Individual Learning Pathway Validation Based on the Syllabus

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Abstract– **The article presents a graph model for building learning pathways between academic courses based on the relations between keywords. In this study, we use two-layer graph model where the first layer is represented by academic courses, the second one – by the keywords. Relations between courses are built based on the relations between the keywords. An approach to individual learning pathway validation by the syllabus keywords graph is proposed.**

I. Introduction

Modern society trends require new approaches to the organization of the educational process. Individualization, as one of the new approaches, will allow educators to master more effective the most necessary competencies in the professional field. Individual approach implementation provides the student with the opportunity to comprehend the educational actions, opening choice possibilities, taking into account personal interest, as well as the formation of their individual learning pathways. Forming an individual learning pathway, student can see prospects that can positively affect learning outcomes.

In the general sense the term learning pathways – or any of its common synonyms, such as multiple pathways or personalized pathways – typically refers to the bunch of various interrelated courses, programs, and learning opportunities offered by schools, community organizations [1].

This paper is organized as follows: section two refers to the related work in the field of learning pathways personalization in higher education, section three gives a detailed discussion of the methods for student's educational pathways validation, while section four presents the approbation. Section five introduces the results. We conclude this paper with an overview of the proposed approach benefits and limitations.

II. Related work

A number of modern technological initiatives in the field of education have led to the desire of making educational process personalized on a mass scale. Plenty of ways to implement personalized learning in educational process has been described encompassing a wide range of opportunities for students.

According to M. Bulger [2], in an educational context, personalized learning describes adaptation to a students' unique combination of goals, interests and competencies, and the ongoing process of shifting instruction as these conditions change. Further, Basham J. et al. in their study [3] claim "personalization is less concerned with measuring performance compared to a hypothetical "average" student across an average curriculum and more focused on each student's skill growth as an individual learner".

Jennifer S. Grof [4] emphasizes the Personalized Learning as a concept, and a practice, allowing the learner to have greater control and ownership of their learning while giving them a more meaningful and effective education.

Personalized learning, according to M. Murphy et al. [5], is based on Learning Analytics and Educational Data Mining methods specialized for use with educational data sets to model individual learning pathways and to answer educational questions. The Learning Analytics objectives and their effectiveness were previously reviewed in [6], [7], [8]. From an observational point of view, personalized learning is designed, embedded, and consistently implemented within many learning environments.

In the study [9], Henning P. et al. created a system based on the concept of multi-level ontologies, deals with time-varying data. The system monitors the learner's progress, draw didactical conclusions from their behavior and then issue recommendations based on a pedagogical ontology.

A. Govorov et al. [10] represent the results of students' progress before and after the system implementation for modelling individual learning pathways when teaching database technologies, and concludes with the use of methods and algorithms for designing learning pathways are effective.

In the paper [11] Patel N. et al. describe data mining techniques used to extract frequent learning pathways from a large educational dataset. A graph-based process discovery algorithm was developed for extracting these frequent learning pathways from the clusters of data and revealed the sequences of learning activities that many students followed. These sequences represented pathways of student learning.

Ibrahim Alcore Alshalabi et al. [12] created an algorithm to select the shortest learning paths to learn the target learner's knowledge based on the concept that the graph is the most efficient representation of online courses in the computer based implementation of an educational system. The course is modeled as a graph, where each node represents a knowledge node (KU) and two nodes are connected to form a semantic network.

Alva Muhammad et al. in the study [13] review the recent research on learning pathway adaptation and trying to identify the adaptation parameter in learning path and reveal the challenges that might be during the learning path implementation.

The results in the Huong May Truong's article [14] offer insights into different developments, achievements and open problems in the field. Based on these findings, the paper also provides discussion, recommendations and guidelines for future researches.

Chih-Ming Chen in the paper [15] proposed a new genetic-based personalized e-learning system which can conduct personalized curriculum considering courseware difficulty level and the concept continuity of learning paths. The results show that proposed system is superior to the freely browsing learning mode because of high quality and concise learning path for individual learners.

