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Automating the choice of the educational path in the Smart-education environment

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Abstract: The paper deals with the issues of choosing a learning path in the Smart-education environment. A methodology for choosing a path based on the use of decision support methods is proposed, which allows using both the experience and knowledge of experts in various areas of organization and provision of the educational process, and the wishes of the student himself. The proposed methodology allows you to automate the process of choosing the most rational learning path and reduce the time to make a decision.

Keywords: Smart education environment, learning path, decision support system, minimum distance.

1. Introduction

The intensity of the development of modern technologies dictates the need to revise the approach to educational standards, means, technologies, methods, the issue of organizing the educational process [1]. The new approach should provide a deeper assimilation of the material, reducing the time and cost of the educational process without compromising its quality. One of the ways to solve this problem can be the use of the Smart Education environment.

Smart education involves the use of a variety of educational elements in a single educational process: technologies, resources and tools. Researchers in the field of Smart education identify the following characteristics/elements of it [2]:
- use of a large number of information sources;
- continuous updating of educational materials;
- maximum variety of multimedia (audio, video, graphics);
- the ability of an educational institution to quickly and easily adapt to the level and needs of the student;
- high professionalism of teachers;
- combination of educational and scientific activities;
- personification of courses and discipline;
- creative approach to the learning process;
- use of Smart-tutorials;
- electronic library;
- automatic filtering by the level of mastering the material (knowledge rating);
- group work of co-authors and readers in the Internet space;
- virtual campus: e-library, interuniversity exchange of materials, e-learning, e-courses;
- interdisciplinary tasks;
- increase in the share of practical training;
- participation in current innovative projects: regional, sectoral, nationwide...

As one of the necessary elements of such Smart-education, the personification of the approach to the educational process is called, in particular, in work [2] - the personification of a set of courses and disciplines, in work [3] - the personification of the content of educational materials.

Using the principle of personification, the authors propose to develop and apply procedures for the formation and selection of individual educational paths that best meet the needs of students in order to increase the effectiveness of the learning process. Under the educational path we will understand the set and

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sequence of applied elements, technologies and teaching aids. On the basis of these data, the most rational path of learning can be formed not only for a specific student, but also for a learning group.

Let's consider in more detail the elements of Smart Education, which can be used in the formation of individual educational paths.

Element 1. A mandatory component of any educational process is the independent study of course materials by students. This can be done using a large number of different information sources [4].

Then, as the first group of elements of the path of Smart-education, we can call :

* standard familiar all textbooks and teaching aids, reference literature;
* scientific periodicals and conference proceedings;
* Internet resources, the list of which is formed by both the teacher and the students themselves;
* Numerous electronic materials and documents prepared by teachers and teaching assistants for better assimilation of the material: text files, presentations, statistical tables, multimedia materials (audio, video, graphics).

Element 2. The next important component of general education, including Smart education, is the way of organizing the learning process (types of learning sessions). Then, as the second group of elements of the Smart-education path, one can name:

* full-time listening to lectures;
* full-time participation in seminars;
* organization of full-time laboratory and practical classes;
* full-time participation in a master class with invited experts;
* participation in full-time student scientific and practical conferences;
* distance learning by viewing a case study materials;
* absentee homework assignments;
* group work of teachers and students in the Internet space;
* independent research on the subject proposed by the teacher;
* Participation in online events (webinars, conferences...);
* participation in business games;
* educational, scientific research and production practices;
* full-time consultations;
* correspondence consultations (on the forums, via e-mail, through instant messaging systems, through the information educational environment of the educational institution, through video conferencing systems).

Element 3. The third group of elements of the Smart-education path includes the size of the study group:

* the possibility of learning in a small group;
* the possibility of studying in a large group (with a flow of students);
* the possibility of individual training;
* alternation of these types of training.

Element 4. The fourth group of elements of the Smart-education path includes technologies for presenting the material. Each person has a different ability to memorize and preferences for the way of assimilation of new knowledge.

A properly selected individual technology of presenting knowledge gives the greatest effect for a particular person. Here we can name the following technologies for presenting knowledge:

* the predominance of visual information (textual, numerical, graphical);
* the predominance of audio information;
* Multimedia sources of information.

