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Gulnaz Zunimova
Master of Science, Assistant professor of the Department of Information Systems
zunimova.g.d@mail.ru, orcid.org/0000-0003-1571-7111
S. Seifullin Kazakh Agrotechnical University, Kazakhstan

Gulzhan Soltan
PhD, Associate professor, Director of Academic Department
gsoltan@mail.ru, orcid.org/ 0000-0002-1603-7524
Astana IT University, Kazakhstan

Dzmitry Likhacheuski
PhD, Associate professor, Dean of the Faculty of Computer-Aided Design
likhachevskyd@bsuir.by, orcid.org/0000-0002-9944-4036
Belarusian State University of Informatics and Radioelectronics, Belarus

Nazym Issayeva
Master of Applied Mathematics and Computer Science,
Senior Lecturer of the Department of Pre-university Education
i.nas@mail.ru, orcid.org/0000-0003-2680-3007
Al-Farabi Kazakh National University, Kazakhstan

INFORMATION-LOGICAL MODEL OF EDUCATION OPTIMIZATION IN REMOTE MODE

Abstract: The educational optimization process is widely researched in the theoretical aspect. Analyzing existing sources made it possible to highlight the research issues: the need to create an optimizing distance studying model, in which work with weaker students becomes possible both within the educational process and in individual or group independent work. The study aims to develop an information-logical model for optimizing distance studying. This model should provide for the learning process organization in such a way as to strengthen the weaknesses of students, reveal their potential and focus on the comprehensive development of knowledge and skills. The task formalization is carried out using the Hungarian algorithm and Boolean variables. The main work limitation is the operation with integers. Discreteness manifests itself already at the modelling stages in many problems, for example, when working with Boolean variables. An example with the most straightforward information model construction using the logical functions "true/false" with the transition to a chain of matrices is given. It demonstrates the studying optimization algorithm and presents an expanded information-logical model. The presented model was preliminary tested in one of the academic groups of the S. Seifullin Kazakh Agrarian Technical Research University. Students' knowledge inspections were carried out at the approbation beginning. Then a student group working on a student project was divided into subgroups according to the algorithm. The knowledge inspection showed an 11.3% improvement in results at the work's end. Further research on this topic may consist of expanding the presented model's capabilities and developing appropriate modules for knowledge control and algorithmization of related tasks.

Keywords: knowledge management technology; integers set; Hungarian algorithm; Boolean variable; discreteness; logical function; educational process optimization model.

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Introduction

Today's students face the challenge of acquiring knowledge and practical skills under conditions that are sometimes far removed from the classical notion of the educational process. Scientific progress, new information opportunities and limitations brought by COVID-19 led to the active implementation of distance studying mode [1]. This mode differs in its methods from full-time and part-time education forms.

Education optimization is a complex and multifaceted process. It is considered through the criteria of rational distribution of time, changes in the system's structure, and the volume and efficiency of knowledge [2]. At the same time, distance learning imposes requirements for optimizing the learning process and puts forward new criteria. For example, the criteria of the irreversibility of the development of information and communication technologies in the educational process, increasing the efficiency of students' independent work efficiency and the objectivity of distance assessment of the knowledge obtained were highlighted [3].

Knowing that optimization is the choice of the best element by some criterion from the set of available alternatives [4], educational optimization can be seen as a reasonable choice of approach to the material presentation of successful tasks implementation [5] and labor costs rationality of participants in the studying process.

The topic's relevance is that, despite the in-depth theoretical study of educational process optimization, the practical aspects of the best choice models of approaches to the material presented, the existing works paid little attention. The reason for this can be explained by the fact that society has been using the best practices of innovative teachers, based on their direct pedagogical experience, to optimize learning for a long time. Society's digitalization, the acceleration of information introduction and communication technologies into every citizen's life, and the forced isolation in the quarantine period have led to a new educational process implementation based entirely on computer technology usage. This form required new management solutions based on mathematical calculations and algorithmization. The above reveals the study problem: developing and improving the evidence base for distance studying optimization.

