Curriculum Optimization by the Criteria of Maximizing Professional Value and the Connection Coefficient of Educational Elements, Using Software Tools

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Abstract. In the article, the process of designing a curriculum is formalized. The structure of the curriculum for the training of specialists is proposed as a set of structural-logical schemes and a set of educational elements. The filling of the developed structural-logical scheme by educational elements allows: to clearly define the content of the educational material and the purpose of training; to provide a clear logical sequence of educational disciplines; to use the automated presentation of the structure of the curriculum. The method for improving the structure of the training curriculum by the criterion of the general significance of educational disciplines content modules has been developed. The informational system for improving the structure of the curriculum of training according to the criteria of general significance has been developed.

Keywords: Curriculum optimization, Curriculum development, Vocational training.

1 Introduction

The main purpose of universities is to produce well-qualified specialists. At the same time, the quality of the training of specialists depends on how well the graduate can meet the modern workplace requirements. The quality of specialist's training is largely determined by his course. The training of professionals that meet modern demand entails the continuous improvement of educational programs. Therefore, the curriculum must be flexible enough to quickly adapt to changing requirements [1, 2].

Currently, the process of designing a curriculum is based on the experience and intuition of university staff, therefore it needs improvement and scientific evidence/support for the decisions made.

The development of modern technical and software, methods of constructing decision support systems makes it possible to improve the efficiency of work in educational institutions through the introduction of modern methods for processing information [3], construction and implementation of mathematical methods and models, tools for the search, analysis, formation and optimization of managerial decisions [4, 5].

The problem of automating curricula designing was considered in many scientific papers. How to optimize the logical structure of curricula based on the apparatus of graph theory was considered in the following works [6, 7, 8]. Improvement of making curricula of higher educational institutions using hierarchical trees of specialist training purposes was considered in the work [9]. In the work [10] algorithms of curricula improvement based on relationships between modules were proposed.

Scientific publications devoted to the optimization of curricula, considering the necessary condition that the volume of modules should be equal to the volume of the curriculum [11]. The problem of optimization the logical structure of curricula on the basis of the theory of graph apparatus, was considered in works [6, 7]. Improving the compilation of curricula of universities using hierarchical trees for the purposes of specialist training was considered in the works [9]. Algorithms of optimization of curricula on the basis of relationships between modules were offered in work [10]. It should be noted that most works fix only the presence or absence of relationships between modules.

Analysis of works on optimization of curricula [6, 9, 11, 12] showed that the main methods of optimizing curriculum include: matrix method, graph method, method of constructing tree of targets.

According to I. M. Morgunov [6], J. Johnson [7], the development of the structure of the curriculum should be based on the theory of graphs and matrix methods. The authors propose, first of all, to establish the logic of the learning, that is, the order of studying the training modules, based on the graph of module's connectivity. For each content module, the time period for a possible study is determined. Then the modules are distributed on weeks according to the chosen optimization criterion.

A. Moskvychenko [9] proposes to improve the structure of curricula with the help of hierarchical trees for the purpose of training a specialist. Target Tree has several hierarchical levels. Main goals of the training are graduate's knowledge and abilities. Each goal is put in accordance to one or more disciplines of the curriculum. Each discipline can be divided into modules. The educational process tree of goals has three levels: the goals of the educational process; blocks of curriculum disciplines; thematic modules of discipline. Thematic modules have equal amount of time.

The inputs are the coefficients of the relative importance of the goals for the educational process, as well as the importance of the second level objectives for the objectives of the first level. Based on these data, the coefficients of the relative importance of the goals of the second level, the importance of the goals of the third level for the purposes of the second level and the ratios of the relative importance of the objectives of the third level are calculated. The modules are placed by the reduction of group weights. It is necessary to select in the curriculum V of the first modules, where V - the volume of the curriculum in the modules. Then an expert survey is conducted to establish relationships between the selected modules in the curriculum.

Such an algorithm does not take into account the relationships between the modules. The relationships between the modules included in the curriculum are evaluated after the content is selected. Therefore, in the process of designing a curriculum, there may be a lack of information for students to master the teaching material of some modules, since the modules required for them as an information base may have insufficiently high group weight.

