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Analysis of the Consistency of Prerequisites and Learning Outcomes of Educational Programme Courses by Using the Ontological Approach

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Abstract: The article presents the results of the application of an ontological approach to the description of the structure and content of the educational programme, and its subsequent analysis for the consistency of prerequisites and learning outcomes of courses. The practical result of the work is an ontology approach implemented in the Protégé 5.5.0 editor, which reflects the studied disciplines in terms of the skills they form and the entrance requirements (prerequisites) for the qualification of the student. The curriculum model includes sequences of semesters and courses of study (academic year) related by time relationships. The developed ontology approach is filled with data from the educational programme "Software Engineering". The authors have earned queries in DL Query and SPARQL languages, which, using logical inference procedures, make it possible to analyse an educational programme for consistency of disciplines in terms of input requirements and the skills of the learner formed during the training period. The developed ontology and rules of logical inference can be used as a part of the educational process management information systems and educational programme designers, for the intellectual analysis of programme integrity and the consistency of learning prerequisites and outcomes in disciplines.

Keywords: ontology; educational programme; prerequisites; educational programme constructor; intelligent analysis of educational programmes

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1. Introduction

Information technology plays a vital role in modern education, just as in many other fields of activity. Effective management of an educational organisation is impossible without using educational process management information systems. Classical information systems based on relational databases allow the automation of typical accounting and analytical procedures. Such procedures include managing the staff of the organisation and the contingent of students, planning the workload and schedule of classes, and accounting for the progress and academic achievements of learners. At the same time, the situation is much worse with the management of the content of educational programmes. In most educational organisations, informatisation tools for working with such entities as "curriculum" or "course curriculum" have been successfully implemented and are being used. Despite this, management procedures are usually limited to taking into account training courses and their formal attributes—the amount of time to study, forms of control, positions in the curriculum, etc. At best, the system will provide a list of topics studied in the course, which, however, is practically not suitable for any computer analysis. This is a consequence of the fact that the information systems mentioned do not solve the problem of managing the educational content. The situation is slightly better in LMSs (Learning Management Systems) designed to deliver educational content and interactive work of trainees. Despite better structuring, LMSs in most cases still use "flat" models of educational content description, which do not allow reflection on the relationship of individual didactic units, both within one course and between different ones. The main problem of most implemented systems and tools for educational purposes is the lack of a formal representation of the content semantics.

According to the authors, to solve the problem of managing educational content at a meaningful, semantic level, it is necessary to use relevant technologies and techniques, which includes the so-called ontological approach. It consists of presenting the content of learning in the form of a semantic network. The ontological approach implements the knowledge model of information representation, which defines universal ways of presenting the semantics of educational content. Semantic technologies represent the next step in developing machine-readable ways of presenting information. They make it possible to implement models of information representation and processing methods, the logic of which is similar to human thinking, which allows the use of intelligent inference procedures.

The ontological approach is based on the representation of any information in the form of a semantic graph of any structure, whose nodes are concepts and the edges are relations. At the formal level, an ontology is a system consisting of a set of approaches and theorems about them, on the basis of which classes, relations, functions and units can be described. Informally, an ontology is a view of the world regarding a specific area of interest. This description consists of terms and rules of their use limiting their meaning in a specific area.

2. Related Works

Semantic networks and ontological approach are widely used in the field of education. The following main directions of these studies can be distinguished:

- ontological approach of the curriculum (curriculum or syllabus);
- ontological approach of the context of the implementation of the curriculum—educational organisation and educational process;
- extraction and structuring of educational content using semantic analysis.

In [1], the authors developed an additional analytical tool that considers the ontological model of the curriculum as a bidirectional graph, the nodes of which are assigned weight coefficients, which allows for optimising the student's educational trajectory.

In [2], the ontological model of the curriculum is used to align the requirements for the preparation of students from business and industry with the current parameters of the educational programme and the requirements of the state educational standard.

In [3], the authors describe the methodology of comparative analysis of educational programmes presented as ontologies to assess their quality and compliance with the specified parameters.

The results of the development of ontological models of educational programmes in the context of the educational organisation and the educational process are presented in studies [4–6].

A significant number of works are devoted to the ontological approach to the competence of students in educational programmes on information technology [2,7–9], as well as in the field of Data Science [10–12].

Some works are devoted to algorithms for selecting educational materials from open sources that are most relevant to the educational programme [13].

An extensive overview of the use of semantic technologies and ontological models for modelling and managing curricula, describing the subject of training, training data, and e-learning services, is given in [14].

Seitz [15] investigated the consistency of curricula between planned, implemented and evaluated curricula. This research contributes to improving the quality of communication between planned, implemented and evaluated curricula in mathematical education. The methodological framework is a model for future research on the harmonisation of curricula for the three components of the education system.

Bay et al. [16] conducted a study to determine the factors influencing the consistency of curricula. This study aims to develop a scale that establishes the factors affecting curricula consistency. To improve the school, a validity and reliability analysis was carried out.

In the following article [17], the authors argued the importance of visualising learning paths within the curriculum, and discussed the introduction of a digital visualisation tool for it. They used four case studies to discuss how the tool was used on four topics: curriculum development, visibility, assessment, and learning improvement.

The author [18] discusses the advantages of curriculum coordination and the development of a new database system called e-CMS (Electronic Content Management System) for organising curriculum coordination initiatives. A fundamental element of the systematic organisation of the curriculum is the understanding of the interaction of the three factors of coordination present in all courses: assessment, TLA (Teaching and Learning Activities) and goals, also known as the triadic model of coordination.

The authors of [19–21] propose a model of a semi-automatic academic teacher to support students in choosing a learning trajectory (consisting of a set of courses forming individual curricula) to achieve learning outcomes. The authors have developed an Academic Tutor, which is intended as a model for an electrical engineering curriculum delivered using semantic web technologies, ontologies that provide a logical and formal description that can be interpreted by humans and machines.

The authors of [20] used the model to develop a meaningful interaction structure that provides tools to improve the quality of learning and provides opportunities for feedback.

In [22], the author describes the methodology and the process of developing an educational ontology, the elements included in it, as well as the process of its evaluation. The ontology is designed to be easily portable and reusable for any curriculum and course.

In the article, the authors focused on developing an integrated learning ontology that conceptualises multi-level knowledge structures, such as curriculum, programme, subject and materials. The report has detailed the developed curriculum ontology. In addition, the authors propose a method for integrating and classifying curricula based on the definition of the semantic model of curricula. This approach promotes the adaptive consistency of concepts and the exchange of curricula [23].

The article describes the design of individual educational trajectories of students based on the educational thesaurus [24]. The proposed method supports a set of generally accepted concepts in the field of student education, ensuring the correct organisation of training of various groups of students. The application model combines three disciplines in a conceptual framework that confirms the effectiveness of the proposed approach.