This article focuses on individual learning pathways development for Russian students. Individual learning pathways development within the educational programs in Russian universities imposes restrictions on the student's individual learning pathways development. Curriculum is developed according to the State educational standards. The educational program graduate must have competencies according to a professional standard. Building an individual learning pathway independently means there might be a situation when students have not gained all the competencies that are necessary according to the curriculum. In addition, an average student is not able to build a learning pathway on his own taking into account the continuity of knowledge within various courses. To find a relevant solution for each problem mentioned above, an approach to validate student-created individual learning pathways should be proposed. To implement the method, the following objectives should be met:

- State educational standard and standard syllabus patterns analysis.
- Academic course keywords graph creation and labeling approach development.
- Student-created individual learning pathway validation algorithm development.
- Software service for building and validating individual learning pathways development.

II. APPROACH BASED ON SYLLABUS KEYWORDS GRAPH CREATION

The approach we propose in this paper is based on an approach for analyzing a subject area by its keywords graph we unveil in [16], and then applied to the subject area of Digital Humanities. Further testing proved the methodology is a one-size-fits-all solution that can be applied to any research area in order to determine its structure, components and closely related domains.

Here, we apply the developed approach to the syllabus analysis and discuss a two-layer graph model. On the first layer, there are curriculum courses, on the second one there are keywords extracted from section titles and topics within the academic courses. Relations between keywords define relations between courses, thus allowing one to build learning pathways that are consistent within a curriculum. The proposed model is depicted in Fig. 1.

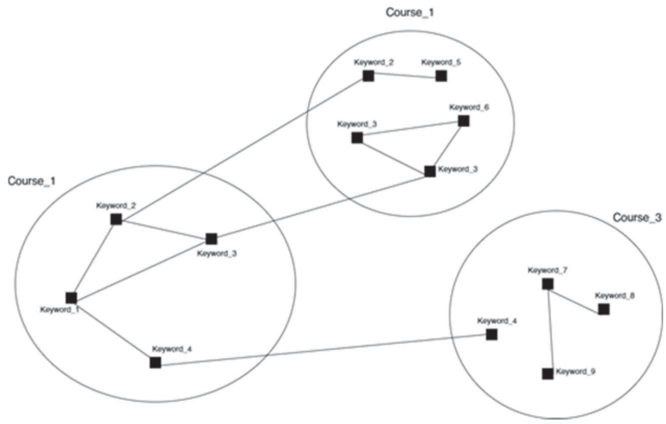

Fig. 1. Two-layer graph model

1) Educational entities classification

This part of the study is focused on educational entities and relations between them. Besides keywords, educational process is described by a significant number of educational entities. To begin with, it should be noted that educational entity is a curriculum element, connected with other ones by structure or logic relations. Educational entities may be structured or unstructured, whether they are presented by structured or unstructured data. Unstructured educational entities represent conceptual basis of the curriculum components:

- Subject areas.
- Subject area keywords.

Structured educational entities are powered by curriculum's hierarchy, contents and requirements. They are:

- Syllabus.
- Syllabus keywords.
- Educational programs represented by the curriculum.
- Individual learning pathways.

Structured educational entities are time-dependent or time-independent, whether they are or are not being modified according to the real-time updates. Time-independent ones are hypothetically modified at regular, predetermined time intervals:

- Syllabus.
- Syllabus keywords.
- Educational programs represented by the curriculum.

Time-dependent educational entities are individual educational pathways that are to be built as and when required. It is also worth mentioning that time-dependent entities are being developed by the means of time-independent ones. Fig. 2 shows the described relations between educational entities.

Fig. 2. Educational entities classification

2) Types of relations between educational entities

For analyzing and interpreting the relations between educational entities of the curriculum, we make a start from relations between the basis-level educational entities – keywords. Educational entities of higher levels are connected by hierarchy relations as shown in the Fig. 1. There are three types of relations we distinguish between keywords.