In the works of E. Herman [12], A. Ovchinnikova [11] algorithms of optimization of curricula on the basis of the graph method are proposed, taking into account the relationships between the content modules. In these works, optimization of the plan is possible provided that the total volume of the modules of educational disciplines is equal to the scope of the curriculum. And only the presence or absence of relationships is noted.

In work O. Trofimova [10] highlighted the possibility of improving the curriculum by several criteria, taking into account the density of the relationship between the modules and the significance of each module, but the algorithm built by the author does not allow to take into account the dual vocational training of future engineers-teachers.

The peculiarity of curriculum designing in engineering and pedagogical higher educational institutions is associated with the direction of the professional training at two sites of the activity: professional training and engineering activities. In the work [13] it is stated that the training of specialists for engineering and educational activities should take into account engineering and teaching components, moreover these components must be interlinked and integrated, that is to make a dual system.

Thus there is a need to develop a qualitatively new approach to design a curriculum for future engineers-teachers of computer profile built on the model of dual content of engineers-teachers' training.

2 Formalization Contents of Training

We will formalize the process of designing a curriculum for the training of engineers-teachers of the computer profile. The curriculum is a set of disciplines that are interrelated and must be studied over a certain period of time. The structure of the educational material of the discipline consists of smaller elements - modules.

$$ZD=\left\{ZM_1, ZM_2, ..., ZM_j, ..., ZM_L\right\} \tag{1}$$

where *ZD* - content of the discipline;

ZMj - *j*- content module of discipline;

L - number of modules in the discipline.

The number of modules for each discipline varies and depends on the volume of discipline.

Each module consists of single elements - educational elements. Educational element is the minimum dose of educational information that preserves the properties of the training object. Educational elements can be represented in the form: concept, phenomenon, relation, and algorithm.

$$ZM=\left\{N_1, N_2, ..., N_j, ..., N_t\right\} \tag{2}$$

where *Ni* – *i*-educational element of the module.

Since one educational element can belong to different content modules of different disciplines, it is advisable to design the training of a specialist as a set of objects of the lowest level - educational elements.

$$N = \left\{ N_1, N_2, ..., N_j, ..., N_g \right\} \quad (3)$$

where N - content of specialist training, Ni - educational element.

To structure the dual content of the professional training of engineer-teachers, we will use the graph method [14]. The structural-logical scheme of professional training of future engineers-educators should be represented in the form of a graph whose vertices are educational disciplines, fig. 1

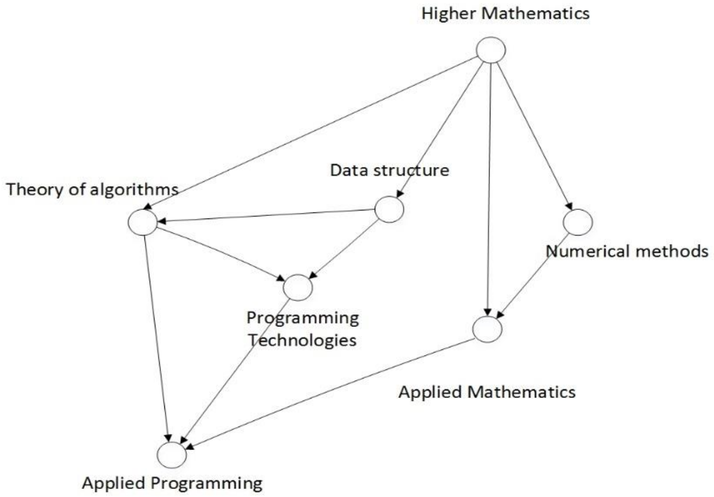

Fig. 1. Fragment of the content graph of the training

We will analyze the discipline for the presence or absence of mutual relationships between the teaching elements. Disciplines between which there is no connection we shall isolate into layers [14]. A group of disciplines joined by a layer will compile a list of disciplines for the academic semester.