Literature review and problem definition

The educational process of a higher educational institution has one or more implementation models. They depend on the form of implementation and the specialties for which training is conducted. This is a generalized educational service product considering the actual level of didactic and methodological teachers' competence [6]. This product acts as a system reflecting the approach to education and as a standard by which the goals and its content are defined [7]. But all the above mentioned has only theoretical justification.

Given the sources [5]–[6], there is a problem of optimizing the model based on people's knowledge and skills. Based on the theory of pedagogy [8], we conclude that it is possible to optimize through the prism of continuity and transfer of pedagogical experience to colleagues [9]. However, this only applies to those methods that do not involve using information technology and formalizing theoretical pedagogical models.

The existing models of learning optimization are mainly focused on knowledge management [10]. Developments in this area have made it possible to create knowledge management technology (KM) [11]. This enabled the developers to quickly adapt the system of obtaining education to work in distance mode during the quarantine measure since the basis of formalization of educational activities has been developed. Foreign platforms with tools allowing specific models to optimize the distance studying process – Convera, Autonomy, FAST, Hummingbird, Exalead, etc. are currently presented on the world market [12, 13]. However, these models are adapted to Western educational standards. They are frequently commercially confidential, and the tools are available for use only after payment in advance.

One of the models of studying optimization available for analysis is the model based on ontologies. The formation of this model was based on thesauruses [14], having systematization by individual constructs. It allowed to automate this process more efficiently and to create a system that is equally effective both in the classroom in full-time training of students and distance learning, including specialized courses with advanced training in various disciplines.

A network graph can represent model formalization with ontologies [15]. On the graph, it is possible to trace transparent relationships and support hierarchy between objects, which provides the observance of information structure during its processing and optimization, including a large amount of heterogeneous information during interdisciplinary relationship optimization. This is important, especially when implementing any interdisciplinary educational project requiring knowledge and skills in different disciplines. The ontological approach [16] is based on the mechanism of dynamic formation and the use of hierarchies in the form of taxonomies [17]. Information is organized, classified, and reflected in an ordered set of information resources. It optimizes the search for information and its retrieval by students and the learning process as a whole.

Analyzing the ontological graph [15], it is possible to see the vertices and the terms-objects of the corresponding ontology related to this vertex (Figure 1). To get the information, it is necessary to walk through the hierarchical relationships between different object classes and make transitions on the specified links. But let us assume that a non-empty set of objects does not meet the requirements [11], in particular: there is no definite hierarchical structure of a finite set of concepts concerning the object of research, there is some free interpretation of concepts and relations, interpretation functions are not formalized, axioms are not defined. In such case, information processing and formalization can be carried out with the help of logical or Boolean programming methods [18], which will allow to optimize training according to the rules set by the standard. For this purpose, first, a sample of information that explicitly or implicitly relates to the subject of the query is performed, then functional transformations using fuzzy logic and the construction of the solutions in the form of linguistic rules-products [16].