Paper [25] presents a semantic recommendation system for educational resources based on the semantic network and pedagogy. To describe the domain knowledge's structure, a domain ontology is created in this system [25]. All resources and user portfolios are described using ontology technology and resource description structure to support semantic inference.

The authors of [26] demonstrate the process of improving semantic learning resources by creating a new ontology and a prototype of their placement system. The developed ontology is based on a metadata profile created by the recommendations developed by the Singapore Structure for Dublin Core application profiles [26].

Article [27] proposes and implements the structure of the intellectual ecosystem of e-learning using ontology and SWRL. A new direction is introduced. It contributes to the creation of four separate ontologies of a personalised complete training package, consisting of a learner's model and all components of the learning process (learning objects, learning activities, and teaching methods).

In [28], the application of many online MOOCs (Massive Open Online Courses) around the world is pointed out. The number of registered MOOCs students has increased rapidly, along with the number of online courses offered. Most universities face two problems: (1) The inability to introduce an association between the formal and informal systems due to the heterogeneity of the platforms used, and (2) Not being able to apply student feedback in informal learning to examine a student's profile. After all, educational platforms contain a lot of data stored in various formats. To get access to an overview of all the data, it is necessary to collect and combine them into one solid system.

The authors of [29] consider contract fraud as a form of academic misconduct in which students delegate evaluation functions to third parties, thereby causing concern among educators. Since detection systems are ineffective, when contract fraud is detected, some schools turn to control systems that have been sharply criticised but are expensive for student and teacher organisations [29], for example, Deep Speaker. It is a speaker identification and verification system that can check with high accuracy whether two audio samples resemble the voice of the same person. This article presents an innovative tool combining the online oral assessment tool Real Talk with Deep Speaker. This proposed system facilitates lengthy discussions between students and teachers, while providing long-term verification of student identity with minimal cost and impact on educational institutions.

In the knowledge base, ontologies are essential resources for many applications. The study of ontologies helps us to simplify the work of manually creating ontologies by automating some tasks. Article [30] presents modern achievements in this field. Various classes of approaches (linguistics, statistics, and machine learning) are considered, including some recent approaches (based on deep learning). In addition, several related solutions (frameworks) are presented that provide strategies and built-in methods for studying ontologies. The descriptive summary is provided based on criteria related to the created ontology components and the degree of automation. This also highlights the difficulty of assessing the reliability of ontologies. This is because it is not an easy task in this area. It is an independent field of study.

The authors believe universities and higher education institutions are constantly renewing knowledge. Therefore, it is necessary to record the generated academic and administrative information, taking into account the huge amount of information that higher education institutions manage and the variety of systems that can coexist in the same institution. Because of this, it is crucial to use technology to share knowledge. Thanks to ontology, it is much easier to access knowledge, ensuring the appropriate exchange of information between people and various systems. Article [31] aims to identify existing research on using ontologies in higher education. A systematic cartographic study was conducted based on a series of 2792 articles. A total of 52 scientific papers were reviewed and analysed. The results show how ontologies are used in higher education, which technologies and tools are used for their development, and which basic dictionaries are reused in ontological applications [31].

This study analyses and develops temporal tracking and multiple semantic functions based on extensive and comprehensive data. First, the factors for determining semantic features and relationships are investigated. Secondly, the network prediction model, with multiple semantic convolution improved Capsule Neural Network (iCaNN), was developed based on the complexity and specificity of learning behaviour. The optimal experimental configuration is demonstrated through extensive training and testing of the model. Thirdly, we visualise many semantic functions, analyse existing problems and study major learning rules and time risks [32].

With the help of various digital tools that support learning, a large and constantly growing amount of data has already been collected. In addition, learning data about teaching and design methods are often unavailable. We need a systematic, student-centred way in which teachers can develop learning data that support them. Drawing on decades of research into Artificial Intelligence in Education (AIED), the authors [33] show how to use the key concepts of AIED: (1) Student model; (2) Open Learner Models (OLMs); (3) testability; and (4) ontology. They show how these concepts are used to develop its OLMs, an interface that allows students to see and interact with an external representation of their learning progress. The authors build on this important work by showing how OLMs can contribute to the design of student-centred learning data [33]. Based on Biggs' work [34–36], the author wants to show the profound impact this has had on education. Like Biggs, this opportunity is still provided to teachers, thanks to which it is possible to create data on subject-based learning and illustrate this approach with the help of a case study. The author also explains how teachers can use this approach today. The larger research program is planned to develop a complete collection of training data in the future. In this article, the author has made three main contributions. First, we introduce the OLMs terms, learner model, scriptability and ontologies as thinking tools for systematic data design.

In [37], the author creates a multi-agent system as a potential solution for online educational systems' implementation, to provide fast and accurate responses from the system and provide meaningful interaction between learners and systems. The existing work on online learning systems using MAS (Multi-Agent System) does not describe how information is transferred from the browser to the internal MAS, nor is it an adaptive component related to changing student requirements. In this study, the authors develop an Event-Condition-Action system with intelligent agents, including a message transfer agent to match the browser with its MAS messages and an adaptive course organiser agent to organise adaptive educational content based on changing needs. The result of the study is the design and modelling of a system defined as discrete objects that can be connected to a Virtual Learning Environment (VLE), with the addition of training agents performing various functions for the formation of an adaptive system. The system is evaluated by checking the results obtained in various case studies using validation tools. The expected behaviour is that the final course programme will match the parameters of the user's originally provided training mode. The results will change as the user's parameters change, while using the self-assessment questionnaire.

E-learning sites help to increase the skills and awareness of the academic environment, including teachers, students, administrative staff, and applicants who are looking for the latest information about various educational institutions. This online learning platform has many advantages, but users face several problems. For example, searching and deciding on suitable training materials and courses based on their needs and preferences. Therefore, providing useful information at the training stage is the main responsibility. The reason for many problems is the lack of feedback during online training. It is necessary to create a system that can properly conduct courses with different types of opinions to improve the skills and knowledge of our students. In this study, the author proposes an architecture that uses virtual agents to create semantic recommendations based on user requirements and preferences, helping to find suitable courses in real conditions [38]. The statistics of the results show that a virtualised agent-based recommendation system improves user learning skills, and also helps to choose the ideal course based on user preferences.

The popularity of teaching Artificial Intelligence (AI) is growing rapidly among teachers and researchers, but research on AI curricula has not been sufficiently studied. Currently, most of the research is focused on the content of educational programmes in Western countries. However, research on developments and activities in the field of artificial intelligence training is limited in the Asia-Pacific region. This meta-review will focus on the K-12 AI curricula adopted in the Asia-Pacific region between 2018 and 2021 by identifying knowledge about content, tools, platforms, activities, theories and models, and assessment methods. The author [39] reviewed 14 scientific papers, as well as the results of the selected studies. The results show that the artificial intelligence curriculum can develop students' knowledge and skills, attitudes to learning and interests in the field of artificial intelligence. Research on AI training was conducted using both qualitative and quantitative methods. This will help to understand how future teachers and researchers will evaluate the effectiveness of

AI training for their students. It also affects innovative educational projects in different ways in terms of educational standards, curriculum development, formal/non-formal education, student learning outcomes, professional development of teachers, and professional development, as well as assistance to the government and researchers [39].