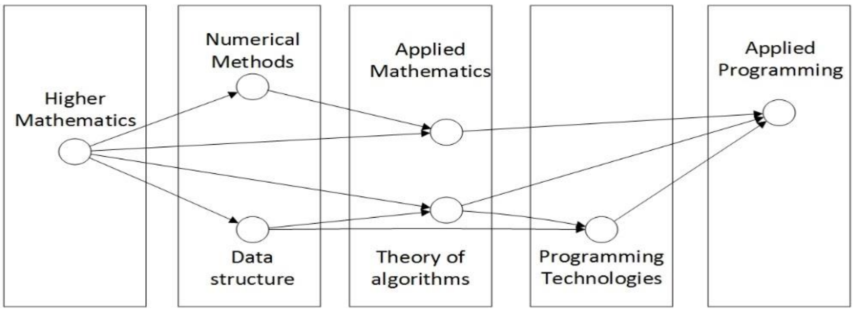

Fig. 2. Fragment of the structural-logical scheme of training engineers-teachers of the computer profile is divided by layers

In fig. 2 shows a fragment of a structural-logical scheme structured in layers. Thus, part of the curriculum is depicted in Fig. 1. can be represented by five layers. Therefore, these disciplines will be studied within five semesters.
The combination of the graph and set of educational elements form components for content model of specialist's training. This model allows to:

- clearly define the content of educational material and learning goals;
- to present the content in a clear and foreseeable manner;
- involve experts in discussion about the completeness and target indicators at the initial design stage;
- ensure the logic of teaching;
- go to computerization of presentation of the content model;
- form a systematic notion of the content of educational material.

3 Mathematical Formulation of the Problem

The process of forming a training plan for future engineer educators should take into account the high dynamics of the development of information and communication technology. This is possible due to the principles of modular selectivity and modular redundancy. The principle of modular selectivity lies in the fact that in each discipline there is a certain part of important modules, which must necessarily constitute the content of vocational training, the so-called invariants of disciplines. The principle of modular redundancy is the ability to form discipline with a large number of related modules. Compliance with these principles allows you to adapt the curriculum to the requirements of the present and provide the most effective professional training.

Thus, when forming a curriculum we will consider two types of modules. Normative modules - modules that are required to study and fall into the curriculum. The number of these modules should not exceed the maximum number of modules *L* for this discipline. Variant modules - modules that may not fit into the curriculum.

The task of improving the curriculum is to select the most important for the professional activity of the material and place it in semesters in an optimal way.

The modules of the curriculum are interconnected that is in the following ones the material from the previously studied modules is used. If the module *Mi* uses information from the module *Mj*, *Mj* is called an ancestor relative to *Mi*, *Mi* is called a descendant relative to *Mj*.

Density of connection *P (i, j)* between the modules *Mi* and *Mj* may be characterized, considering which part of the module *Mi* is used in the material of module *Mj*.

$$P_{(i,j)} = k_1 * k_2 \tag{4}$$

where *k1* – the number of study elements used in the module of *Mj* descendant of the module *Mi*;

k2 – the number of these connections.

After evaluating all connections of all modules the density of communications is normalized from 0 to 10. In determining the coefficient of module significance for study of further material we will take into account not only the module contribution to the study of its direct descendants, but also the later studied modules. For this purpose let's enumerate all the modules, giving one index to each. Let the number of modules be *M*. Then the graph of connectivity can be provided by a two-dimensional matrix *A* of *MxM* dimension, each element of which is *a (i, j)*, which is equal to the density coefficient of communication between modules *i* and *j P (i, j).*

Introduce the concept of iterative power of *k* order of m – $p^k(m)$ module. Iterative power of *m* module of the first order characterizes the value of the contribution of a module-ancestor to explore its descendants and is equal to the sum of weights of connections that go from it.

$$p^1(m) = \sum_{i=1}^{M} a(m,i) \tag{5}$$

where $a(m,i)$ – coefficient of density connection of module-ancestor with the module-descendant.