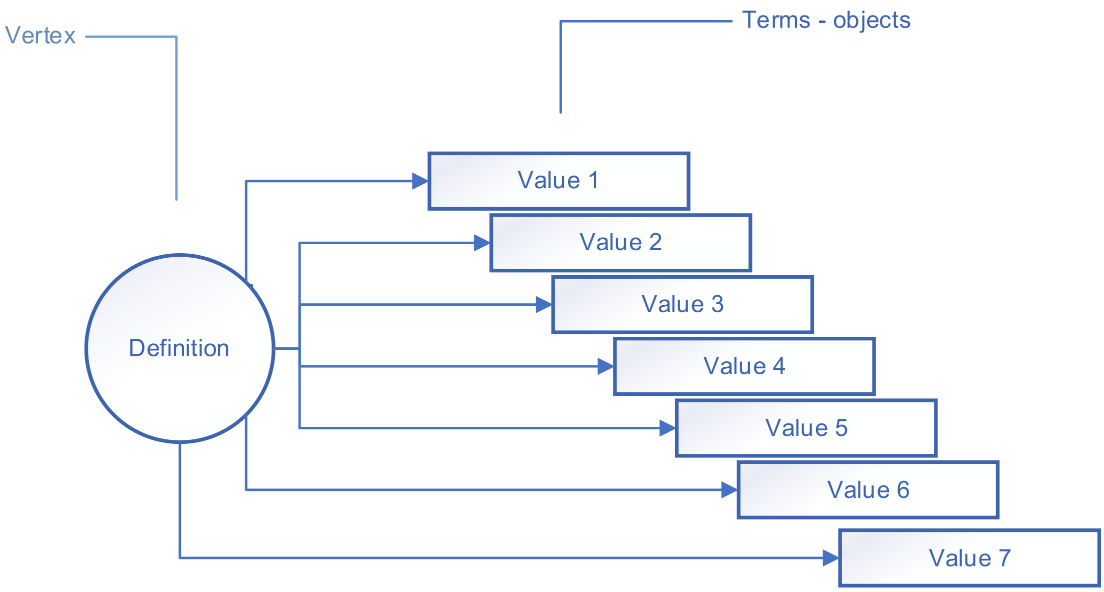

Figure 1. Model diagram of an ontological graph

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The studying optimization model using ontologies can be applied in any distance education system. As a result, the educational service will contain not just arrays of information structured by the subject but formed arrays of data based on symbolic transformations.

However, there are significant disadvantages to using this model:

For each academic discipline, it is necessary to create its system of ontologies. Accordingly, for each educational institution, it makes sense to develop its own model rather than to use a ready-made model with modifications and adaptation to the requirements of universities;

This model assumes that all students, without exception, have approximately the same knowledge and skills. In this case, relatively weak students will immediately move into the group of those who the system will screen as failures without a chance to improve their level of knowledge.

The last point is especially relevant when the institution operates in a distance mode. The teacher cannot give sufficient attention to students falling behind, delegating the problem to the field of self-directed solutions.

Based on the above, we see the need to develop such a model of distance learning optimization, in which the task of working with weaker students would be possible as part of the learning process, as well as in the course of individual or group work.

Aim and objectives of the study

The outlined problem has one significant addition - work optimization with weaker students is not an end in itself of the developed model. That is why the work aims to create an information-logical model for optimizing distance studying, which will organize the educational process to strengthen the weaknesses of all students, reveal their potential, and orient them to the comprehensive development of knowledge and skills.

Based on the aim, we formulated the following objectives of this study:

- To formalize the distance studying optimization model;
- To present possible solutions to the training optimization with an analysis of the factors that significantly affect the model;
- To present the information-logical model of distance studying optimization block diagram.

Materials and Methods

When modelling various instructional optimization problems, there is a requirement that some controlled variables belong to a special set. For example:

1) A set of integers – the students' number in the group, the subgroup working on a training project, the number of workstations in the laboratory, the number of computers to perform the programming task, etc.
2) The set of discrete values are standard values in the educational process tasks, fixed in advance (the number of students succeeding, the number of students not present in class, etc.)

In such tasks, we have to look for variable values that are not real numbers [18]. The variables sought must belong to a pre-fixed set of values D.

The study's methodology is based on the fact that these problems can be solved by mathematical optimization problems with a linear objective function and constraints [19]. With Linear Integer Programming (LIP) we can represent an NP-hard problem [20], with an algorithm in which the variables take two values, {1} and {0}, treated as "true" and "false".

Based on [12, 18] and using the approach of [21], both universal methods and specific optimisation methods can be used to solve such problems. Using the above methods simultaneously is the most interesting approach. For example, using a problem of the form:

$$L = \sum c_j x_j \to \min \tag{1}$$

$$\sum a_{ij} x_j \le b_i, i = \overline{1,m} \tag{2}$$

$$x_j \in Z, j = \overline{1,n} \tag{3}$$

where:
L – target function;
x_j – a free variable with any sign;
c_j – basic variable;
Z – certain set;
a_{ji}; b_i – free members acting as limitations of the set problem.

Based on models (1)-(3), both integer and partial integer solutions can be obtained. In the latter case, expression (3) will have $n_1 < n$ instead of n.

