Development of Curricula Based on the Combination of Modular and Competence Approaches

Gevorg Margarov
National Polytechnic University of Armenia
Yerevan, Armenia
e-mail: mgi@polytechnic.am

Marine Usepyan
National Polytechnic University of Armenia
Yerevan, Armenia
e-mail: musepyan@polytechnic.am

***Abstract* — The main consideration of the paper is the problem of smart generation of specialist training curricula based on the modular-competence approach in higher education system. A formal methodology for the formation of subject module content and a three-stage approach dividing the curriculum into semesters are proposed, and the curriculum optimizing problem is also raised. The paper presents a mathematical formulation of the problem of the curricula synthesis, as well as substantiated the choice of criteria for optimizing the curriculum.**

***Keywords* — curriculum, modular-competence approach to learning, optimization criteria, modeling of the educational process.**

I. Introduction

One of the most promising methods of designing modern curricula, which forms the basis for the modular-competence-based approach in the education system, is the organization of a logically interconnected structure of disciplines to form general and professional competencies of students [1].

The main idea of combination of modular and competence-based learning approaches is to isolate as much as possible individual blocks (modules) of educational material in such a way that each module, in the studying process, ensures the achievement of some specific didactic goals.

It is obvious that the educational material covered by a separate module should be such a complete block that it would be possible to construct a single content from separate modules without violating the logic of the presentation of the material and at the same time could provide the required competencies of specialists.

II. The Formation of the Content of Modules

With the modular structure of the educational process, the following formal methodology for the formation of the content of subject modules is proposed.

A graph of the logical structure of the subject is built, in which not only intra-subject, but also inter-subject connections are indicated. Then in the individual educational elements that make up the structure of the module, are completely those topics taken from the graph of the logical structure that are necessary for the study of a specific educational element which enable its greater autonomy and achieve the completeness of the content of educational material in it. In this regard, in the content of the educational element, in addition to the above topics, topics from other subjects are also included, which were indicated by interdisciplinary connections.[2]

The essence of the method of forming the content of modules is the building of a goal tree of the educational process based on the specified criteria of specialist training in a specific specialty, in this case engineering specialists. The goal tree can have several hierarchical levels and is built in different ways.

In essence, the training criteria determine the competencies (knowledge, skill, ability) of graduates of a given specialty, and in accordance with this the goals of training specialists are set. In this case, each goal is associated with one or several disciplines of the curriculum, each of which, in turn, can be broken down into separate topics.

The volume of the curriculum in hours can be considered predetermined, and the task comes down to filling this volume with the most important content for a given specialty. As a rule, the educational process is based on two relatively equal semesters in duration (“autumn” and “spring”). In this regard, it is convenient to divide each discipline into K-hour autonomous elements. Accordingly, we can assume that the educational process goal tree should contain three levels:

- educational process goals,
- curriculum sections (modules),
- K - hour elements.

The input data are the coefficients of the relative importance of the educational process goals, as well as the weight of the second level goals relative to the first level goals. Considering these data, the coefficients of the relative importance of the second level goals are calculated, the weight of the third level goals is relative to the second level goals and the coefficients of the relative importance of the third level goals (K – hour elements), as well as the group weight of the curriculum elements. The given volume of the curriculum specified in hours can be easily translated into elements of the curriculum. Having placed these elements in descending group weight order, it is necessary to select the first R elements in the curriculum, where R is the volume of the curriculum in elements.

Further, to improve the quality indicators, an expert survey may be conducted on the connections between the elements selected in the curriculum. This approach does not consider the connections between modules that fall into the curriculum, which are assessed after the selection of the content.

In this regard, informational insufficiency may appear for the study of some modules, since the parent elements necessary for them as an information base may have an insufficiently high group weight.

III. Dividing the Curriculum into Semesters

To divide the curriculum into semesters, the following three-stage approach is proposed:

- At the first stage, the contours in the graph of the connections of the educational material are removed (the graph is built based on expert assessments). Arcs with the least weight are removed from the contours.
- At the second stage, the graph without contours is divided into layers.
- And, in the third stage, the elements of the curriculum are arranged according to semester.

At the third stage, for the first semester, the elements of the first layer are selected, then, if the semester is not full, the elements of the next layer are included in it so that the sum of the weight of the arcs is minimal in one semester. In this case, the optimization criterion is the sum of the weight of the arcs, which must be minimized. If the semester is overloaded, then the elements from it are transferred to the next semester according to the same rule i.e. those elements are transferred, the weight of the arcs is minimal. While creating appropriate software, this approach makes it possible to form not only a general curriculum for a given specialty, but also individual curricula within the framework of the modular-competence approach.