Ontology technology has been studied in different fields and is currently being used in many of them. The majority of ontology studies were used with the help of e-learning, which made it possible to combine educational objects, modelling, and enrichment of educational resources, as well as personalisation of recommendations on educational content. The author [40] systematically analysed the research of e-learning ontologies from 2008 to 2020. This review examines the question "How are ontologies used to model knowledge in the context of e-learning and "What are the different ontological applications based on e-learning?". Classifying the existence of educational ontology, the author divided them into six types and five categories. The latter include the design methodology, the construction procedure, the scale of the ontology, semantic richness, and evaluation of the ontology, and are analysed by one indicator [40].

Creating a curriculum is a process. Partial automation and integration of this process can markedly facilitate the work of the creator of the curriculum, since it is a process that requires considering a huge number of restrictions, conditions, and parameters. This kind of research [41] is aimed at reducing the complexity of curriculum development in higher computer education and at improving the quality of a specific educational programme or curriculum. Formal formulations of problems are determined with the dual purpose of correcting existing curricula and forming new curricula. The solution algorithm that the author offers us is based on a weight matrix of competencies obtained by the learning outcomes analysis. The analysis is performed using methods of mathematical statistics and specially designed structures, such as the Rush measurement model and Bloom's taxonomy. Some terminological aspects of the competence model and educational trajectory are also discussed. The potential of modern learning management systems is also being studied, to provide the necessary statistics to be used as input data for analytical results [41].

Educational Data Mining (EDM) applies data analysis techniques to solving education management problems. This article suggests a general EDM process for recommending elective courses based on student performance. The good and bad sides of the application of the traditional measures in the field of course recommendations are investigated and supplemented with new proposed quality measures. Several methods have been studied to create assessment models for elective courses. The results show that the SVD (Singular Value Decomposition) classifier using course information gives the best results [42]. It is known that the proposed model can offer individual recommendations to individual students depending on their abilities [43].

The well-known programme Computing Curriculum 2005 (CC 2005) is being updated as part of a project called Computing Curriculum 2020 (CC2020). This project helps to predict the future of computer education by providing the world with the opportunity to receive a comprehensive report, comparing curriculum recommendations and providing more detailed information about computer education. Thanks to this process, a system of educational principles has been developed that is linked to other systems of skills and qualifications. This report provides an example of the transition from current practice to awareness-based practice. This article will help to determine the future of computer education worldwide. The Computing Curriculum 2020 programme brings together 36 specialists from 16 countries and six continents to create a resource that reflects achievements in the field of computing and education. The article shows the statuses and approaches developed by the CC2020 Task Force [44].

Study [45] conducts a content analysis to extract common terms from the curricula of the best universities in Latin America. In addition, the authors added the main aspects so that the programme performs its three main functions in previous studies. They combined automatic and manual methods to bring the curriculum's structure into a semantic network. The semantic network made it possible to describe the content of the curriculum knowledge in a graphical representation. With the help of semantic network representation, it is possible to transform the network into an ontological model, with which automatic processes can be performed [45].

Despite much work on the ontological approach to educational programmes and related subject areas, some significant problems can be identified regarding the methods and tools of using semantic technologies, such as:

1. Rare use of inference (reasoning) capabilities and tools for executing smart documents for DL Query, SPARQL, as well as the description of inference rules of the SWRL language. Meanwhile, these elements are the greatest advantage of semantic technologies compared to all other points of view.
2. The developed models only reflect the obvious structural connections between the elements of the educational programme and the context of its implementation, ignoring the relationship between the concepts lying in the domain of time.
3. Neglecting the principle of object-oriented design when designing ontological models. When designing the class structure, it is advisable to use the top-down design principle and assign the most common classes in the hierarchy, additionally creating derived classes through the inheritance mechanism. Class properties—i.e., object properties and data properties—should also be defined at the highest possible level, specifying them in derived classes where necessary.

3. Research Questions

The consideration presented in the Introduction chapter, and the results of the literature review allowed the formulation of the following research questions:

Q1. Is it possible to build, using an object-oriented approach, a detailed ontological model of an educational programme that combines courses, skills, and training periods?
Q2. Is it possible to automate the analysis of the consistency of course prerequisites and learning outcomes of an educational programme and its ontological model with the use of appropriate software?
Q3. Can the developed ontological model of the educational programme be easily integrated with the Learning Management Systems software?

4. Methodologies Used

The primary way to represent semantic information is a triplet—a syntactic structure consisting of three elements: subject, predicate, and object (Figure 1). A triplet can express a connection between two concepts, semantics which is defined by a predicate, for example "Course–Require–Skill". In addition, the subject property can act as a predicate, and the value of this property can act as an object, for example "Course–Has-name–Java Script Programming". Either an entity or a literal (numeric or string value) can act as an object.

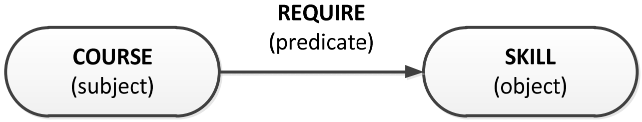


Figure 1. Triplet—the basic unit of semantic information representation.

An essential part of the semantic model is the principle of the uniqueness of object names. In the Semantic Web concept, it is customary for these names to have the form URI (Uniform Resource Identifier).

The most famous application of the ontological approach is the Semantic Web project—semantic web. This is a concept for the development of a web environment for the introduction of metadata into information that allows to store and process the semantics of documents. In addition, using special tools for data extraction will allow for not contextual but "semantic search", i.e., looking for an answer to a question and using logical inference. Semantic Web technologies can also be used in other areas—for system integration, description, the cataloguing of information resources, and the creation of intelligent software agents.

The ontological approach has several advantages in the implementation of information models of poorly formalised subject areas, which include the content of the educational programme:

- The "transparency" of the data model, which provides for its expansion by adding new concepts and relationships throughout the system's life cycle.
- The ability to model complex relationships and the use of logical inference.
- The usage of agreed (shared by all) terminology with precisely defined semantics.

5. Development of an Ontological Model of an Educational Programme

5.1. Skills and Courses Model

An educational programme is a set of interrelated training courses designed to teach (train) any skills (skill). Obtaining a skill usually requires the presence of other skills in the trainee. If we consider this in the example of a fragment of the bachelor's degree programme "Software Engineering," then, for example, obtaining object-oriented programming requires the skills of basic programming, procedural-oriented programming and algorithmisation.

