content modules of the professional training of masters in the field of DIT.

3 Results of ontological modeling of competencies and construction of queries to the model

The proposed classification of competencies and the high-level terminology of the subject domain “Knowledge and skills for product design” were presented in the form of an ontological model. Object Properties of this model, which map different concepts on each other, are based on the results presented in figures 1–3. This model, described in OWL/RDF [28], was implemented using the ontology editor Protégé [29]. Its terminology (TBox fragment) is visualized using plug-ins Protégé VOWL and OntoGraf [30]. The results of the visualization are shown in figure 6 and figure 7.

The extensional (ABox fragment) implementation within the framework of the obtained model allows using it to extract information when making decisions on the development of specific trajectory educators in educational institutions. Table 1 shows examples of query generation for this ontological model on SQWRL [31]. This query language based on first-order logic allows to obtain the necessary information on the results of processing the ontological models described in the OWL language.

Clauses of SQWRL queries use concepts from the TBox of an ontological model and some special expressions [32]. The results of the execution of these queries allow the decision-maker to support his activity. Experimental verification of the proposed approach and the developed software package was carried out for the subject area of the BIOART project. For this project an artificial implant is the technological product for which the necessary competencies and the corresponding educational content are selected using queries to the ontological model. Figure 8 shows a fragment of the individuals of entities of the applied ontology of the subject area “Master’s Degree of IT in Medicine”, which specifies some of the masters expected from the IT skills that provide professional competence, as well as the production skills of graduates as employees in the field of information-communication technologies in medicine (for the artificial implant design).

Modern implants are complex products that include mechanical parts and electronics. The task of the implant
Figure 5. A fragment of the ontology for the subject area “Educational process”, which was developed using categorical-ontological model.

Figure 6. Visualization of the ontological model of the subject area “Knowledge and skills for product design”, described in OWL / RDF using the plug-in Protégé VOWL.
Figure 7. Visualization of the ontological model of the subject area “Knowledge and skills for product design”, described in OWL / RDF using the plug-in Protégé OntoGraf.

Table 1. Queries to the ontological model of the subject area “Knowledge and skills for product design”

<table>
<thead>
<tr>
<th>N</th>
<th>Queries in natural language</th>
<th>Queries in SQWRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What competencies do students need to develop the specified technological products, taking into account relevant skills that require such competencies?</td>
<td>Product(?p) ∧ Element_Of_Product(?e) ∧ Skill(?s) ∧ Competence(?c) ∧ includes(?p, ?e) ∧ for_development_demands(?e, ?s) ∧ supports(?s, ?c) -&gt; sqwrl:select(?s, ?c) ∧ sqwrl:columnNames(“Skills”, “Competencies”)</td>
</tr>
<tr>
<td>2</td>
<td>What competencies do students need to develop the specified technological products, taking into account relevant knowledge that supports such competencies?</td>
<td>Product(?p) ∧ Element_Of_Product(?e) ∧ Knowledge(?k) ∧ Competence(?c) ∧ includes(?p, ?e) ∧ for_development_requires(?e, ?k) ∧ provides(?s, ?c) -&gt; sqwrl:select(?k, ?c) ∧ sqwrl:columnNames(“Knowledge”, “Competencies”)</td>
</tr>
<tr>
<td>3</td>
<td>What competencies do students need to develop the specified technological products, and which disciplines provide for such competencies?</td>
<td>Product(?p) ∧ Element_Of_Product(?e) ∧ Knowledge(?k) ∧ Skill(?s) ∧ Competence(?c) ∧ includes(?p, ?e) ∧ for_development_requires(?e, ?k) ∧ provides(?k, ?c) ∧ supports(?s, ?c) ∧ Content_Modulus(?cm1) ∧ sustains(?cm1, ?s) ∧ Discipline(?d1) ∧ composes_part_of(?cm1, ?d1) ∧ Content_Modulus(?cm2) ∧ maintains(?cm2, ?k) ∧ Discipline(?d2) ∧ composes_part_of(?cm2, ?d2) ∧ sqwrl:makeSet(?set, ?p) . sqwrl:groupBy(?set, ?p) . sqwrl:select(?c, ?p, ?d1, ?d2) ∧ sqwrl:columnNames(“Competencies”, “Product”, “d1”, “d2”) ∧ sqwrl:orderBy(?c)</td>
</tr>
</tbody>
</table>
Figure 8. Fragment of the ontology of the subject area “Master’s Degree for IT Specialty in Medicine” (for the artificial implant design) [2].