Element 5. Also in the learning process, it is necessary to organize the current and final control of knowledge. As the fifth group of elements, it is possible to use various methods of testing the student's knowledge:

* full-time performance of control work;
* face-to-face examination;
* full-time/correspondence testing;
* participation in business games;
* implementation of projects;

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Date of Publication:08-07-2022

* doing homework;
* defense of term papers;
* defense of interdisciplinary term papers;
* Evaluation of reports on various types of practices: educational; production; scientific research.
* final interdisciplinary examination;
* defense of final qualifying works.

Element 6. You should also choose the pace of delivery of the material for a particular student. The sixth group of elements can be the following option:
* slow with multiple repetitions of the material covered;
* standard with fixation of the main provisions;
* accelerated with an emphasis on self-preparation;
* student-adjustable (when ready, move on to the next section).

Element 7. One of the most important elements is the organization of the educational process in terms of the sequence and number of subjects studied at the same time. The seventh group of Smart-learning elements includes the following:
* semester system (a set of subjects studied in parallel for half a year);
* modular training (a small number of disciplines studied in a relatively short period of time 2-3 months);
* a sequential path of studying disciplines one after another (one discipline - a few weeks and the transition to the next one only after successfully passing the exam in the current one, otherwise re-study);
* individual training plan.

It should be noted that the set of elements and their content may vary depending on the educational institution, the type of educational program and the basic educational standard.

The goal of smart education is to bring the quality of the education provided and the quality of the education received into line [5]. The developed methodology for automating the choice of the learning path makes it possible to determine the most rational for the learner and teacher of the individual path of Smart-education, consisting of a certain set of e-learning. On the basis of the chosen path, scenarios of educational activities of all courses can be created that will captivate the student, encourage him to study and scientific activity [3].

As an experiment, Smart-University can organize a test period of study. For students in the initial period of study, Smart-University reveals the effectiveness of applying various elements of Smart-education in practice in order to choose the most rational path of learning in the future. For example, during several classes, consecutive full-time training is conducted, then distance learning, participation in mini-projects, business games is offered, the pace of delivery and the technology of presenting the material changes. why the study of the response of the participants in the educational process is carried out.

Formulation of the problem

The idea of the proposed methodology is to help the student build an individual learning path and form an individual case of learning materials, learning tools and technologies. Such paths can be built both for one course and for the entire educational program. Comparison of paths can be carried out either by the student himself, or by a group of experts using decision support methods.

The task of the university is to introduce Smart technologies into the educational process in the educational programs of basic and additional education. A group of experts should be formed, including methodologists, psychologists, teachers, curators, economists, administrative workers or other specialists at the discretion of the head of the educational program. A group of experts for each student should form a set of elements and paths of Smart-learning, based on an assessment of the university's capabilities and the results of some entrance testing/survey of the student and familiarization with his portfolio

The search for a solution to the problem posed is laborious. This problem can be classified as a multi-criteria decision-making problem under conditions of certain initial information, so it makes sense to automate the choice of a path based on the application of decision support methods. It is required to form a set of alternative solutions (educational paths) and criteria for choosing the most rational path under specific conditions.

The alternative solutions will be the learning paths formed by the experts. For example, one of the paths might look like this:

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Date of Publication:08-07-2022