1. Hierarchy (⊂).

The hierarchy describes the structure of the higher-level educational entity by keywords. One generic keyword covers several detailed ones. A hierarchical relation produces three subtypes of relations (Fig. 3):

1.1 Entity_1 “includes” Entity_2, Entity_3, ..., Entity_n (“one-to-many”).

1.2. Entity_2 “refers to” Entity_1, Entity_3 “refers to” Entity_1, ..., Entity_n “refers to” Entity_1 (“many-to-one”).

1.3. Entity_2, Entity_3, ..., Entity_n “are parts of one section” (“many-to-many”).

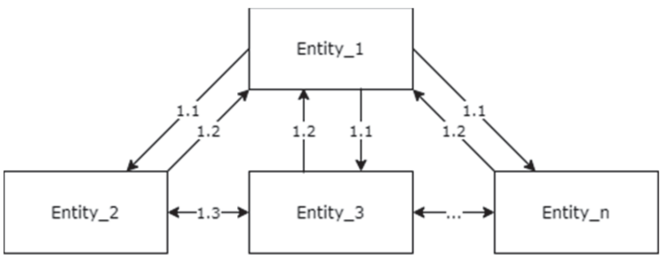

Fig. 3. Hierarchy relations between keywords

2. Prerequisites / Results (→).

Prerequisite type of connection allows one to describe the logical order of keywords. One keyword may have many prerequisites, and at the same time may be a prerequisite for a set of keywords itself (“many-to-many”). This type of connection is described by two statements (Fig. 4):

2.1. Entity_1 “is a prerequisite for” Entity_2, ..., Entity_n “is a prerequisite for” Entity_2.

2.2. Entity_2 “has a prerequisite” Entity_1, ..., Entity_2 “has a prerequisite” Entity_n.

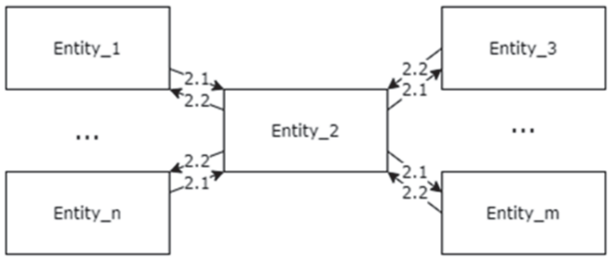

Fig. 4. Prerequisite relations between keywords

3. Identity (≡).

Identity is a type of connection between keywords that describes synonymous entities, as well as equivalents in other languages (“many-to-many”). The general model and system interface are shown in Fig. 5.

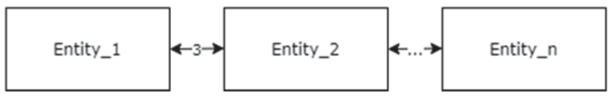

Fig. 5. Identity relations between keywords

Properties of the relations between keywords:

1. $\forall a,b,c \in A:((a \to b) \cap (a \to c) \cap (b \to c) \Rightarrow (a \to b \to c))$, where a, b, c are keywords, A is a graph of keywords.
2. $\forall a,b,c \in A:((b \subset a) \cap (c \subset a) \cap (c \subset b) \Rightarrow (c \subset b \subset a))$, where a, b are keywords, A is a graph of keywords.
3. $\forall a,b \in A:((a \equiv b) \Rightarrow (a \not\subset b) \cap (b \not\subset a) \cap (a \nrightarrow b) \cap (b \nrightarrow a))$, where a, b are keywords, A is a graph of keywords.

(1) and (2) mean that if keyword a is followed by keyword b and keyword c and keyword b is also followed by keyword c, one must study a and then b in order to pass on to c. The statement is true for hierarchy and prerequisite relations.

(3) means that if two entities are identical one of them cannot be considered as a prerequisite or subsequent entity for the other.

The example in the Fig. 6 shows a correctly built educational pathway: successive studies of courses from a mathematical unit. Starting with three mandatory terms of Mathematics, the route passes through Probability theory in the 4th term, Mathematical optimization and Mathematical statistics in the 5th one, tying up the track with the Decision theory in the 6th term.