Each course trains the learner in some skills and, in turn, requires the learner to have certain skills to start training. By the logic of the educational process, the required skills (prerequisites) of the student are trained in previously studied courses. Since the trained skills can be arbitrarily distributed among courses, the relationships between the trained skills and the input requirements (prerequisites) form an oriented acyclic graph (Figure 2).

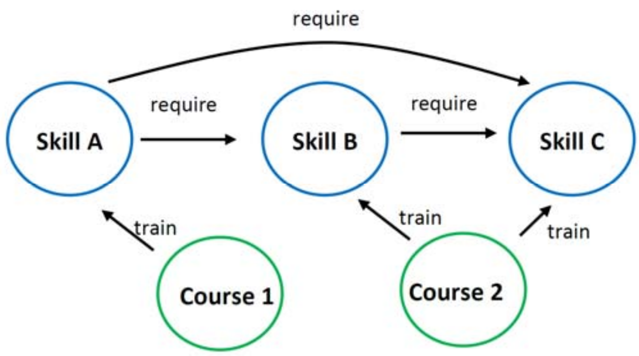


Figure 2. Transitivity of skills and their relation to disciplines (an example).

The dependence of one skill on another is transitive (Figure 2)—if skill B requires skill A, and skill C requires skill B, then skill C requires skill A. Since Course 2 is aimed at acquiring skills B and C by trainees, then, from the point of view of Course 2, skill A is an input requirement (prerequisite) for this course.

5.2. Model of Training Periods

The model defines two classes that are subclasses of the TimeInterval class—AcademicYear and Semester, which are connected by the includes/isPartOf relationship. To determine the sequence of intervals that follow directly, the TimeInterval class, and hence its child classes, is bound by two mutually inverse properties (object properties)—precede and followBy. These properties are not transitive. To determine the relations in a time of a more general nature—which of the intervals follows earlier and which later, regardless of the "distance" between them—two super properties are defined—goesBefore and goesAfter. The superpowers goesBefore and goesAfter are transitive. Thus, any period in the chain of periods linked by the follow By/precede relationship with its neighbours will be linked to the remaining periods by the goesBefore and goesAfter relationships (Figure 3).

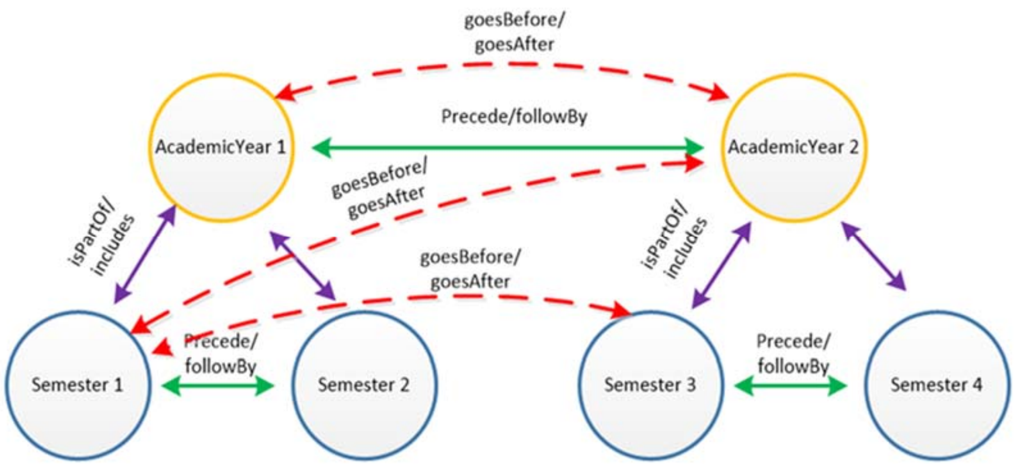


Figure 3. Relations between concepts—time periods.

For the goesBefore/goesAfter relationship between AcademicYear containers to also extend to the relationship between semesters and the relationship between the AcademicYear container and the semester, it is necessary to build an appropriate chain of relationships: isPartOf -> goesBefore = goesBefore (see Figure 4).

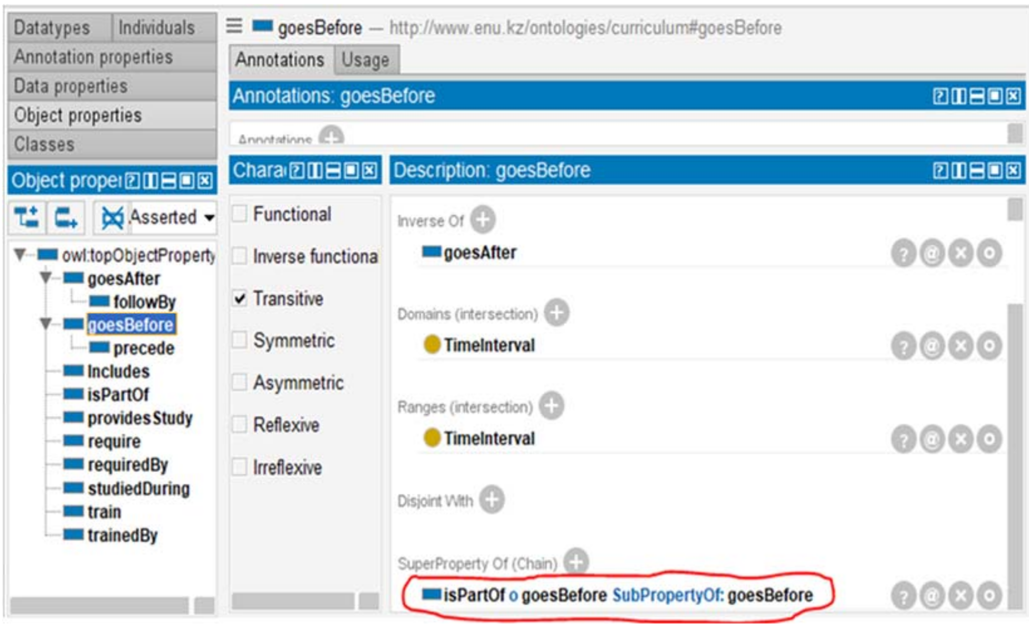


Figure 4. Definition of the Object Properties chain for the connection of AcademicYear and Semester in time.

The concept of "Course" is connected with the semester by the functional property "studiedDuring" and the inverse property "provideStudy".

The diagram of classes and properties obtained using the ProtégéVOWL plugin is shown in Figure 5.