If Boolean variables belonging to the set $\mathrm{B} = \{0,1\}$ are used, the constraints will take on a logical character. But acting on these variables in models (4) to (6) will introduce an additional requirement:

$$x_j \in \{0,1\} \tag{4}$$

Suppose all variables turn out to be Boolean. In that case, problem (1)-(4) will be a linear Boolean programming (LBP) problem, which will eventually allow the optimization model to use Boolean logic in statements and rule formation. In this case, the model of studying process optimization, with its formalization and algorithmization, can approach the parameters of an intelligent computing system. In addition, efficient fast algorithms (including those with "hardware support") have been developed for LBP [21, 22], which makes it possible to obtain an automated process control system in a fairly short time.

Developing an algorithm to optimize learning using universal and specific methods will not only automate a particular learning model, but also solve the complex LIP problem using LBP. That is, to control and manage the learning process in a timely manner using the criteria of the NP-hard task [20] and to exclude unacceptable or subjective decisions. The complexity of the algorithm depends on the learning effectiveness matrix – that is, the number of elements used to compile the full set of characteristics of an effective learning process. The Hungarian algorithm [23] can be used to simplify the actual algorithmic process of this problem. This solution allows implementing the proposed algorithm as an additional module for distance learning platforms.

The information-logic model of distance studying optimization can be considered through the most common tasks of the educational process, which are solved by means of discrete programming.

Students' knowledge assessment has firmly entered the practice of higher education to conduct a knowledge cross-section in various disciplines. Using a grade sample by the results of various tests, you can build a simple information model of the knowledge level using logical functions "true/false" (Table1).

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Table 1. Information model of the students' knowledge level

Students / Disciplines	Student A	Student B	Student C
Sciences	true	false	true
Technology	0	true	true
Engineering	true	0	false
Mathematics	true	0	true

For illustration, the distribution of disciplines is done by category STEM (S – science, T – technology, E – engineering, M – mathematics). STEM-education – different sciences integration, which allows the modernization of methodological foundations and the technologization and optimization of the educational process [24]. When implementing STEM at the higher (professional) level, this approach allows the implementation of various methods to optimize the educational process and realize all kinds of innovative projects, including remote mode.

Based on Table 1, we can conclude that Student C has the highest average score of the given group, and Student B is the laggard. Therefore, it is possible to accept the numerical evaluation of the received scores:

- true – a student has a grade for the test in the discipline $x \geq 4$;
- false – a student has a grade for the test in the discipline $x = 3$;
- 0 (zero) – test failed.

As a result, we can assign several points and calculate the highest score (Table 2) by distributing students to complete some projects so that, on average, each group has the same number of points.

Table 2. Number of points scored by students

Students / Disciplines	Student A	Student B	Student C
Sciences	4	3	4
Technology	0	4	4
Engineering	4	0	3
Mathematics	4	0	4
The amount of points scored	12	7	15

However, this approach will lead to approximately the same problem that was revealed in the analysis of works [15, 16]: some of the lagging students will be not allocated in groups and will lose the chance to catch up with the lost knowledge. For example, student B (Table 2) by the number of points is at a level that does not allow to work on equal terms with students A and C.

The information-logical model proposed below is based on the Hungarian algorithm [23]. To implement it, remember that if the matrix *C* in the original problem is not square, it is necessary to augment it to a square by zero elements.

We assume that the preliminary transformations of the efficiency matrix *C* of this problem have already been performed, and a non-negative matrix D containing at least one zero element in each row and each column has been obtained. Then the model can be algorithmized as follows:

Step 1:

a) Mark (for example, with an asterisk) some zero in the first column of matrix D (0*); mark with an asterisk some zero in the second column which does not lie in that row where 0* from the first column lies (if such a zero in the second column can be found); mark with asterisk one of the zeros in the third column, lying in the row where there are no zeros with asterisk yet (if such a zero in the third column can be found); and so on, until pass all columns of the matrix.

b) If the zeros number marked with an asterisk equals *n*, the process is over: the places occupied by zeros with an asterisk correspond to *n* variables x_{ij}, equal to 1, in the optimal solution of the original problem.

c) If the zeros with an asterisk are less than n, then go to Step 2.