Path 1

Element 1. Types of information sources: paper textbooks and teaching aids; scientific periodicals; author's teaching aids provided by teachers; Internet resources.
Element 2. Method of organizing the educational process: full-time classes (lectures, seminars, laboratory ...).
Element 3. Study group size: study in a larger group (with a flow of students).
Element 4. Technologies for presenting educational material: multimedia sources of information.
Element 5. Ways to test the knowledge of the trainee: full-time performance of control work; face-to-face examination; implementation of projects; final interdisciplinary examination; defense of final qualifying works.
Element 6. Material feed rate: standard with fixation of the main provisions.
Element 7. Priority of studying subjects: semester system.
Selection criteria are formed by experts on the basis of normative documents, professional experience, information about the possibilities and preferences of students, experience of previous years of study. As such criteria, one can name, for example, the following [2], [3]:
K1. Quality of education (complex criterion consisting of several nested sub-criteria):
K1.1. Fulfillment of the requirements of educational standards.
K1.2. The degree of development of professional competencies.
K1.3. The degree of development of universal competencies.
K1.4. The degree of achievement of the stated goals and learning outcomes.
K2. Accessibility of the elements of the educational path.
K3. The cost of education.
K4. The time spent on mastering the educational program (discipline).
K5. The degree of satisfaction of the expectations of the participants in the educational process from the provided educational services.
K5.1. Reliability of the received information.
K5.2. The fullness of the received information.
K5.3. The integrity of the received information.
K5.4. Clarity of the presentation of the material.
K5.5. Relevance of educational material.
When choosing a decision support method, it is necessary to take into account that the criteria for evaluating educational paths are both numerical and linguistic in nature, and the number of alternative educational paths, as a rule, is small (does not exceed 10), in accordance with the legend of experts. Since the decision on the choice of educational path can be made with the agreed opinion of all experts, it is advisable to use group methods of decision support [6].
Let us consider some of the methods used to coordinate group (expert) decisions.
The preference method is based on the ranking of all alternative paths performed by a group of experts [7]. Each expert independently performs the ranking of paths. If the opinions of experts differ greatly, then it is necessary to refine expert estimates until an acceptable value of the coefficient of consistency of estimates is obtained. The main difficulty of this method lies in achieving a given consistency of expert judgments.
A similar complexity arises when using the rank method (each expert builds the order of alternatives itself), which differs from the preference method only in the way of setting expert rankings [8].
The method of clustering expert assessments makes it possible to obtain coordinated expert assessments by means of a fairly complex iterative process of correction and coordination of expert positions.
This method requires specifying the degree of preference for an alternative in absolute units on given scales of criteria without a procedure for pairwise comparison of alternatives, which can lead to an error in evaluating alternatives, since this procedure is difficult for the decision maker (the person making the decision) according to the results of psychological research [9].
The minimum distance method makes it possible to find a compromise solution in terms of satisfying the opinions of all experts equally by using the procedure for pairwise comparison of alternatives by each expert and using these comparative estimates to learn The minimum distance method is quite easy to algorithmize, although the number of calculations can be large and depends on the number of alternatives. The procedures

ISSN NO: 2770-4491
Date of Publication:08-07-2022

used by experts in the method of minimum distance are admissible based on the results of psychological research.

In any case, the decision-making procedure should be automated, since it requires repeated application by experts who are not experts in the field of decision-making.

An example of solving the problem of choosing a Smart-learning path

Let's say five experts participate in the assessment. The experts formed a set of possible paths (T1, T2, T3, T4, T5) with specification by educational element. For definiteness, let's call this set of alternative paths the set of 1 alternatives. Suppose they formed the selection criteria: K1, K2, K3, K4.

To automate the procedure for selecting/ranking alternatives T1–T5, we use the minimum distance method based on the calculation of the Kemeny–Snell median, which is a ranking of alternatives with a minimum ranking sum of all expert distances. The desired matrix and ranking will show the preference for alternative paths for a particular student, ranking alternative solutions from best to worst.

At the first step of applying the method, each expert builds matrices Y for pairwise comparison of alternatives from set 1 according to a set of criteria.

If the expert finds it difficult to build such a matrix, then we can suggest that he look at the problem in more detail and first evaluate the importance of each of the alternatives for each criterion. To do this, it will be necessary to determine the importance of each criterion in the overall assessment of the alternative. The mutual importance of the criteria should be pre-evaluated with the participation of all experts in order to get an objective view of the problem from different points of view.

To automate the calculation of the criteria weights, one can apply the methods of supporting group decisions: the preference method, the rank method.

Consider the procedure for calculating the criteria weights based on the rank method. Let's assume that a decision maker, for example, the head of an educational program, appoints a group of five experts (kE = 5). Further, the decision maker can determine the importance of the vote of each expert. It can be of equal importance or different.

In the second case, it will additionally be necessary to calculate the coefficients of expert competence using, for example, the rank method.

According to this method, the decision maker sets the numerical assessments of the competence of experts (C_{Ei}) on a ten-point scale, on the basis of which it is possible to calculate their competence coefficients (W_{Ei}) according to the formula $W_{Ei} = C_{Ei}/\Sigma$, where Σ is the sum of all For example, the decision maker determined the following numerical assessments of the competence of the experts' votes (Table 1, first line), the sum of which will be 43 points (see Table 1 - last column), and the coefficients of competence WEi are calculated in line 3 of Table 1.