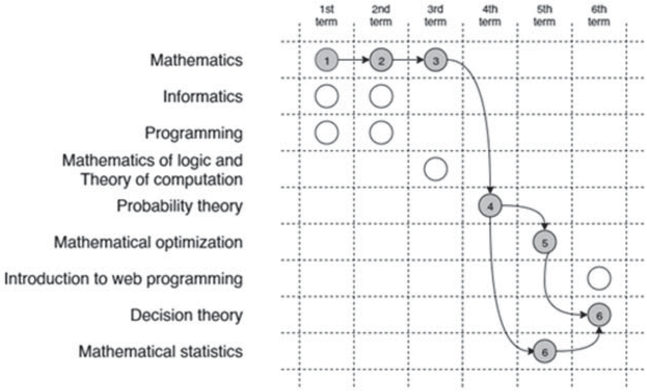

Fig. 6. Correct pathway example

In the Fig. 7 there is another example situation depicting an incorrect individual learning pathway, when its endpoint is Introduction to web programming. As it is shown in Fig. 8, to master in the course it is necessary to study Informatics and Programming. Here, we can observe an incorrect decision making when a student decides that for the Introduction to web programming it will be enough to go through Mathematics of logic and Theory of computation, and Informatics as its syllabus as well as Programming's contains the basics of programming as given.

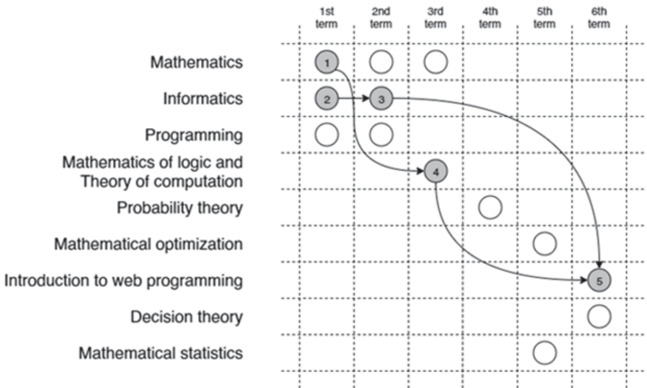

Fig. 7. Incorrect pathway example

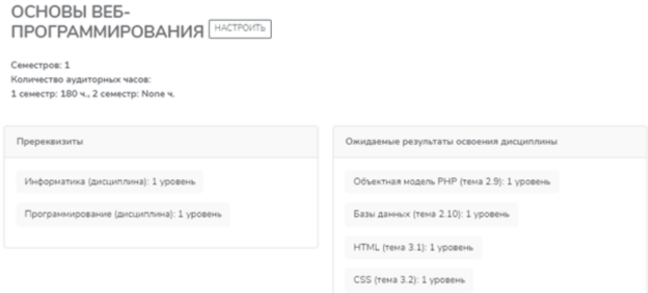

Fig. 8. Introduction to web programming prerequisites and results

3) Student-created learning pathway validation

In terms of information system development, student has an access to look through information about the syllabus courses and add the ones of necessity for his further professional career to his personalized curriculum, thus building an individual learning pathway. Unfortunately, this approach has some weaknesses, namely:

- A student can create such a pathway that will lead to the excessively heavy study load.
- As it was discussed earlier, academic courses have prerequisites – skills and knowledges that a student should gain in order to take the course of interest. Student will not be able to look into all prerequisites for each course and build the correct learning pathway.
- To master the educational program, the student must gain all the competencies from the curriculum. Syllabuses in the student's individual learning pathway should cover all the educational program competencies.

To solve the problems listed above, an algorithm for student-created individual learning pathway validation was developed.

As input, the algorithm takes information about the pathway between the academic courses compiled by the student, a list of competencies, competency indicators that student needs to obtain and data on the teaching load. The educational program is usually designed for a certain number of terms. The algorithm loops through each term filled with courses by student, collects information about competency indicators that will be gained, then compares obtained indicators list with the list of curriculum competency indicators. If the student-created pathway does not cover all necessary competencies student will be asked to rebuild the pathway. While looping through terms, the algorithm records the learning outcomes after mastering the academic courses and compares them with the prerequisites of the following courses. If student's skills do not match with the prerequisites for the course, he gets a recommendation to rebuild the pathway.