Step 2:

a) Mark (for example, with "+" at the top) columns of the matrix that have 0*, and consider these columns occupied.

b) During the process, occupied rows will also appear. Elements at the intersection of an unoccupied column and an unoccupied row will be considered unoccupied, the remaining elements will be occupied.

c) If there are no unoccupied zeros in the matrix, go to Step 5.

d) If there are unoccupied zeros, choose the first of them (by looking through the matrix rows from left to right in turn). Then, mark it with some intermediate sign (e.g. a dash - 0'). If his row does not contain zero with an asterisk, go to Step 4; if his row contains 0*, go to Step 3.

Step 3: free up (remove the "+" sign and consider it unoccupied again) the column that contains 0*, which lies in the same row as the zero just marked with a stroke. Next, mark (for example, with the "+" sign on the right) the row that contains 0' and consider it occupied. Go back to point c) of Step 2.

Step 4: Starting from the 0' just marked, build a chain of zeros: from that 0' down the column to 0*, from it down the row to 0', and so on, as long as possible. The chain will break at some 0'. Remove the asterisks from the zeros in the chain and replace the strokes from the zeros in the chain with asterisks. The new set of zeros with asterisks contains one more than the previous one and is also correct.

Remove all marks except the asterisks and go back to part b of Step 1.

Step 5: Find the minimal element among unoccupied matrix elements (let it be h), subtract it from all unoccupied rows, and then add it to all occupied columns. No marks are removed. A matrix equivalent to the previous one containing unoccupied zeros is obtained. Go back to step d of step 2.

A block diagram of the implementation of this model in steps is shown in Figure 2.

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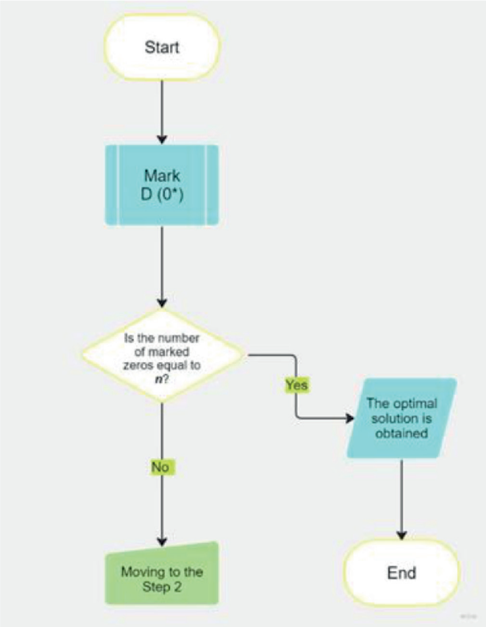
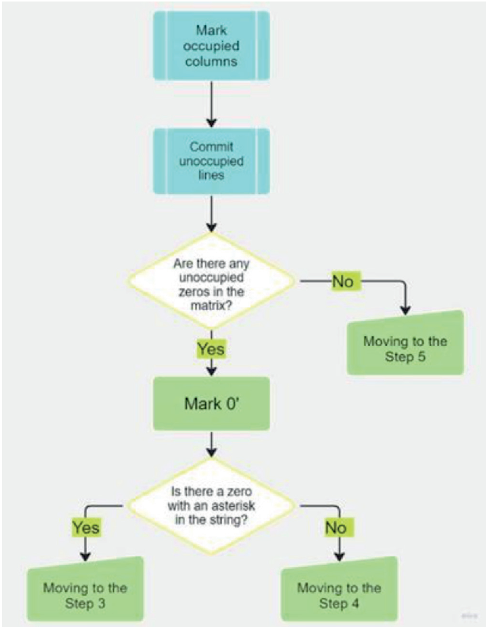
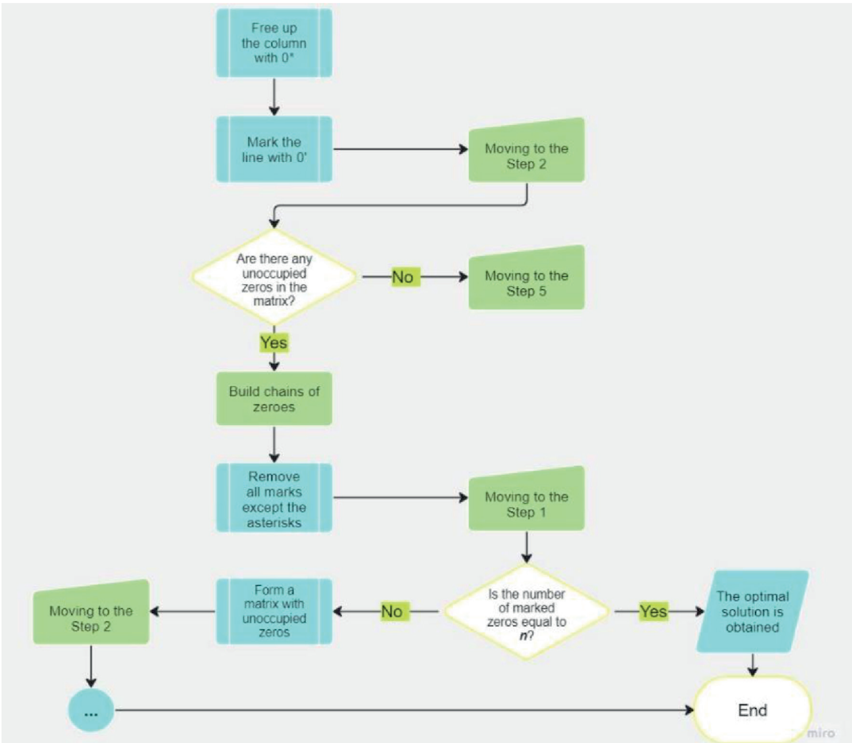