In essence, a two-stage task of optimizing the curriculum is posed. At the first stage, elements are selected into the plan according to the criterion of the maximum total group weight. At the second stage, connections are established between the elements selected in the plan, and the distribution of elements by semester is carried out according to the criterion of the minimum total weight of arcs from different layers that fall into one semester, and arcs from the same layer that fall into different semesters.

Within the framework of the formal statement of the problem, two integral criteria can be offered as optimization criteria:

- a criterion for minimizing time gaps between sections:

$$F_1 = \sum_{i=1}^{n} \sum_{j=1}^{n} l(i, j) \to \min ,$$

where ***n*** is the number of sections, $l(i,j)$ is the length of the arc between the sections ***i*** and ***j***;

- a criterion that considers the amount of forgotten information:

$$F_2 = \sum_{u_{i,j} \in U} \varphi_{i,j}(t) \to \min ,$$

where $\varphi_{i,j}(t)$ is the amount of forgotten information between sections ***i*** and ***j*** during time ***t***; ***u*** is a set of connections between sections.

IV. Mathematical Formulation of the Problem of the Curricula Synthesis

Suppose all the possible study content is presented as a set of disciplines which, in turn, consists of educational elements:

$$MOD = \{\alpha_{i,j}\}; \quad i = \overline{1, N}; \quad j = \overline{1, m(i)},$$

where $\alpha_{i,j}$ is the ***i***-th module of ***j***-th discipline, ***N*** - number of disciplines, ***m(i)*** - number of modules in the ***i***-th discipline.

It should be noted that considering the presence of a certain number of arbitrarily selected modules ("elective subjects"), the total volume of all modules exceeds the limited volume of the curriculum.

A curriculum on discrete time intervals will be called a set:

$$Cr = \varepsilon\{a(i,j) \in MOD \,|V_{Cr} \leq V_{MOD}\},$$

where V_{MOD} is the volume of all modules of the set ***MOD***, V_{Cr} is the volume of modules belonging to a subset of the curriculum.

Then the curriculum will be a subset of the ***MOD*** set, the total volume of modules does not exceed the limited volume of the curriculum.

The task of curriculum development gets to the following: initially, there is a volume of disciplines that exceeds the volume of the curriculum. Development of a curriculum means choosing the most important disciplines for a given specialty from the entire volume of disciplines and arranging them according to semesters in an optimal way.

To construct a solution to the synthesis problem, we introduce a discrete unit. An academic year is divided into two parts (semesters), each containing K weeks. Provided that each discipline is studied throughout the semester, it is convenient to select the section corresponding to one hour class per week during the semester as a minimum volume module. Therefore, as a standard module, a module can be chosen with a volume that is a multiple of K hours. Small deviations from the standard volume (particularly, in case of the differences of semester length (usually the final one) $K' < K$ weeks) can be considered insignificant.

The beginning and the end of the j-th semester will be noted by ***n (j)*** and ***k (j)***, respectively. They represent the week numbers, considering the holidays. We will start counting from week zero, which is the beginning of the first semester ***n (1) = 0***. The modules of the curriculum are interconnected, i.e. material from previously studied modules is used in subsequent modules. If module $\alpha_{j,r}$ uses information from module $\alpha_{i,l}$, then $\alpha_{i,l}$ is called an ancestor with respect to $\alpha_{j,r}$, and $\alpha_{j,r}$ - a descendant with respect to $\alpha_{i,l}$. Each arc connecting the modules is assigned a certain number that reflects the closeness of the connection. Then we get some graph, called the meaningful connections graph.

The closeness of the connection $P_{i,l;j,r}$ between modules $\alpha_{i,l}$ and $\alpha_{j,r}$ can be characterized by assessing what part of the entire lecture material from module $\alpha_{i,l}$ is used in the lecture material of module $\alpha_{j,r}$.

As mentioned above, the module $\alpha_{i,l}$ can be represented as a set of parameters and functions:

$$\alpha_{i,l} = \{x_{i,l,1}, x_{i,l,2}, x_{i,l,3}, x_{i,l,4}, x_{i,l,5}, x_{i,l,6}, x_{i,l,7}, x_{i,l,8}, x_{i,l,9}, x_{i,l,10}, F_{i,l,1}, F_{i,l,2}\},$$

where $x_{i,l,1}$ - the beginning of the module study (week number), $x_{i,l,2}$- the end of module study (week number), $x_{i,l,3}$ - coefficient of significance of module for professional training, $x_{i,l,4}$- the volume of lectures, $x_{i,l,5}$ – the volume of practical works, $x_{i,l,6}$ – the volume of laboratory works, $x_{i,l,7}$ – the volume of independent work, $x_{i,l,8}$ - the volume of individual lessons, $x_{i,l,9}$ - the coefficient of significance of the module for the study of subsequent material, $x_{i,l,10}$ – the coefficient of the generalized significance of the module, $F_{i,l,1}$ - descendants finding function, $F_{i,l,2}$ - ancestors finding function [4].