Next, five experts must form the weights of the criteria. The procedure for determining the weights was considered by the authors in [10]. Let five experts (i = 1, ..., 5) choose four criteria (j = 1, ..., 4) for consideration and form the following decimal ratings (R_{ij}) of the criteria (Table 2, integer values) .

Then we calculate the weighted estimate C_{Kj} of the K_j criterion, taking into account the coefficient W_{Ei} of the competence of each expert according to the formula $C_{Kj} = W_{Ei} \bullet R_{ij}$ (see Table 2, decimal values in brackets).

Next, the sum of the weighted criteria scores is calculated according to the formula SK = ΣC_{Ki} = 29.47 and the criteria weights according to the formula $W_{Ki} = C_{Ki} /S$K (see Table 2, last line). According to the obtained weights, it is possible to build criteria by importance (from best to worst): K3, K1, K2, K4. Using these assessments, experts can explore in more detail the mutual importance of alternative learning paths.

Table 1 : Calculation of the importance of expert votes

i	1	2	3	4	5	∑
C_{Ei}	10	8	9	9	7	43
$W_{Ei} = C_{Ei}/\sum$	0.24	0.19	0.21	0.21	0.16	1.00

Table 2 : Expert assessments R_{ij} of the importance of criteria

i	W_{Ei}	R_{ij} ($C_{kj} = W_{Ei} . R_{ij}$)			
		j = 1	j = 2	j = 3	j = 4
1	0.24	8(1,92)	9(2,16)	6(1,44)	5(1,25)
2	0.19	5(0,95)	7(1,33)	8(1,52)	9(1,71)

 ISSN NO: 2770-4491
Date of Publication:08-07-2022

3	0.21	9(1,68)	6(2,26)	8(1,68)	9(1,89)
4	0.21	9(1,68)	7(2,47)	8(1,68)	9(1,05)
5	0.16	9(1,28)	7(2,12)	9(1,44)	6(0,96)
Weighted score		7,51	7,34	7,76	6,86
Criteria weights		0.25	0.24	0.26	0.23

Ultimately, the experts must form matrices $Y^1 \div Y^5$ of pairwise comparison of alternatives from set 1. In the matrix, each element y_{ij} shows the mutual importance of the path T_i with respect to the path T_j according to the following (1) worse (–1), is equivalent to (0). Let, for example, the following evaluation matrices be obtained:

$$\mathbf{Y}^1 = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 \\ -1 & 0 & -1 & 1 & 1 \\ -1 & 1 & 0 & 1 & 1 \\ -1 & -1 & -1 & 0 & -1 \\ -1 & -1 & -1 & 1 & 0 \end{pmatrix} \quad \mathbf{Y}^2 = \begin{pmatrix} 0 & -1 & 1 & -1 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & -1 & 0 & -1 & 1 \\ 1 & -1 & 1 & 0 & 1 \\ 0 & -1 & -1 & -1 & 0 \end{pmatrix} \quad \mathbf{Y}^3 = \begin{pmatrix} 0 & 1 & 0 & 1 & 1 \\ -1 & 0 & -1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 \\ -1 & -1 & -1 & 0 & -1 \\ -1 & -1 & -1 & 1 & 0 \end{pmatrix} \quad \mathbf{Y}^4 = \begin{pmatrix} 0 & -1 & 1 & 1 & -1 \\ 1 & 0 & 1 & 1 & -1 \\ -1 & -1 & 0 & -1 & -1 \\ -1 & -1 & 1 & 0 & -1 \\ 1 & 1 & 1 & 1 & 0 \end{pmatrix}$$

$$\mathbf{Y}^5 = \begin{pmatrix} 0 & 1 & -1 & 1 & 0 \\ -1 & 0 & -1 & 0 & -1 \\ 1 & 1 & 0 & 1 & 1 \\ -1 & 0 & -1 & 0 & -1 \\ 0 & 1 & -1 & 1 & 0 \end{pmatrix}$$