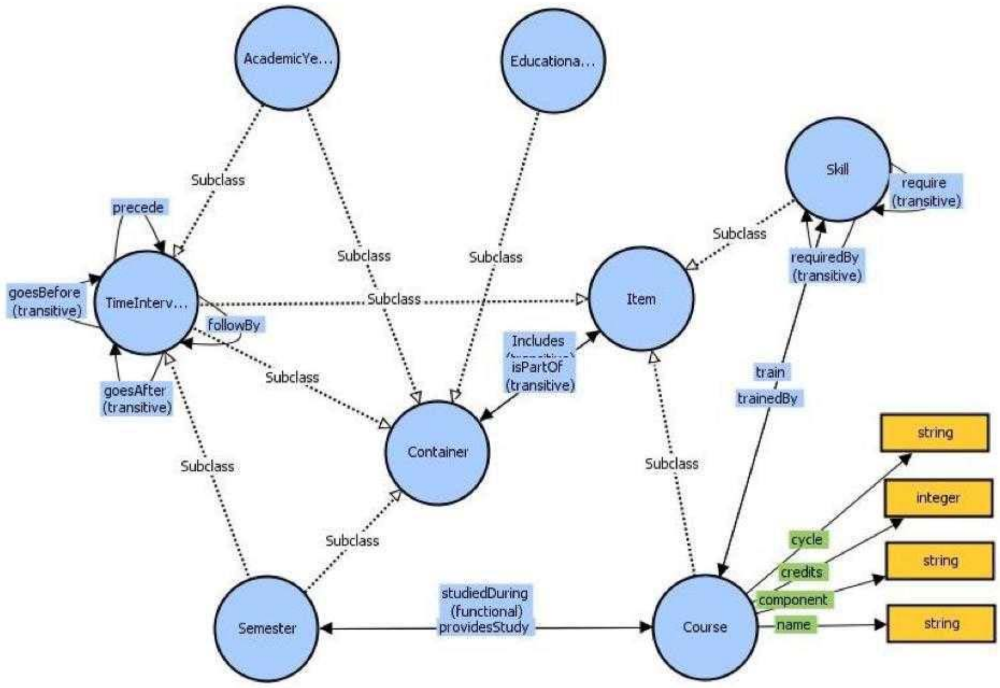


Figure 5. Semantic network graph describing the relationship between course, semester and skills.

5.3. An Example of Ontological Model Developed

The developed ontological model of the educational programme was implemented in the ontological editor Protégé 5.5.0. As an example, the model was filled with data describing a fragment of the bachelor's degree programme "Software Engineering". Figures 6–8 show the structure of the classes of the implemented ontology, the list of instances (individuals), and the hierarchy of object properties. In Figure 7, the names of individuals belonging to the Course class have a three-digit prefix of the form "999_".

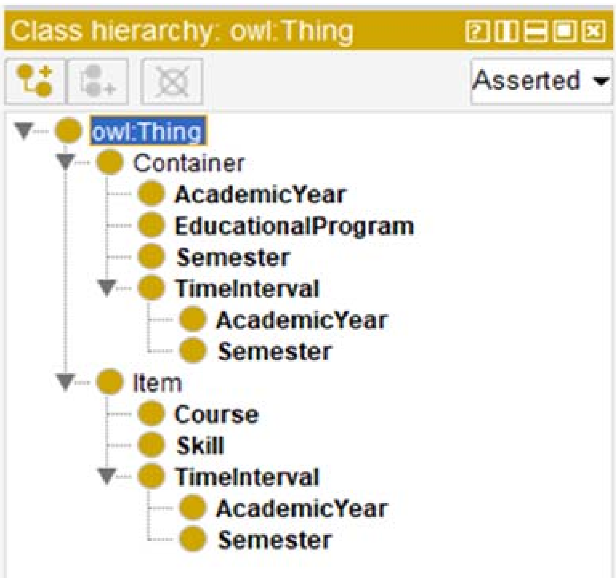


Figure 6. Class hierarchy of the ontology developed.

Figure 7. Individuals of the ontology developed.

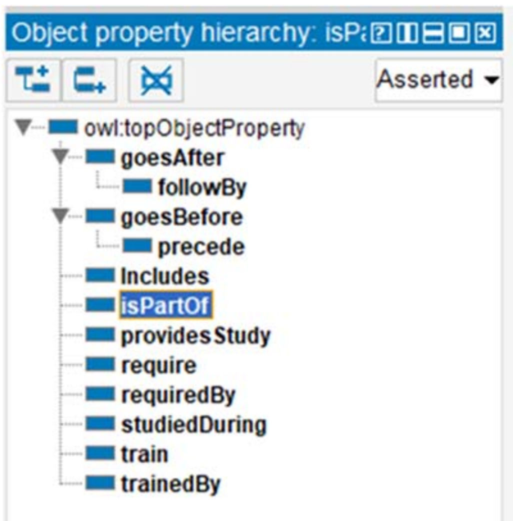


Figure 8. Hierarchy of object properties.

The complete ontological graph of the developed ontology, including classes, individuals, and properties, is shown in Figure 9. This graph was automatically generated by the Protégé software based on the ontology model (Figures 6–8). It presents a high degree of complexity of the developed model and is used here for demonstration purposes.