Iterative power of module of the second order describes its contribution to the study of its descendants and the descendants of the second generation

$$p^2(m) = p^1(m) + \sum_{i=1}^{M} p^1(i) \times P(m,i) \tag{6}$$

Usually just a few iterations to rank all the elements of the matrix are needed. After the ranking of the elements ceases to change, one can finish the calculation. Note through k_c the significance coefficient of module for the further material study.

$$k_c = \frac{p^{\max}(m)}{\sum_{i=1}^{M} p^{\max}(i)} \tag{7}$$

The significance coefficient for the further study of the material – descendants comes to the scale from 0 to 10.

Construction of the curriculum is based on the data obtained from experts. In the training process of engineers-teachers of computer profile it is important to consider the educational component of each engineering module and the engineering component in each pedagogical module. Therefore, the task of experts is to determine for each module the coefficient of significance for the future activity of computer systems engineer and the coefficient of significance for the future activity of a teacher.

In this study, special attention was given to criteria weighting, considering the influence of weight assignment on the final result [15].

The coefficient of professional significance is found with the formula:

$$k_{np} = \frac{1}{5} k_n + \frac{4}{5} k_i \tag{8}$$

where k_n– the average assessment of the module by experts-teachers;

k_i – the average assessment of the module by experts-engineers.

For each module the coefficient of the total value is calculated.

By solving the task of optimizing the training curriculum, we will understand the multicriterial task for maximizing the professional value and maximizing the connection [16, 17]. Let us reduce the multicriteria problem to a single criterion [18, 19].

$$k_з = 0.5 * k_c + 0.4 * k_n + 0.1 * k_i \tag{9}$$

The formation of the content in the form of a directed graph and a set of educational elements that form the maximum value of the generalized significance will be considered to be the solution for the task of optimizing specialist's training content.

4 Stages of Automation of the Design of the Curriculum of the Disciplines of Professional Training

Method of optimization of the curriculum for future engineers-teachers ~~after~~ for the criterion of maximizing the generalized significance considering the connectivity of modules consists of the following ten steps:

1. Getting expert data. Linking educational elements (data that reflects the basic educational elements for each educational element that is necessary to study). Assessment of pedagogical and engineering significance of modules.
2. Building the modules dependency graph.
3. Calculation and ranging the coefficient of density dependence between modules.
4. Removing contours. Finding the cycle in the graph and removing the edge, which belongs to the cycle and has the lowest coefficient of density dependence between modules.
5. Calculating the overall significance coefficient of the module.
6. Removing excessive modules from the graph. For each discipline compare the total number of modules and the permissible number of modules, and if there are too many modules, we remove the excessive ones, choosing the module with the lowest coefficient of general significance.
7. Building the graph of dependence between disciplines.
8. Calculating and ranking the values of density dependence coefficients between disciplines.
9. Removing the contours from the graph.
10. Dividing the contours into layers.

The algorithm for optimization of the curriculum for future engineers-teachers after the criterion of maximizing the generalized significance is presented in Fig. 3