The following parameters are used by the algorithm:

- S, term number.
- SumHours, hours per term: sum of each course hours in the term.
- NumberWeeks, number of weeks in the term.
- Discipline, academic course.
- WpItems, a syllabus prerequisites array.
- UserItems, a syllabus results array.
- Competence, competency.
- Indicator, competency indicator.
- UserIndicators, list of competency indicators gained in education.

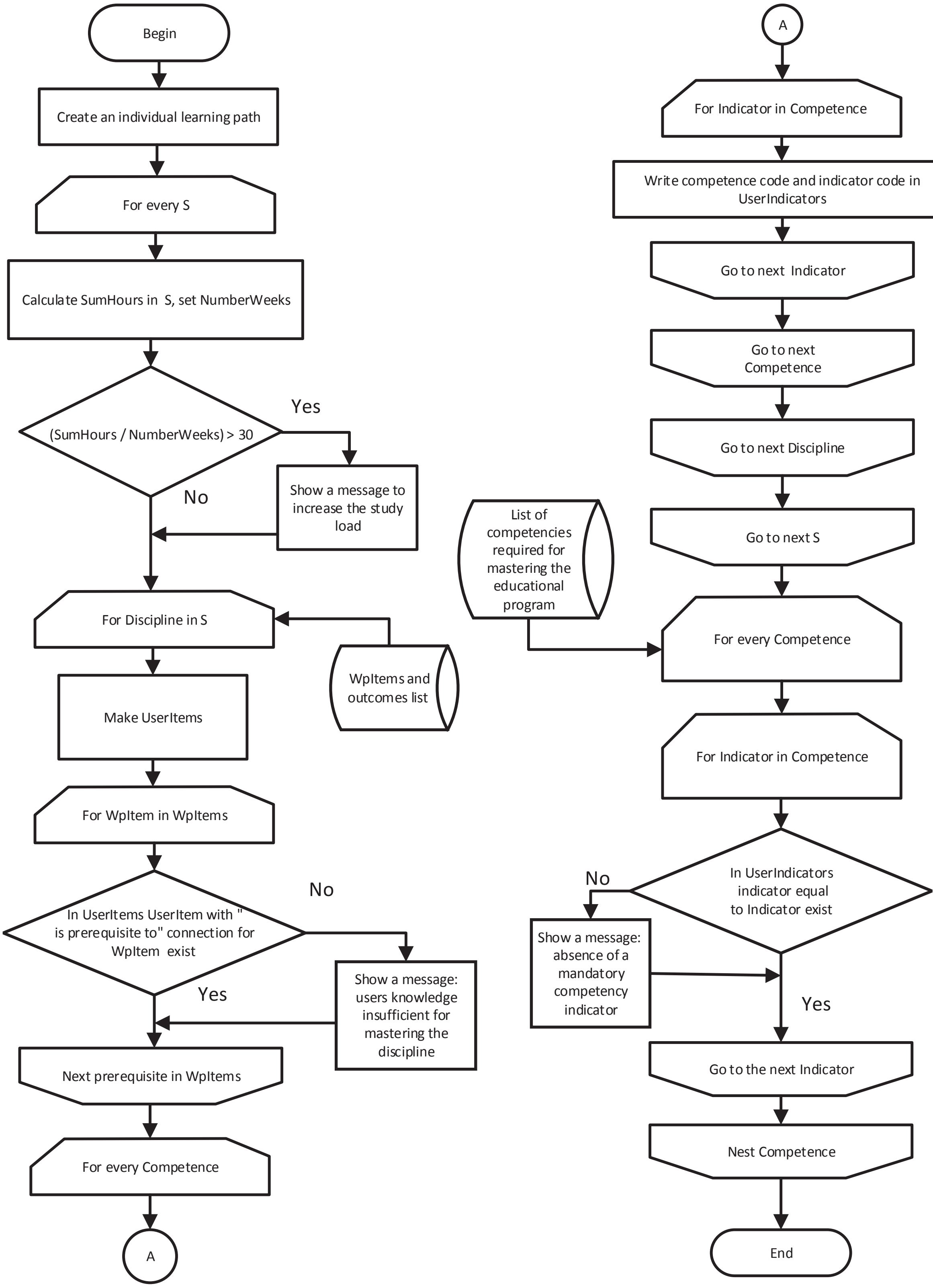

Fig. 9. Scheme of the modified A* algorithm

III. RESULTS AND DISCUSSIONS

Based on the proposed approach, to create and use keywords graph model in the personalized educational process support a special software service is being developed. Courses are represented as hierarchy of keywords. It allows us to visualize the content and structure of the course.

First, this service provides the university staff who is in charge of educational programs with an opportunity to upload keywords (obtained from learning support materials), establish relations between domain and academic courses both manually and automatically, as well as between academic courses alone. Keywords graph is created upon this data. The developed service is a tool for experts to create and verify connections between academic course and subject areas keywords.

Second, there is a user interface for individual learning pathway creation developed for students. Student-created pathway is automatically checked and validated by the algorithm described in the previous section. After the validation is done, the student gets a feedback with some advice and recommendation on how to rebuild his learning pathway if necessary.