a) Step 1



b) Step2



c) Steps 3 – 5

Figure 2. Block diagram of the studying optimization model implementation

The informal meaning of the above algorithm consists of successive transitions from one correct incomplete choice of zeros (Figure 2a) to another (Figure 2b) containing one more zero than the previous one until a complete, correct choice is obtained (Figure 2c). At some stages, it may be necessary to switch to a new matrix equivalent to the previous one (Figure 2fic transition from Step 2 to the end of the algorithm).

Let's consider an example of using the algorithm. Assume that multiple project assignments can be accomplished by students possessing a particular level of knowledge and skills Assign-

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ing projects to students based on the group's academic journal may result in a student with a lower level of knowledge being selected to complete a more difficult project. A student with a high level of knowledge may be assigned a relatively easy project, which may not stimulate their intellectual curiosity or foster the development of their knowledge and skills. Students' knowledge can be represented criterion-wise by the number of points obtained in subjects whose knowledge is required to complete projects. Assuming that there are five students and five projects, represented as an array. Find the optimal assignment if the efficiency matrix is as follows:

$$\begin{pmatrix} 2 & 3 & 3 & 5 & 4 \\ 4 & 2 & 4 & 6 & 2 \\ 2 & 2 & 2 & 4 & 3 \\ 4 & 3 & 4 & 3 & 5 \\ 0 & 1 & 0 & 2 & 0 \end{pmatrix}$$

We present a chain of matrices obtained in solving the problem with corresponding marks according to the proposed algorithm (Figure 1). The rank of the matrix is 5. The process will be completed at the last step, resulting in $n = 5$ zeros with an asterisk. The determinant of the matrix is 28. Optimal prescribing options: $x_{15} = x_{24} = x_{31} = x_{43} = x_{52} = 1$, others $x_{ij} = 0$, i.e., the first student is assigned to the fifth project, the second to the fourth, the third to the first, the fourth to the third, and the fifth to the second. In the same way, roles can be distributed in one project. Then each student can do the best on the work for which they have a higher score and, in conjunction with other students, can raise the knowledge level on those works for which they have a lower score.