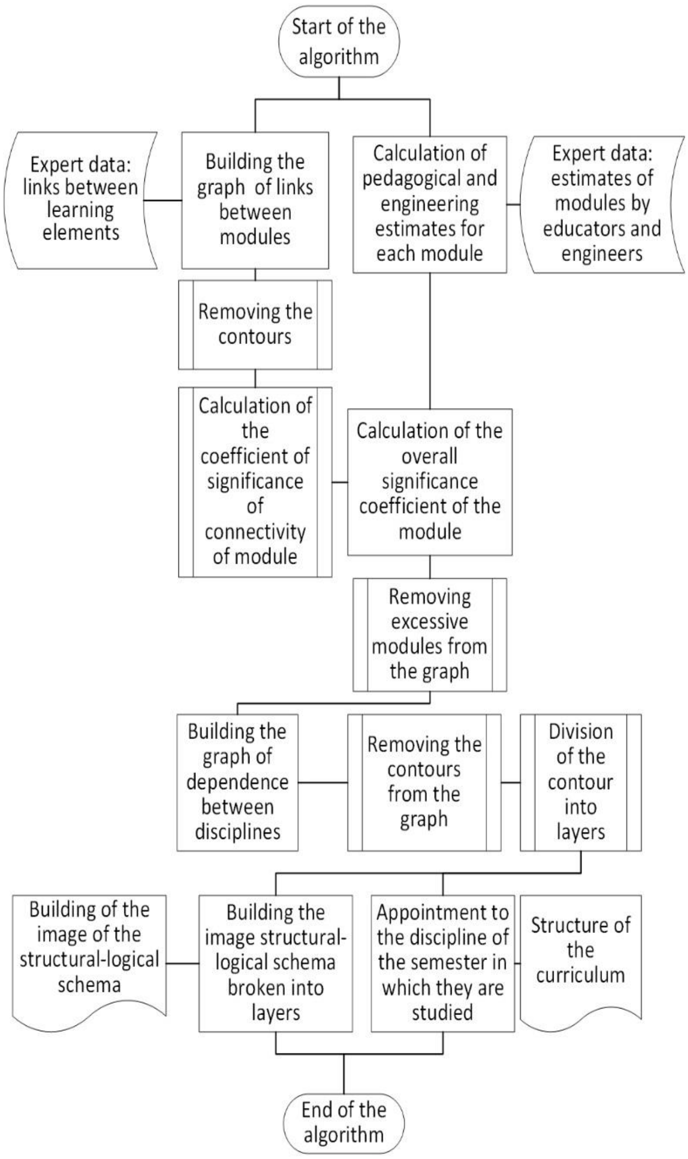

Fig. 3. An algorithm for optimization of the curriculum

Based on the described mathematical apparatus the information system of management of curriculum designing in terms of dual training was designed and implemented.

Information system is a software tool based on the use of .NET Framework and ASP.NET MVC. Microsoft SQL Server is used to store data. The MVC model is presented in fig. 4.

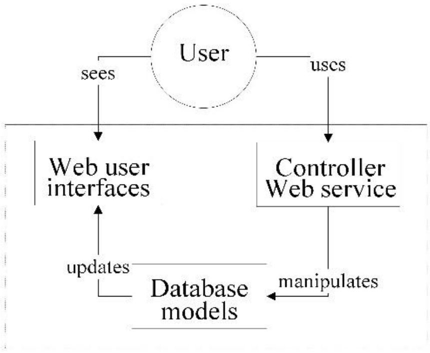

Fig. 4. MVC model

The Web service provides the following functionalities:

- authorization of users and differentiation of the rights of their access to the possibilities of the site;
- management of discipline directory: the ability to create, edit and remove disciplines;
- management of content modules directory: the ability to create, modify and delete modules;
- management of the Directory of Educational Elements: the ability to create, edit and delete educational elements;
- linking to the module of the list of learning elements studied within the framework of this module;
- linking to the learning elements of other learning elements, which are determined by the basic elements for studying this learning element;
- to make expert evaluation by engineering and pedagogical specialists of variational content modules, which are part of disciplines with an excessive number of modules;
- management of user lists: create, edit, delete users, assign roles to differentiate rights;
- processing expert data and forming a structural and logical scheme for the training;
- the isolation of the layers of the structural-logical scheme of training;
- constructing an image of a structurally-logical scheme for the training, broken down into layers.

To work with the database, we chose .NET Entity Framework, namely the Code First approach. This approach involves describing database models with the help of a program code, and from it the database is generated. As a result, we received the database depicted in Figure 5.