The coefficient of significance of module for professional training $x_{i,l,2}$ is determined by experts on a scale from 0 to 1 or reduced to this scale. The coefficient of importance of a module for studying other disciplines $x_{i,l,9}$ can be determined by the algorithm for leader election [3].

In this case, not only the contribution of the module to the study of its descendants is considered, but also to the modules studied later according to the logic of connections. To fulfil this, it is necessary to number all the modules, assigning one index to each. Let us consider the quantity of modules is M. Then the connectivity of the graph can be represented by a two-dimensional matrix A of dimension M x M [5], each element of which $a(i,j)$ is equal to the coefficient of closeness $P_{i,j}$ of the connection between the modules ***i*** and ***j***.

Let us introduce the notion of an iterated force of order ***k*** for module ***m*** $p^k(m)$. The iterated force of the module ***m*** of the first order characterizes the value of the contribution of the ancestor module to the study of its descendants and is equal to the sum of the connection weight emanating from it:

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

where $a(m,i)$ is the coefficient of connection closeness between the module-ancestor ***m*** and the module-descendant ***i***.

The iterated force of a second-order modules characterizes its contribution to the study of its descendants and second-generation descendants:

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

Usually, just a few iterations are enough to rank all the elements of the matrix. After the rank of the elements stops changing, it is possible to finish the calculations.

Then the force (importance) of the module ***m*** at $k \to \infty$ can be defined as the ratio:

$$x_{m,9} = \frac{p^k(m)}{\sum_{i=1}^{M} p^k(i)},$$

The value of significance coefficient for the study of descendant-modules is reduced to a scale from 0 to 1.

The generalized significance of the module $x_{i,l,10}$ is calculated by the formula:

$$x_{i,l,10} = \frac{A \times x_{i,l,3} + B \times x_{i,l,9}}{A + B}$$

Coefficients A and B are also set by experts depending on what is given significant importance - the consistency and degree of assimilation of the material or the total generalized importance of the training content for professional training. For an initial approximation, we can take ***A =1*** and ***B =1.***

For the convenience of presentation and software implementation, let us introduce the following parameters characterizing the module, which are easy to obtain from the above:

- the intensity of the lecture material study for module $\alpha_{i,l}$:

$$I_L(i,l) = \frac{x_{i,l,4}}{x_{i,l,2} - x_{i,l,1} + 1}$$

- the intensity of classroom lessons for the module $\alpha_{i,l}$:

$$I_A(i,l) = \frac{x_{i,l,4} + x_{i,l,5} + x_{i,l,6} + x_{i,l,8}}{x_{i,l,2} - x_{i,l,1} + 1}$$

- the intensity of independent work for the module $\alpha_{i,l}$:

$$I_S(i,l) = \frac{x_{i,l,7}}{x_{i,l,2} - x_{i,l,1} + 1}$$

- the intensity of individual lessons for the module $\alpha_{i,l}$:

$$I_I(i,l) = \frac{x_{i,l,8}}{x_{i,l,2} - x_{i,l,1} + 1}$$

Obviously, not every combination of the corresponding modules with their logical connections can be considered a permissible curriculum. Several restrictions are imposed on the curriculum arising from the organization specificity of the educational process, the main of which are:

- the calendar time for the completion of the implementation of any academic discipline section should not exceed the established training period ***t***:

$$\max_{\alpha_{i,l} \in Cr} \alpha_{i,l} \le t$$

- the number of disciplines ***N*** in the curriculum must have an upper limit ***K***:

$$N \le K \text{ where } N = |L| = \varepsilon\{l \mid x_{i,l,1} \ge 0 \wedge x_{i,l,2} \le d\};$$

- the number of disciplines in any semester ***Nₛ*** must have an upper limit ***Kₛ***:

$$\forall S[L(S) \le K_S]$$

$$\text{where } L(S) = |L_S| = \varepsilon\{l \mid x_{i,l,1} \ge n(S) \wedge x_{i,l,2} \le k(S)\}$$