For each matrix $Y^1 \div Y^5$, the ranking of alternatives is calculated according to the rule: all elements in the rows of the matrices are added, and in the ranking the alternative with the maximum amount is considered the best, and the worst - with the minimum, equivalent - with the same amounts. Based on these matrices, it is possible to draw a conclusion about how each of the experts ranked the available paths in order of importance:
* expert 1 ranking (by Y^1 matrix) = T1, T3, T2, T5, T4;
* expert 2 ranking (by matrix Y^2) = T2, T4, T3, [T1, T5] (alternatives T1 and T5 are equivalent);
* expert 3 ranking (according to matrix Y^3) = [T1, T3], T2, T5, T4 (alternatives T1 and T3 are equivalent);
* expert 4 ranking (by Y^4 matrix) = T5, T2, T1, T4, T3;
* ranking of expert 5 (by Y^5 matrix) = T3, [T1, T5], [T2, T4] (alternatives T1 and T5 are equivalent and alternatives T2 and T4 are equivalent).

Next, it is required, taking into account all the opinions of experts, to calculate a new ranking of alternatives, the closest to all the indicated rankings. To do this, we calculate the final matrix of estimates Y, equidistant from all five matrices $Y^1 \div Y^5$. For the new matrix Y, the assertion will be true that the sum of moduli of the differences of its elements and the elements of any of the matrix $Y^1 \div Y^5$ must be minimal.

The calculation of such a new matrix occurs by the method of enumeration of all existing matrices with zero main diagonal and skew-symmetric relative to it (the value "1", which is above the diagonal, symmetrically, which is "-1", which is symmetric, and vice versa). It is most convenient to perform such an enumeration programmatically. Based on the new calculated matrix Y, a new ranking is built for the given alternatives according to the degree of preference.

However, there may be several such equidistant matrices, as well as several rankings of alternatives by preference.

According to the initial data, the program calculations give the following result. The list of the most preferred alternative paths with decreasing preference will be as follows:
* T1, T3, T2, T5, T4;
* T3, T1, T2, T5, T4.

This means that the most preferable (and equivalent) are the alternatives T1, T3, i.e. it is necessary to choose the only one from several equivalent alternatives - the most suitable for the student. For definiteness, let's call this new list of alternative, but equal in preference paths, a set of 2 alternatives.

ISSN NO: 2770-4491
Date of Publication:08-07-2022

Since the experts have already taken part in the selection, it remains to give the right to decide to the learner himself. If he finds it difficult to make a choice, then one of the methods of supporting the adoption of individual decisions can help him. The most appropriate method is the method of analytical hierarchies [6], since it is applicable in the case of a small number of alternatives (in the worst case, this number will be equal to the number of experts) and, in the case of a small number of selection criteria (formulas expected, and most likely their number will also not be too large). Also, the advantage of this method is its visibility and ease of use by non-specialists in the field of decision making. Let us consider an example of the application of this method.

If you run the program with the following initial data - the rankings of five experts:

* Expert ranking 1 = T5, T2, [T1, T3], T4;
* Expert ranking 2 = T2, T4, T3, [T1, T5];
* Expert ranking 3 = [T1, T3], T2, T5, T4;
* Expert ranking 4 = T5, T2, T1, T4, T3;
* Expert ranking 5 = T3, [T1, T5], [T2, T4],

then we get the following result for the desired most preferred rankings:

* T5, T2, T3, T1, T4;
* T2, T3, T5, T1, T4;
* T3, T5, T2, T1, T4.

Since the above rankings indicate different alternatives (T2, T3, T5) as the most preferable path, additional procedures for choosing one of them are required.

Let's assume that the trainee, for deciding on the choice of one of three (or more) paths, compiled a list of the most important selection criteria for himself:

K1 - minimum cost of training; K2 - minimum training period; K3 - training intensity (preferably full-time classes); K4 - types of information sources (preferably electronic textbooks and Internet resources); K5 - minimum size of the study group.

These criteria may repeat completely or partially the criteria for estimating paths from set 1 mentioned above by experts, or may be completely different from them. In the case where the criteria are partially or completely repeated, a situation is possible in which all selected as the best alternative paths from set 2 meet the repeating criteria, since the experts conducted the selection taking into account the opinion of the trainee. Then, after analyzing the composition and structure of the path elements from set 2, it is possible to remove the indicated criteria from the list, thereby reducing the number of criteria and simplifying the selection problem.