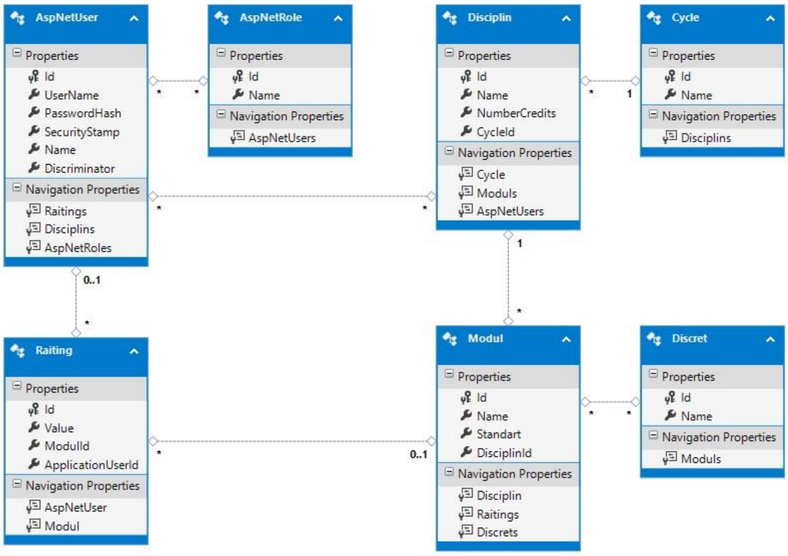

Fig. 5. Structure of the database

Now let's look at the basic classes of database models. Class "Discipline" contains information about the discipline in fig. 6.

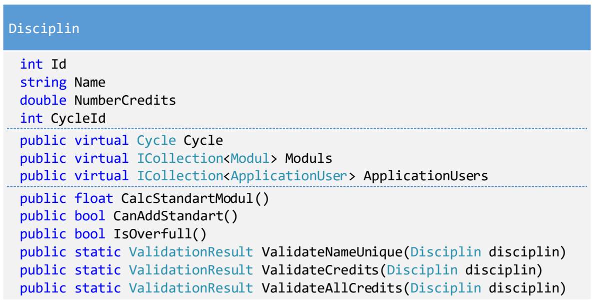

Fig. 6. Diagram of the Discipline class

Field Id - stores a unique object index.

Field Name - keeps the name of the discipline.

Field NumberCredits corresponds to the number of credits assigned to the discipline.

CycleId field - saves the unique key referencing to the table of cycles (Cycle).

Cycle property - the virtual field returns an object of the type Cycle (a training cycle) whose key corresponds to CycleId.

Property Moduls - returns a collection of Modul type objects (modules) that refer to this discipline.

CalcStandartModul () function returns the number of credits reserved by standard modules.

CanAddStandart () function returns true values if it is possible to attach another normative module in the discipline, the value false otherwise.

IsOverfull () function returns the true value if the number of modules is greater than the maximum value of the number of modules for this discipline, the value false otherwise.

Functions ValidateNameUnique, ValidateCredits, ValidateAllCredits - check the boundary values for the saved object to the database.

ValidateNameUnique - checks for the uniqueness of the name of the discipline.

ValidateCredits - checks that the number of credits is multiple of 0.5.

ValidateAllCredits - Does not allow you to keep discipline if the number of credits for the course is over.

Depending on the user's role ("Developer", "Expert" ("Educator" or "Engineer"), "Administrator"), "Web-site" has different functionality.

The functional capabilities of the system for the user in the role of "Curriculum developer" allow the creation and editing of disciplines, modules of teaching disciplines, educational elements, as well as establishing links between educational elements. Based on these connections, the system calculates the coefficient of connectivity between the content modules.

The functional capabilities of the system for the user in the role of "Expert" ("The teacher" or "Engineer") allow to view and edit any discipline, content module, training elements and determine the professional importance of the content modules of the disciplines. This assessment is taken into account by the system to determine the duality factor of the content module and to decide on the feasibility of including this content module in the curriculum. Depending on the role of "Teacher" or "Engineer", the professional pedagogical or professional engineering significance of the content module is determined.

The system function for the user as Administrator allows you to add, edit and delete users of the system. The administrator also has every opportunity to develop a curriculum. However, he cannot make an expert assessment of content modules.

The "Structure of the curriculum" requires the presence of Microsoft Windows Server operating system and Microsoft SQL Server database management systems. Workstations must have Web browsers and Microsoft Excel installed.

Web interface for the main page of the "Structure of the curriculum" is depicted in Fig. 7.