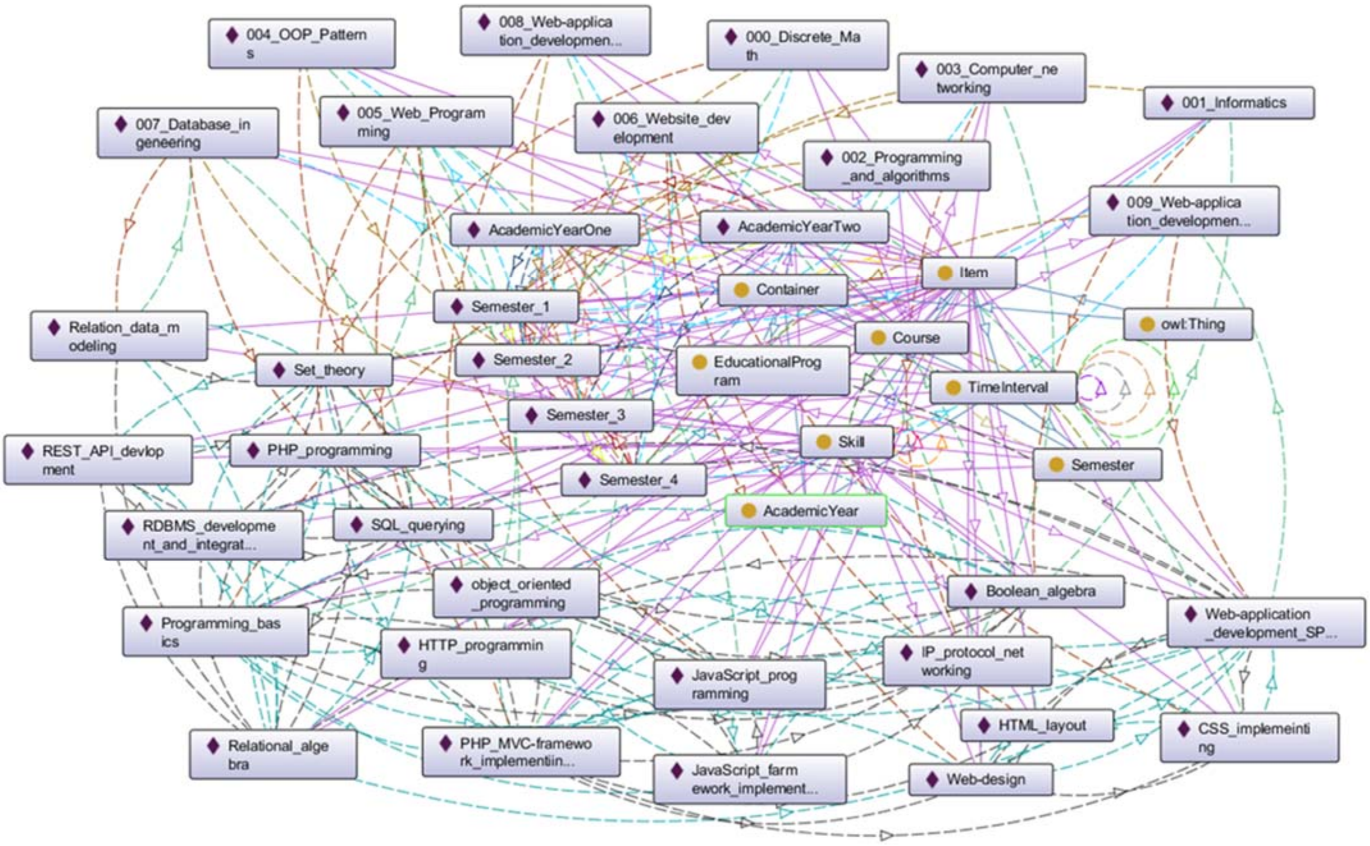


Figure 9. The complete graph of the ontology of the educational programme.

5.4. Analysis of the Consistency of Course Prerequisites and Learning Outcomes

The developed ontological model makes it possible to analyse the educational programme with various goals. The SPARQL query language is the most effective and flexible tool for extracting data from an ontology. It allows to operate with data sets extracted from an ontology, as with sets of elements. This makes SPARQL similar to the SQL query language used for relational databases. The peculiarity of the implementation of this language in the Protégé editor is that SPARQL does not perform calculations using the results of logical inference (reasoning). To solve this problem, it is necessary to save all the axioms obtained using reasoner (inferred axioms) as a separate ontology.

For example, the query for obtaining a complete set of all input requirements for skills developed during the study of subjects in semester 4th looks like this:requiredBy some (trainedBy some (studiedDuring value Semester_4)).

The query's results in the form of a list of individuals of the Skill class are shown in Figure 10.

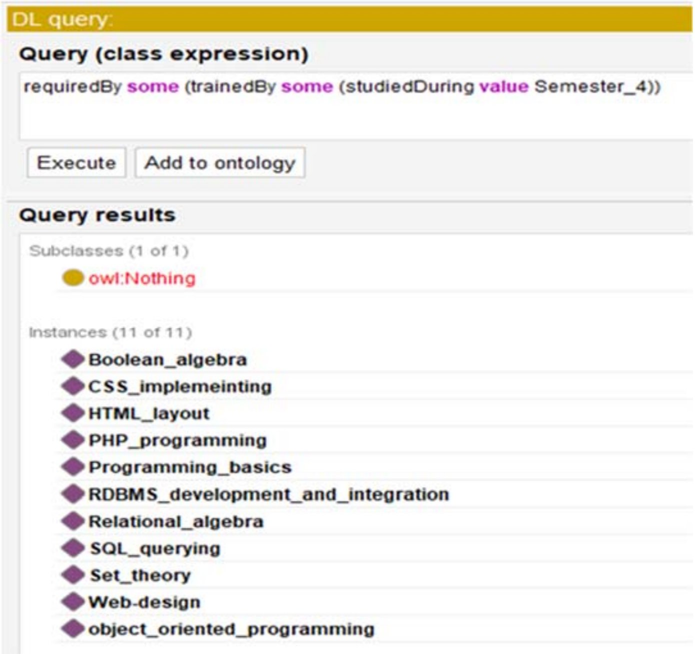


Figure 10. The list of skills that are the entrance requirements for the courses of the 4th semester.

To assess the consistency of the educational programme in terms of the disciplines studied during the 4th semester, it is necessary to make sure that all the required skills (Figure 10) will be formed in the student during the previous semesters 1–3. The list of skills formed during all semesters preceding the fourth one can be obtained using the following query in the DLQuery language:

trainedBy some (studiedDuring some (goesBefore value Semester_4)).

The query's results in the form of a list of individuals of the Skill class are shown in Figure 11.

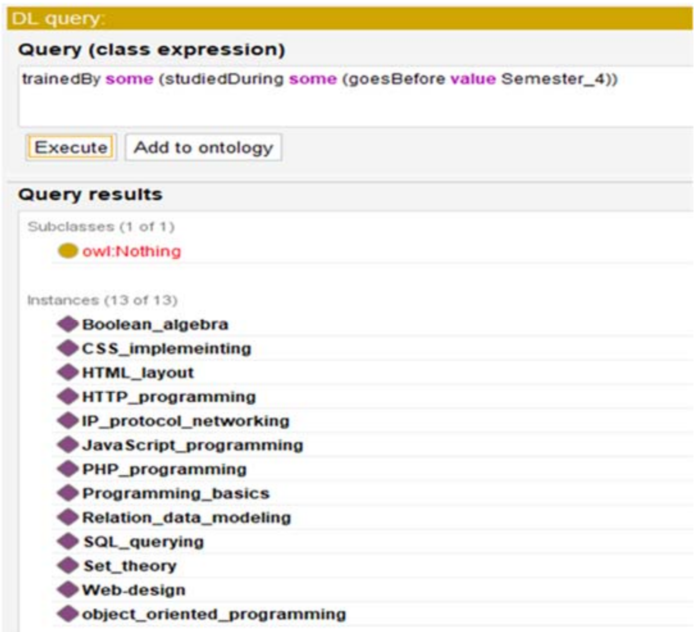


Figure 11. The list of skills acquired by the student during the study of courses preceding the 4th semester.

To assess the consistency of the educational programme, it is necessary to compare the acquired skill sets. From this comparison, it can be seen that not all the skills necessary for studying the 4th semester courses (Figure 10) are present in the set of skills acquired by the student earlier (Figure 11), which means that the educational programme in this part is not coordinated. The DL Query language does not allow operating to obtain the difference of sets. You can use the SPARQL query language to get an explicit set of skills included in the first set, but it is not included in the second. The peculiarity of this language implementation in the Protégé editor is that SPARQL does not perform calculations using the results of logical inference (reasoning).