The model shown in Figure 1 can be supplemented by determining the minimum number of students who could complete a given project with the best result. For this purpose, using the approach [15], we represent the selection system as a graph with edges and nodes, similar to an ontological graph. To solve this problem, we need to find a subset of edges which is incident to any vertex of this graph and, at the same time, minimize the number of the edges in this subset. Then if j is the number of edges and Π is the set of edges, then

$$x_j = \begin{cases} 1, j \in \Pi \\ 0, j \notin \Pi \end{cases} \tag{5}$$

We build a mathematical model.

The target function will be of the form:

$$z = \sum x_i \to \min \tag{6}$$

a – is the incidence matrix of the original graph, the elements of which:

$$a_{ij} = \begin{cases} 1, i \approx j \\ 0, i \not\approx j \end{cases} \tag{7}$$

Each vertex must be incident to at least one cover edge:

$$\sum_{j=1}^{n} a_{ij} x_j \geq 1, i = \overline{1,m} \tag{8}$$

Thus, we obtained the problem (7, 8), which is a linear Boolean programming problem. It allows for fully formalizing the studying optimization processes, easily implemented in MS Excel and using C++, Python, and Java programming languages.

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The approbation of this model was carried out with the participation of first-year students according to the results of the academic year 2020-2021. Table 3 shows the results of the knowledge cross-section, which was conducted before the beginning of the experiment.

Table 3. Test results of students' knowledge before the experiment

Course	Speciality name	Students' number at the examination session beginning	Have to pass the exams	Showed up for all the exams	Didn't show up for at least one exam		Passed all exams in session	% of absolute success	The number of students with academic Number of students with academic backlog, falling grades, unattested			
					For a good reason	For bad reason			Total	for the 1st subject	for the 2nd subject	in 3 or more subjects
1	Maintenance, repair and operation of motor vehicles	58	58	58	0	0	56	96.6%	2	2	0	0
1	Business informatics	22	22	19	0	3	12	54.5%	10	8	2	0
1	Software engineering	29	29	29	0	0	26	89.7%	3	3	0	0
1	Computer engineering	28	28	25	0	3	15	53.6%	13	8	4	1
1	Digital agricultural systems and complexes	28	28	27	0	1	20	71.4%	8	6	2	0
1	Agroengineering	28	28	28	0	0	26	92.9%	2	2	0	0
1	Food technology	21	21	20	0	1	19	90.5%	2	1	1	0
1	Technological machines and equipment	52	52	51	0	1	32	61.5%	20	17	3	0
1	Mechanical engineering	68	68	68	0	0	63	92.6%	5	5	0	0
1	Transport, transport equipment and technologies	30	30	30	0	0	20	66.7%	10	7	3	0
	Summary	364	364	355	0	9	289	79.4%	75	59	15	1

The total number of students was divided into 91 groups of four. Each group had one failing student with arrears in at least one subject. The latter was the initial condition for forming a group. The restrictions were as follows: there had to be at least one student in the group with a high score of 9 to 10, two students with an average score of 8 to 6, or three students with grades of 10 to 6 in the course subjects. The group work experiment lasted one month, after which a new knowledge cutoff was made (Table 4).

Table 4. Test results of students' knowledge after optimization

Course	Speciality name	Students' number at the examination session beginning	Have to pass the exams	Showed up for all the exams	Didn't show up for at least one exam		Passed all exams in session	% of absolute success	The number of students with academic Number of students with academic backlog, falling grades, unattested			
					For a good reason	For bad reason			Total	for the 1st subject	for the 2nd subject	in 3 or more subjects
1	Maintenance, repair and operation of motor vehicles	58	58	58	0	0	58	100%	0	0	0	0
1	Business informatics	22	22	22	0	0	16	72.7%	6	6	0	0
1	Software engineering	29	29	29	0	0	26	89.7%	3	3	0	0
1	Computer engineering	28	28	28	0	0	26	92.8%	2	1	0	1
1	Digital agricultural systems and complexes	28	28	27	1	0	27	96.4%	1	0	2	0
1	Agroengineering	28	28	28	0	0	28	100%	0	0	0	0
1	Food technology	21	21	20	1	0	19	90.5%	2	2	0	0
1	Technological machines and equipment	52	52	51	0	1	46	88.5%	7	4	3	0
1	Mechanical engineering	68	68	68	0	0	64	94.1%	4	4	0	0
1	Transport, transport equipment and technologies	30	30	30	0	0	20	66.7%	10	10	0	0
	Summary	364	364	355	0	9	330	90.7%	36	30	5	1

According to the experiment results (see Table 4), follow-up knowledge testing showed an 11.3% increase in the number of students who performed well, and the number of students with outstanding courses decreased to 36.