- To know the basic concepts of the development of medical technologies for a variety of purposes, including nano-medicine, orthopedics, stimulation, diagnostics, and the use of implants.
- To master the terminology and solve applied problems in the field of application of IT and hardware in medicine.
- To master and apply methods of mathematical modeling in medicine.
- To master the skills of receiving, transmitting and processing digital signals of biomedical purposes, apply various methods of transformation and analysis of signals in computerized medical systems.
- To have basic ideas about bioinertness, non-toxicity, electroneutrality, tribological fatigue strength of materials used in medicine.
- To carry out designing of medical products and devices taking into account physical and mechanical properties of biomedical materials.

The mechanical part is to ensure the strength of the structure, its kinematics, and the longevity of the work after installation to the patient. Electronics allows you to control the parameters of a person and an implant, as well as transmit the necessary information for storage in a control system or for controlling an implant. The third component of the overall system is the software subsystem, which ensures the joint operation of its elements, the logic of processing the received data. The competencies that students should receive on the basis of the developed curriculum should be grouped and formulated in accordance with these components of the implant.

The results obtained above and the application of the ontological approach allowed to properly formalize the knowledge of business processes in organizational-technical systems involved in the development and production of biomaterials, measuring and control devices and technological processes for the receipt and use of implants. The categorical-ontological model of the educational process standardization, developed and presented above, has helped to identify and formulate requirements for the content and scope of the acquired knowledge and the results of the acquisition of skills in the process of acquiring the students the competencies necessary for the implementation of the types and tasks of economic activity in the field of bioengineering, as envisaged by the project BIOART.

4 Conclusions

1. It has been determined that an important basis for information support of engineering activities is the effective presentation of knowledge and standardization of training tasks based on ontological models of investigated subject areas. The competence approach to the organization of the educational process and the requirements for the training of specialists from the part of enterprises and organizations, in which they will carry out their professional activities, requires the development of a comprehensive model of learning processes and objects that participate in them, based on high-level abstractions.

2. The presentation by the categorical-ontological approach of competences, skills and knowledge for the implementation of the educational process in the preparation of masters in the field of information technologies in medicine allowed to systematize the plans and content of training, to develop a draft standard and its methodological support. The list of competences to be obtained by a student who will be trained in the courses and disciplines of the bioengineering profile developed within the framework of the BIOART project is proposed and substantiated.

3. Thus, on the basis of the results obtained in this work, the methodology of informational support of engineering activities was further developed on the basis of: the construction and use of relevant ontologies and knowledge bases, organizing the learning process and standardization of education based on a categorical-ontological approach.

4. Within the framework of the development of STEM-STEAM-STREAM education, a number of scientific works are carried out on the DSEA, students study engineering disciplines that are necessary for the formation of a modern engineer and specialist in the field of information technologies. In the process of learning, students master a number of technologies that are the basis for the implementation of modern software systems for various purposes: for engineering, medicine and other fields of activity. The use of the results of categorical-ontological modeling of the SA allowed to reconcile the interests of active agents of the OTS, the subjects of ed-
ucational activity and the ability of students to acquire the necessary knowledge and skills.

References


[27] Haluzeyvii standart vyshchoi osvity Ukrainy z napriamu pidhotovky 6.050101 “Kompiuterni nauky” (Industry standard of higher education of Ukraine in the direction of training 6.050101 “Computer Science”) (Kyiv, BHV, 2011)