The results of the query in the form of a list of individuals of the Skill class are shown in Figure 12. These results show that the inconsistency of the programme lies in the fact that two skills from the set of skills of the entrance requirements of the 4th semester courses are not provided by them in previous semesters.

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX curriculum: <http://www.enu.kz/ontologies/curriculum#>
SELECT ?rs
WHERE { ?c curriculum:studiedDuring  curriculum:Semester_4. ?s  curriculum:trainedBy ?c. ?rs
curriculum:requiredBy ?s.
              FILTER ( NOT EXISTS  {?rs curriculum:trainedBy  ?cp. ?cp  curriculum:studiedDuring
?sp. ?sp curriculum:goesBefore curriculum:Semester_4})}
```

rs
Relational_algebra
RDBMS_development_and_integration

Figure 12. The list of skills that cause inconsistency in the educational programme in the 4th semester.

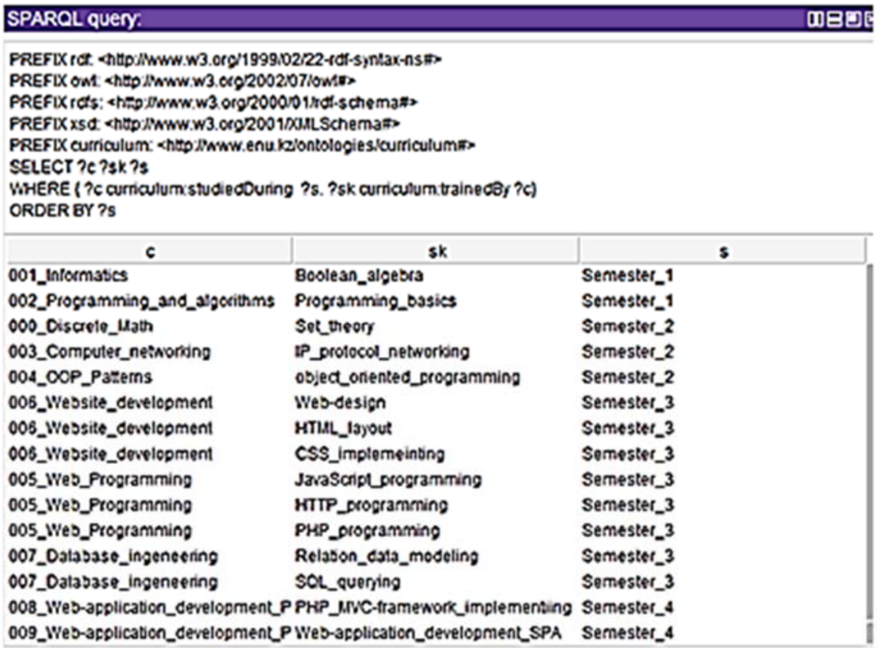
Figure 13 shows a SPARQL query that receives a list of all courses in the curriculum with an indication of the semester. Figure 14 shows a query that receives all the skills generated by the curriculum courses, indicating the semester.

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX curriculum: <http://www.enu.kz/ontologies/curriculum#>
SELECT ?c ?s
WHERE { ?c curriculum:studiedDuring  ?s}
ORDER BY ?s
```

c	s
001_Informatics	Semester_1
002_Programming_and_algorithms	Semester_1
000_Discrete_Math	Semester_2
003_Computer_networking	Semester_2
004_OOP_Patterns	Semester_2
006_Website_development	Semester_3
005_Web_Programming	Semester_3
007_Database_ingeneering	Semester_3
008_Web-application_development_Part_1	Semester_4
009_Web-application_development_Part_2	Semester_4

Figure 13. The list of courses in the curriculum with the indication of the semester.

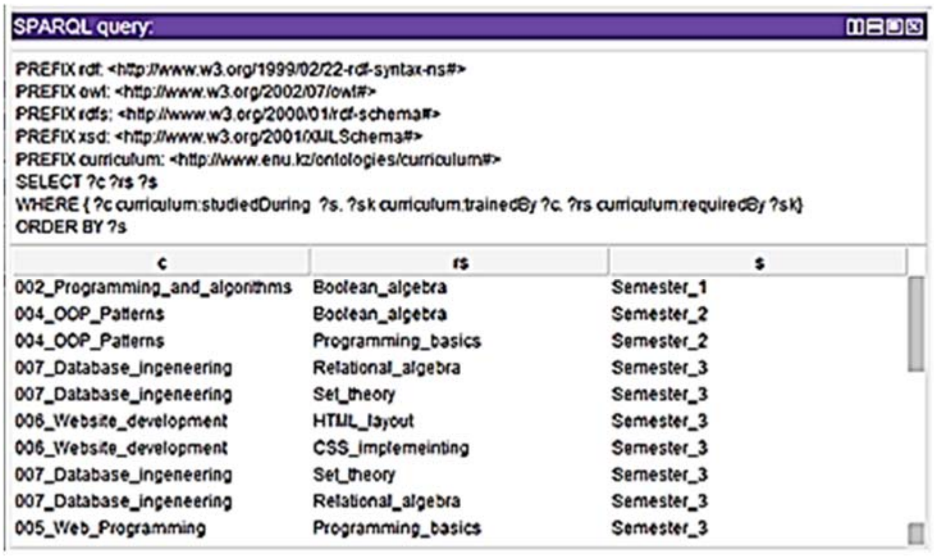

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX curriculum: <http://www.enu.kz/ontologies/curriculum#>
SELECT ?c ?sk ?s
WHERE { ?c curriculum:studiedDuring ?s. ?sk curriculum:trainedBy ?c}
ORDER BY ?s
```

c	sk	s
001_Informatics	Boolean_algebra	Semester_1
002_Programming_and_algorithms	Programming_basics	Semester_1
000_Discrete_Math	Set_theory	Semester_2
003_Computer_networking	IP_protocol_networking	Semester_2
004_OOP_Patterns	object_oriented_programming	Semester_2
006_Website_development	Web-design	Semester_3
006_Website_development	HTML_layout	Semester_3
006_Website_development	CSS_implemeinting	Semester_3
005_Web_Programming	JavaScript_programming	Semester_3
005_Web_Programming	HTTP_programming	Semester_3
005_Web_Programming	PHP_programming	Semester_3
007_Database_ingeneering	Relation_data_modeling	Semester_3
007_Database_ingeneering	SQL_querying	Semester_3
008_Web-application_development_P	PHP_MVC-framework_implementing	Semester_4
009_Web-application_development_P	Web-application_development_SPA	Semester_4

Figure 14. Skills formed by the courses of the curriculum with the indication of the semester.

The essential stage of the analysis of the educational programme is the consistency of the input requirements imposed by any course to the learner's skills (prerequisites), and the learner's skills acquired during the study of previous courses. To do this, we will obtain a list of sets of all input requirements for skills formed during the study of courses of each semester. The corresponding SPARQL query and the result of its execution are shown in Figure 15. The results show that each subsequent semester includes the prerequisites of all previous semesters due to the transitivity of the required property (Figure 15).


SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX curriculum: <http://www.enu.kz/ontologies/curriculum#>
SELECT ?c ?rs ?s
WHERE { ?c curriculum:studiedDuring ?s. ?sk curriculum:trainedBy ?c. ?rs curriculum:requiredBy ?sk}
ORDER BY ?s
```