Moving on to the technology stack, MVC Django framework version 3 was used. Validation algorithms are developed using Python programming language. In addition, Django REST framework was used to provide various ITMO University information services with API interfaces for data extraction.

To describe the course syllabus, the structure of educational standards and syllabus templates adopted at ITMO University was analyzed. Then, a model for the syllabus description by the means of IDEF0 notation was implemented (Fig. 10). The next step was to develop a data model to store data about syllabus (Fig. 11).

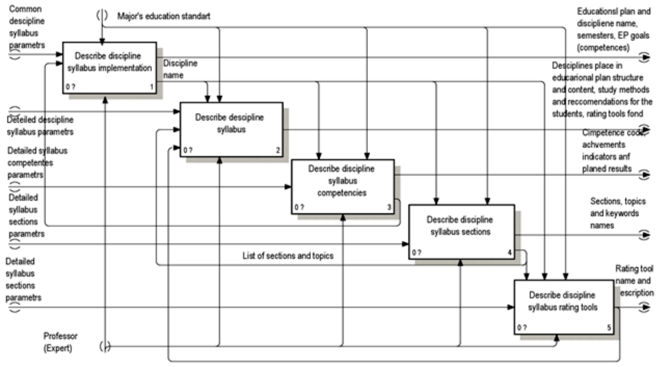

Fig. 10. IDEF0 model for syllabus description

Table "Syllabus" describes the course syllabus, tables "Topic", "Discipline_section", "Evaluation_means", "Competencies" and related associative entities are necessary to fully represent the course syllabus.

The syllabus can be used in various directions. The "Direction" table is connected with syllabus by a many-to-many relationship.

"User" table represents the user. To implement a user's learning pathway, each education step is stored in the table "Route_composition".

Syllabus has learning outcomes and prerequisites. Our database has table "Keyword" responsible for storing keywords. Depending on the way it is connected with certain syllabuses, it could be course prerequisites or learning outcomes.