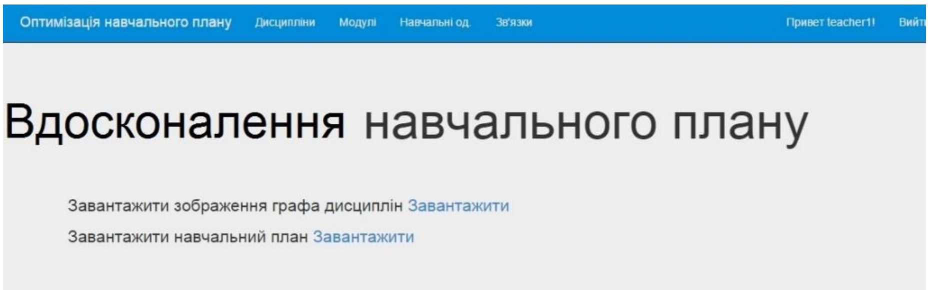

Fig. 7. Web-interface of the "Structure of the curriculum"

Inputs for the information system "Structure of the curriculum" are: a directory of disciplines, a directory of modules, a directory of educational elements, links between educational elements, expert assessment of the professional significance of each module.

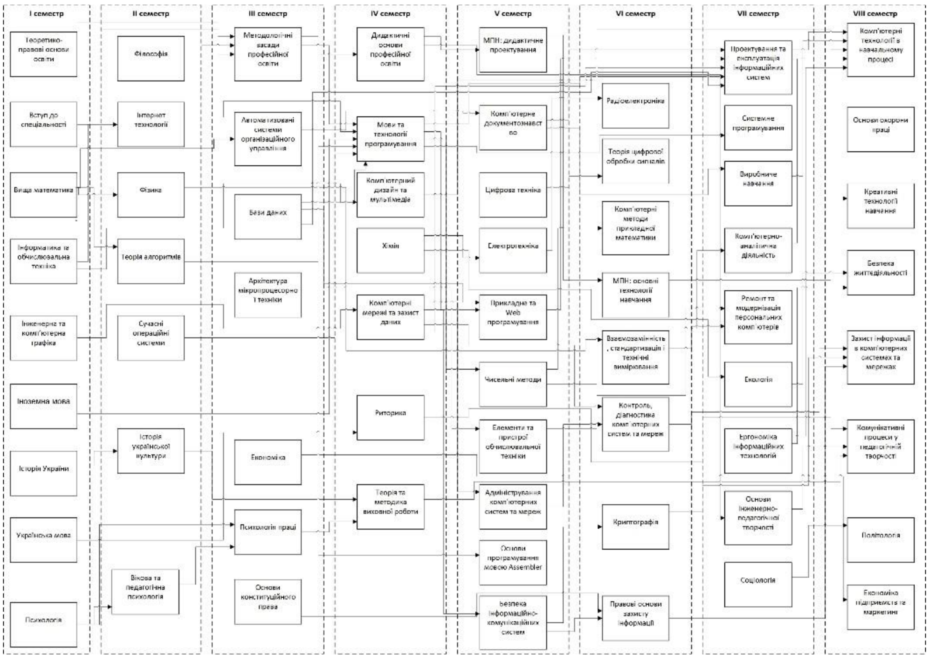

Fig. 8. The structural-logical scheme of training

Output - there are two documents: the first document - a graphical representation of the structural-logical scheme of training (Fig. 8); The second document is the Excel spreadsheet file, which contains a list of disciplines with semesters in which it is recommended to study these disciplines.

5 Conclusion

The structure of the curriculum for the training of specialists is proposed as a set of structural-logical schemes and a set of educational elements. The filling of the developed structural-logical scheme by educational elements allows: to clearly define the content of the educational material and the purpose of training; to present the contents of the educational material in a visual and accessible form; to engage experts to discuss the completeness of content and targets at the initial design stage; to provide a clear logical sequence of educational disciplines; to use the automated presentation of the structure of the curriculum; to form a system representation of the content of the educational material both from the developers and the teachers.

The method for improving the structure of the training curriculum by the criterion of the general significance of educational disciplines content modules has been developed.

The informational system for improving the structure of the curriculum of training according to the criterion of general significance has been developed. This system provides the possibility of distance work on the development of the structure of the curriculum.

With the help of the information system, the structure of the curriculum of training of the bachelor's degree in major "Professional Education. Computer Technology" is improved.

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