c	rs	s
002_Programming_and_algorithms	Boolean_algebra	Semester_1
004_OOP_Patterns	Boolean_algebra	Semester_2
004_OOP_Patterns	Programming_basics	Semester_2
007_Database_ingeneering	Relational_algebra	Semester_3
007_Database_ingeneering	Set_theory	Semester_3
006_Website_development	HTML_layout	Semester_3
006_Website_development	CSS_implemeinting	Semester_3
007_Database_ingeneering	Set_theory	Semester_3
007_Database_ingeneering	Relational_algebra	Semester_3
005_Web_Programming	Programming_basics	Semester_3

Figure 15. Entrance requirements (prerequisites) of the curriculum courses with the indication of the semester.

The next result of the analysis is to find the skills that cause inconsistency in the educational programme for each semester. To assess the consistency of the educational programme in terms of the disciplines studied during a certain semester, it is necessary to make sure that all the required skills will be formed in the student during the previous semesters. To do this, it is important to find the difference in each semester between the entrance requirements of the courses of each semester and the set of skills acquired by the student before the beginning of this semester. The SPARQL query that solves this problem and the result of its execution is shown in Figure 16.

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX curriculum: <http://www.enu.kz/ontologies/curriculum#>
SELECT ?rs ?c ?s
WHERE { ?c curriculum:studiedDuring ?s. ?sk curriculum:trainedBy ?c. ?rs curriculum:requiredBy ?sk.
            FILTER ( NOT EXISTS {?rs curriculum:trainedBy ?cp. ?cp curriculum:studiedDuring ?sp. ?sp
curriculum:goesBefore ?s}))
ORDER BY ?s
```

rs	c	s
Boolean_algebra	002_Programming_and_algorithms	Semester_1
Relational_algebra	007_Database_ingeneering	Semester_3
HTML_layout	006_Website_development	Semester_3
CSS_implemeinting	006_Website_development	Semester_3
Relational_algebra	007_Database_ingeneering	Semester_3
Relational_algebra	009_Web-application_development_P:	Semester_4
RDBMS_development_and_integration	009_Web-application_development_P:	Semester_4

Figure 16. List of skills that cause inconsistency in the educational programme.

Figure 16 shows that the inconsistency of the programme lies in the fact that there are seven skills from the set of input requirements of courses in semesters 1, 3, and 4 that are not provided by the courses of the previous semesters.

The described methodology and technology for checking the consistency of the educational programme will work for any number of training periods, as well as for any arbitrary structure of skill dependencies and any degree of their detail.

6. Results and Discussion

The main results of the work performed are as follows:

(1) An analysis of scientific publications devoted to the use of semantic technologies for modelling educational programmes was carried out. Typical disadvantages of the proposed ontological models are revealed. They mainly consist of the fact that the developed models are poorly adapted for using logical inference tools, and the practice of such application has not been investigated. In addition, the existing models are constructed mainly using a limited set of roles (relationships) that reflect only the structure of the educational programme. They do not describe the relationship between concepts over time and the content of the educational process.

(2) An ontological model of the educational programme has been developed, reflecting the studied courses in terms of the skills they form and the entrance requirements (prerequisites) for the student's qualification. The model provides for the interrelationships of training periods over time, allowing to operate with sequences of study courses.

(3) SPARQL queries have been developed that allow analysing the educational programme for consistency of the input requirements of the courses and the skills of the student formed during the previous training period. The result of the queries is a subset of skills that relate to the input requirements of a certain training period, but were not formed during previous training periods.

The conducted research made it possible to answer the research questions posed.

Q1. Is it possible to build, using an object-oriented approach, a detailed ontological model of an educational programme that combines courses, skills, and training periods? The answer to this research question is: YES, we did it. It should only be noted that for real cases (eg a four-year educational programme with a large number of courses, skills and training periods), the developed models are very complex and difficult to use.

Q2. Is it possible to automate the analysis of the consistency of course prerequisites and learning outcomes of an educational programme and its ontological model with the use of appropriate software? The answer to this question is also: YES. Specialized software was used in the work not only to build the model, but also to explore it quite easily and automatically. A special query language for logical reasoning was used: SPARQL.

Q3. Can the developed ontological model of the educational programme be easily integrated with the Learning Management Systems software? The answer to this question is: NO. LMSs mostly use relational database management systems in the data layer. Meanwhile, SPARQL queries cannot be easily implemented in this technology, i.e., in Structured Query Language (SQL). The implementation or integration of both technologies will require separate research.

7. Conclusions

This article uses an ontological approach to develop the ontological model of the educational programme. The model represents the curriculum's structure as a sequence of courses being studied. The skills formed in the learning process are determined for each course, as well as the skills that are the input requirements for the student. The authors pay great attention to the semantic modelling of concepts describing the sequence and nesting of time intervals that are periods of learning.

The model's major purpose is to analyse the consistency of the curriculum. The condition of the curriculum's consistency is met if all the skills required to start studying the courses of any semester were formed during the study of the courses of the previous semesters. The authors demonstrated the solution to this problem using a logical inference machine (reasoner) and query execution in SPARQL. The proposed approach can be used not only to analyse the consistency of a separate educational programme, but also for a comparative analysis of programmes among themselves.

The effectiveness of using semantic technologies to analyse the consistency of the curriculum is due to the graph nature of the ontological model. The ontological model makes it possible to model a complex structure of connections, as well as to obtain a result in conditions of incomplete information about the simulated subject area using the mathematical apparatus of descriptive logic. The demonstrated advantages of the ontological approach will manifest themselves the more complex the semantic model of the domain will be from the point of the topology of connections and more voluminous from the number of concepts.

The ontological model proposed by the authors can be reduced to more fully and adequately reflect the subject area and expand it. One of the ways to refine the model may be the implementation of new conditions for the consistency of the curriculum. Additional consistency conditions may consider the volume of the training course, its classification in terms of the curriculum, the types of training sessions provided by the course, and others. It is also possible to implement in the model the division of skills into theoretical knowledge and practical skills.

The semantic approach gives excellent opportunities for multi-faceted analysis of educational programmes, but has significant limitations in practical application. Virtually all educational process management systems are built using relational databases. Solving the described problem using a relational data model will be possible only with a limited number of training periods and a limited length of skill dependency chains, since the SQL relational database query language does not allow recursive queries. This is the subject of future research.

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