- the number of teaching hours per week should not exceed the specified norm

$$\forall t\left[\sum_{i \in I} \sum_{l \in L} [I_A(i,l) + I_S(i,l) + I_I(i,l)] \le T\right]$$

$$\text{where } I = \varepsilon\{i \mid x_{i,l,2} \ge t \wedge x_{i,l,1} \le t\}$$
$$L = \varepsilon\{l \mid x_{i,l,2} \ge t \wedge x_{i,l,1} \le t\},$$

here ***t*** is the week number, ***T*** is the maximum number of hours per week

- on each academic week, the amount of classroom hours of classes should not exceed the weekly time resource of classroom sessions
- the beginning and the end of the any discipline study must be "inside" of any semester

$$\forall i \forall l \exists S[n(S) \le x_{i,l,1} \wedge k(S) \ge x_{i,l,2}]$$

- any discipline studied in more than one semester must be studied "continuously"

$$\forall S \forall k \forall t(I_d(l,S) \ne 0 \wedge I_d(l,S+t) \ne 0 \Rightarrow I_d(l,S+k) \ne 0)$$

where ***k*** and ***t*** are integers, moreover ***k*** < ***t*** and ***k+t*** < ***S***

- in one discipline per semester, plan either an exam or a test:

$$\forall l \forall S(K_t(l,S) = 0 \vee K_t(l,S) = 1)$$

where $K_t(l,S)$ is the control points of discipline ***l*** in the semester ***S***

- the number of exams in one semester should be not more than a given E_x

$$\forall S\left(\sum_{K_t(l,S)\in K_t(S)} 1 \le E_x \mid K_t(l,S) = 1 \right)$$

where $K_t(S)$ is the set of Semester ***S*** control points

- the number of testing, testing for term papers and projects, in one semester should be not more than a given Z_a.

$$\forall S\left(\sum_{K_t(l,S)\in K_t(S)} 1 \le Z_a \mid K_t(l,S) = 0 \right)$$

- the number of term papers and projects in one semester should be not more than a given K_p:

$$\forall S\left(k_p(S) \le K_p\right)$$

V. Development of Optimization Criteria

The task of optimizing the curriculum can be viewed from different points of view. Particularly, developing a curriculum, the synthesis problem is posed as follows: it is necessary to select the most important material for professional activity in the curriculum and arrange it in the optimal way by semester.

As a criterion characterizing the importance of the material in the curriculum for a specific specialty, the following functionality can serve, for example:

- a criterion that maximizes the total significance (for the professional training) of the modules included in the curriculum:

$$\sum_{\alpha_{i,l}\in MOD}^{n_m} x_{i,l,3} \to \max,$$

where n_m is the number of modules;

- criterion that maximizes the total generalized significance of the modules included in the curriculum:

$$\sum_{\alpha_{i,l}\in MOD}^{n_m} x_{i,l,10} \to \max;$$

- criterion for the optimality of the module arrangement by semester:

$$\sum_{i=1}^{n} \sum_{l=1}^{m} \sum_{j=1}^{n} \sum_{r=1}^{m} k(i,l;j,r) \times P_{i,l;j,r} \times [x_{j,r,1} - x_{i,l,2}] \to \min,$$

where $k(i,l;j,r) = \begin{cases} 0, & если \ x_{j,r,1} - x_{i,l,2} > 0, \\ -f, & если \ x_{j,r,1} - x_{i,l,2} \le 0, \end{cases}$

and the coefficient ***f*** in this case is determined from the ratio:

$$\forall i \forall j \forall l \forall r[\, f \times P_{i,l;j,r} \ge Q_{\max}.$$

Q_{max} is the maximum value of the criterion. It can be estimated based on the ratio:

$$Q_{\max} = \sum_{i=1}^{n} \sum_{l=1}^{m} \sum_{j=1}^{n} \sum_{r=1}^{m} P_{i,l;j,r} \times [k(n_{\max}) - n(1)],$$

where n_{max} is the number of the last semester.

VI. Conclusion

This construction of the educational process has its advantages and disadvantages. As an advantage, it can be pointed out that a sufficiently high level of flexibility is achieved, which is especially important with a modular training system. It is possible to move individual modules of educational material in time without analyzing their external relationships, since the modules are the most isolated and complete structures.

As a disadvantage, one can note the fact that the modules contain information that is not directly related to the discipline being studied. Moreover, the information of fundamental sciences for a given specialty (especially, engineering education - mathematics, physics, and other general technical disciplines) can be duplicated several times in different modules. This, of course, has a positive effect on the quality of the assimilation of the material, but it significantly reduces the total volume of educational material that can be placed in a limited amount of the curriculum.

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