Results discussion

The results provide an opportunity to expand and deepen the theory outlined in the works [2, 3, 6]. In particular, based on the work [2], the possibility of practical proof of the interaction between the teacher and the student in the studying optimization process is obtained. And according to the study [3], it is possible to demonstrate the optimal result when performing practical tasks, including – in a remote mode, when the teacher can only interact with the student with the help of information and communication technologies. Based on the work of [6], a new optimization model has been presented with some synergistic effects. For example, combining the strengths of the different participants increases the overall potential of the whole study group working on the project.

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Regarding the last thesis, we would like to say that conducting a trial testing of the information-logical model – dividing students into groups according to the given algorithm to perform an educational project, the subsequent testing (knowledge cross-section) showed the result of 11.3% higher than before the start of the project. In particular, the number of students who failed the test decreased. Also, the number of students who received "6" or higher scores increased. Questioning a student group confirmed the thesis [5] and the problem outlined in the literature review about the need to develop an optimization model that would not reject weaker students but allow them to rise to a higher level.

Comparing our results with the works [15,16], it can be noted that our presented approach operates with a Boolean data type. It is simpler than ontologies because it allows the implementation of tasks through a numerical data type. We see this in Table 1 and Table 2, as well as in the resulting problem (7), (8). The Boolean variables type can be used in most programming languages by converting the data to a numeric type according to the language rules. This means that the information-logic model can be built into almost all existing distance learning platforms, creating a convenient tool to optimize the educational process directly in the course of classes. For example, a short test is conducted, the results are entered into the processing system, and thanks to the model presented, we can divide students into groups that are most effective for the task at hand. It supports the competence paradigm in education [9] and will absolutely agree with [11], as it fully reflects the approach of knowledge management technology. In addition, the presented model fits into the concept of STEM education [24]; that is, it is not inferior to the advanced approaches and models [13] of the educational process in Europe and the USA.

The weak side of this study is quite labor-intensive calculations. Still, the libraries of programming languages C++, Python, and Java allow you to algorithmize the computational processes and obtain data using universal methods.

A promising development of this information-logical model to optimize studying in a distance mode is the development of additional modules of knowledge control and algorithmic tasks arising directly during classes, which may allow students to learn different disciplines in parallel, exercising independent power and preliminary knowledge self-assessment.

Conclusion

As a result of this work, an information-logical model of distance studying optimization was presented. It allows organizing the educational process by strengthening the weaknesses of all students while closely integrating the work of both students and the teacher, even when working in distance mode.

Formalization of the distance studying optimization model was solved using the Hungarian algorithm and Boolean variables, demonstrating the development of a simple knowledge-level information model using "true/false" logical functions.

The presented examples of problems are implemented through a matrix chain, with clear transitions traceability from matrix to matrix through the algorithm points of the developed model.

As a result of the work is presented a basic block diagram of the algorithm by which the information-logical model operates.

The optimization model was initially tested in S. Seifullin Kazakh Agro Technical Research University among the students of one academic group. Students' knowledge tests were conducted at the beginning and end of the testing. Students were divided into groups for the experiment to implement a practical task on a student project. After this optimization, the knowledge cutoff result was 11.3% higher. Predominantly this increase was due to students who could pass the test and those who increased their score from "6" or higher.

A promising direction of this research could be additional knowledge control modules development, as well as the algorithmization of the tasks arising directly during classes. It will provide a full-fledged information-analytical system to optimize learning in a modern institution of higher education.

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