Assume for definiteness that all alternative paths of set 2 (T2, T3, T5) satisfy criteria K3 and K4. Then, deleting the indicated criteria from consideration, we will form the final list of criteria for choosing the most preferable alternative from set 2:

K_1 - minimum cost of training; K_2 - minimum training period; K_3 - smallest size of the study group.

For simplicity of calculations, we rename the available alternatives:

A_1 - path T2; A_2 - path T3; A_3 - path T5.

For the remaining criteria in the method of analytical hierarchies [8], as in most support methods, the student is asked to evaluate the mutual importance from his point of view of each of the criteria, and according to the result of the assessment, fill in the matrix X of the mutual preference criteria (2). In it, instead of the element X_{ij}, the degree of superiority of the criterion K_i over the criterion K_j is indicated. We will use the scale of relative importance of criteria K_1, K_2, K_3: equal importance - 1, moderate superiority - 3, significant and strong superiority - 5, significant superiority - 7, very large superiority - 9, for example, if x_{ij} = 5, then X_{ji} = 1/5 and always X_{ii} = 1:

$$X = \begin{pmatrix} 1 & 9 & 5 \\ 1/9 & 1 & 1/7 \\ 1/5 & 7 & 1 \end{pmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

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Date of Publication:08-07-2022

According to the matrix X (2), we find the value of each criterion by the formula
$C_{ki} = \sqrt[3]{P_j X_{ij}} \quad (i = 1 \ldots 3, j = 1 \ldots 3)$.
We get the following values:
$C_{K1} = 3.56$; $C_{K2} = 0.25$; $C_{K3} = 1.12$. The sum of criteria values is CK = 4.93.
Next, we calculate the weight of each criterion according to the formula :
$W_{Ki} = C_{Ki} / CK$. We get $W_{K1} = 0.72$; $W_{K2} = 0.05$; $W_{K3} = 0.23$.
Now we will compare three alternatives from set 2 by the method of analytical hierarchies, for which we will construct three more pairwise comparison matrices (Z^1, Z^2, Z^3) of mutual preference of alternatives for each of the three criteria:

$$Z^1 = \begin{pmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 1/7 \\ 1/5 & 7 & 1 \end{pmatrix} \quad Z^2 = \begin{pmatrix} 1 & 1 & 7 \\ 1 & 1 & 1/5 \\ 1/7 & 5 & 1 \end{pmatrix} \quad Z^3 = \begin{pmatrix} 1 & 1/3 & 1/5 \\ 3 & 1 & 1/7 \\ 5 & 7 & 1 \end{pmatrix}$$

….(3)

In each matrix Z^k, in place of the element Z^k_{ij}, the degree of superiority of the alternative A_i over the alternative A_j according to the criterion A_k is indicated. We will use the same scale of relative importance as for comparing criteria. Then, by analogy, we calculate the weight W^k_i of each *i*-th alternative for each *k*-th criterion:

$$W_1^1 = 0.63 \qquad W_2^1 = 0.09 \qquad W_3^1 = 0.28$$

$$W_1^2 = 0.57 \qquad W_2^2 = 0.17 \qquad W_3^2 = 0.26$$

$$W_1^3 = 0.09 \qquad W_2^3 = 0.17 \qquad W_3^3 = 0.74$$

Next, you should calculate the value of each alternative, taking into account the weights of the criteria according to the formula:

$$U_{Ai} = \sum_{j=1}^{3} (W_{kj} \,.\, W_i^j); \qquad U_{A1} = 0.50\,, \qquad U_{A2} = 0.11\,, \qquad U_{A3} = 0.39$$

Comparing the resulting weighted estimates of alternatives from set 2, one can easily choose the most preferable of them according to the maximum weighted estimate. In this example, this turned out to be alternative A1 - path T2 (value = 0.50).

Conclusion

The use of the proposed methodology makes it possible to obtain a holistic description of the learning path, which represents the most rational combination of educational elements that ensure the achievement of the specified criteria for evaluating learning outcomes.
The recommendations received will allow teachers to build the most rational way for the learning process both individually with each student and with the study group.
An important advantage of the proposed methodology is the possibility of automating the process of choosing an educational path, taking into account the characteristics of a particular student, as well as the capabilities and requirements of the university.

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