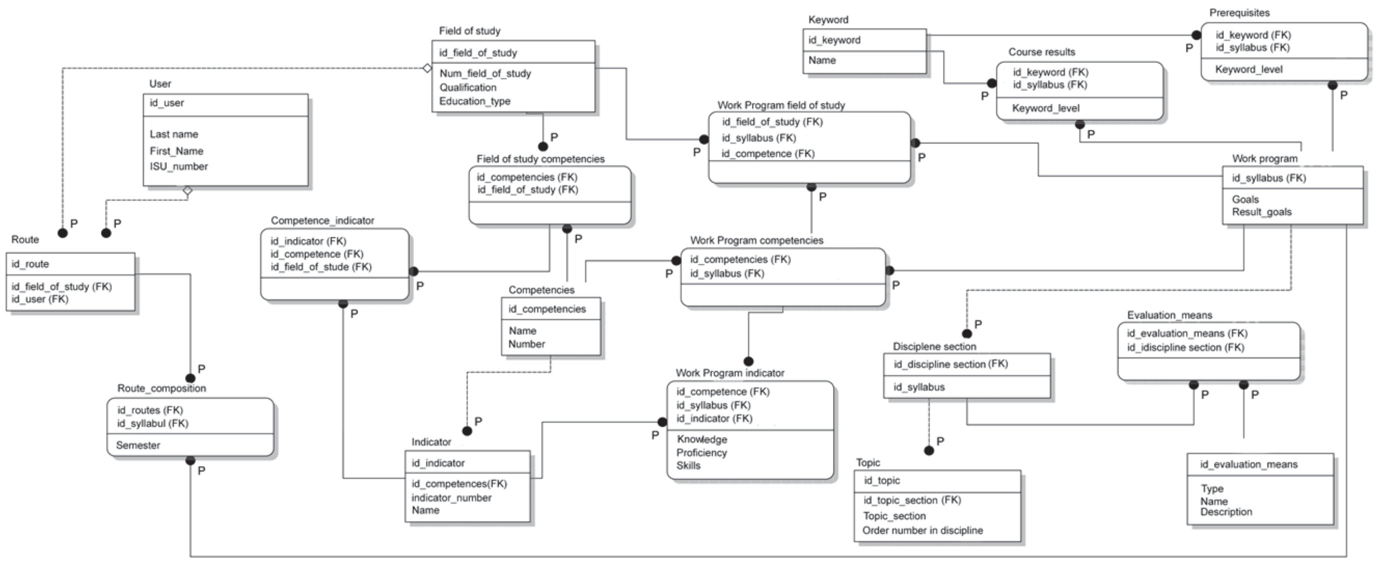

Fig. 11. Database model

In response to the data model, the following information system interfaces were implemented:

- Subject area settings interface.
- Interface for creating, deleting and editing keywords entities.
- Interface for setting up relationships between keywords entities.
- Interface for creating and editing syllabus developed according to the model described in the Fig. 10.
- Interface to view student-compiled pathway with each course syllabus.
- Interface to view student-created learning pathway validation results.

The example below shows syllabus list interface for different groups of users. In terms of this interface, a student has an opportunity to add courses to his learning pathway, and tutor can look through academic courses and adjust course settings.

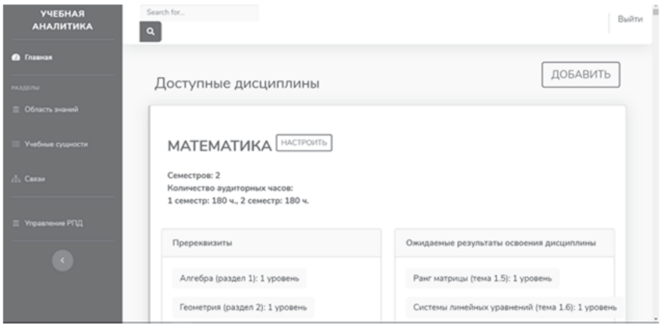

Fig. 12. Syllabus list interface

IV.CONCLUSION

In this article, an approach to keywords graph creation used to describe the relations between academic courses has been developed. When describing the proposed method application, the correct learning pathway and the incorrect one are shown. The situation when the student will not be able to master the educational program without studying additional learning support materials is provided as an example. In order to solve the incorrect learning pathway-building problem, an algorithm for individual learning pathway validation is proposed. Moreover, to solve the problem of continuity between academic courses' materials, the proposed algorithm checks if study load and set of competency indicators that a student should gain to successfully complete his education meets the educational standard and program requirements.

To use the proposed approach in response to the model Russian State educational standard structure and the syllabus description concept, a software service for building and checking individual learning pathway between academic courses has been developed.

Finally, it was concluded that the developed information system within the proposed approach would help students avoiding mistakes in the individual learning pathway building.

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