

# Modeling Interdisciplinary Relationships and Evaluating Their Effectiveness in Educational Technologies

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**Abstract.** It is known that the structure of educational technology largely determines the quality and cost of education. Despite many years of experience in the practical use of educational technologies, the improvement of these technologies has not stopped to this day. One of the most effective and low-cost methods of improving the educational process is the use of adequate mathematical models. One of these models, which allows us to rethink educational technology and get practical recommendations based on it, is the matrix learning model.

## Introduction

Examples of possible interdisciplinary connections are the synchronization of the study of related topics in higher mathematics and computer science courses: analytical and numerical solutions to tasks of differentiation, integration and differential equations.

The purpose of the work is to obtain a quantitative assessment of the impact of interdisciplinary connections on the effectiveness of the educational process. The object and subject of research is the matrix modeling of learning technology and obtaining, based on the developed models, a quantitative assessment of the impact of interdisciplinary connections on the effectiveness of the educational process.

## 1. Matrix Model of Educational Technology

When solving the problem of the influence of interdisciplinary connections on the effectiveness of learning, a matrix model of educational technology is used [1, 2, 3, 4]. To build it, matrix models of students' knowledge, the learning process,

and the knowledge control process were consistently developed, taking into account the influence of interdisciplinary connections on the quality of the educational process.

### 1.1. Matrix Model of Students' Knowledge

The matrix model of students' knowledge describes the distribution of students by the number of solved tasks or by selected knowledge classes. In our case, the following traditional knowledge classes are distinguished: "excellent students" – students who solve 85% or more of tasks; "good students" – students who solve 75-84% of tasks; "mediocre students" – students who solve 60-74% of tasks; "underachiever students" – students who solve less than 60% of tasks.

According to this classification, the knowledge model or "knowledge vector"  $\mathbf{f}$  has a size  $m \times 1$  where  $m$  – the number of knowledge classes. At the same time,  $f_1$  – the proportion of "underachiever students" whose level of knowledge is close to zero;  $f_m$  – the proportion of "excellent students" with the highest level of knowledge.

The numerical value of the elements of the vector  $\mathbf{f}$  for a group of students shows the proportion of students belonging to the  $i$ -th class of knowledge. The normalization condition of the knowledge vector has the following form:

$$\sum_{i=1}^m f_i = 1. \quad (1)$$

### 1.2. Learning Process Model

The learning process model transforms the vector of students' knowledge before learning into the vector of students' knowledge after learning. The well-known [1] matrix equation of the learning process has the form:

$$\mathbf{f}_{\text{after}} = \mathbf{A} \cdot \mathbf{f}_{\text{before}}, \quad (2)$$

where  $\mathbf{f}_{\text{before}}$ ,  $\mathbf{f}_{\text{after}}$  – the distribution of students by knowledge (knowledge vector) before and after training, respectively;  $\mathbf{A}$  – the learning matrix with size  $m \times m$ ;  $m$  – number of knowledge classes;  $\mathbf{A} = [a_{ij}]$ . Each value of an element of the learning matrix  $a_{ij}$  shows the probability of students moving from the  $j$ -th to the  $i$ -th class of knowledge after studying.

To determine a specific type of learning matrix, it is proposed to use the entropy method [5]. The entropy method of modeling the learning process assumes that the learning process is determined by a combination of both deterministic and random factors that are almost impossible to formalize and describe within the framework of deterministic approaches.

### 1.3. Knowledge Control Model

To describe the process of knowledge control, a probabilistic characteristic is used – a diagonal control matrix  $\mathbf{C}$ , the values of the elements of which  $c_{jj}$  show the probability of passing the control with a positive assessment by students of the  $j$ -th grade of knowledge. Obviously, for students with different knowledge (from

different knowledge classes) these probabilities will vary. The vector of students' knowledge after the control can be determined through the product of the control matrix and the input vector of knowledge:

$$\mathbf{f}_3 = \mathbf{C} \cdot \mathbf{f}_1, \quad \mathbf{f}_2 = (\mathbf{I} - \mathbf{C}) \cdot \mathbf{f}_1, \quad (3)$$

where  $\mathbf{f}_2, \mathbf{f}_3$  – knowledge vectors for students who failed and passed the control, respectively;  $\mathbf{I}$  – identity matrix;  $\mathbf{f}_1$  – the initial distribution of students by knowledge before the control;  $\mathbf{C}$  – the control matrix.

## 2. Technological Learning System

The following matrix model is used to describe the educational technology, which includes several training and control operations [1]:

$$\mathbf{K} \cdot \mathbf{F} = \mathbf{F}_0, \quad (4)$$

where  $\mathbf{K}$  – the block matrix with size  $(n \times n)$  blocks, defining the structure and composition of the technological training scheme;  $\mathbf{F}$  – the block matrix with size  $n \times 1$  blocks, describing the knowledge vector at the entrance to the  $n$  elements of the circuit;  $\mathbf{F}_0$  – a block matrix of knowledge vectors external to the technological learning system (TLS).

The solution of equation (4) with respect to  $\mathbf{F}$  has the form:

$$\mathbf{F} = \mathbf{K}^{-1} \cdot \mathbf{F}_0, \quad (5)$$

where  $\mathbf{K}^{-1}$  – the inverse matrix of the  $\mathbf{K}$  matrix.

Each column of the block matrix  $\mathbf{K}$  refers to one element of the circuit. Taking into account the introduced notation, the matrix  $\mathbf{K}$  for a technological learning system of an arbitrary structure is filled in according to the following formalized rules [1]:

1. Matrix  $\mathbf{K}$  – square size  $(n \times n)$  blocks or  $(mn \times mn)$  elements, where  $n$  – the number of elements in the scheme,  $m$  – number of observed knowledge classes.
2. On the main diagonal of the block matrix  $\mathbf{K}$  there are unit matrices of size  $\mathbf{I} (m \times m)$  with a minus sign.
3. Each column of the block matrix  $\mathbf{K}$  characterizes an element of the circuit. For a training operation, a column can contain no more than two non-zero blocks, and for a testing operation, no more than three.
4. If the  $i$ -th element is a learning operation, then  $k_{ji} = \mathbf{A}$ . The same time, the  $j$  index shows that the “product” is fed into the  $j$ -th element of the circuit after training. If the “product” leaves the TCO after training, then the  $i$ -th column contains only one non-zero block element located diagonally.
5. If the  $i$ -th element of the scheme is a test, and the students who have passed the control are sent to the  $j$ -th element, then  $k_{ji} = \mathbf{C}$ . If students who fail the test are sent to the entrance of the  $j$ -th element, then  $k_{ji} = \mathbf{I} - \mathbf{C}$ .

### 3. Modeling Interdisciplinary Connections

Taking into account interdisciplinary connections when modeling learning technology seems to be a newly developed approach. The scheme of the teaching technology for the two subjects for which interdisciplinary connections are organized is shown in Figure 1. The calculation scheme of the training model for one discipline includes four training blocks and four control blocks. To analyze interdisciplinary connections, the model presents two technological chains that correspond to two simultaneously studied subjects, between which interdisciplinary connections are organized.

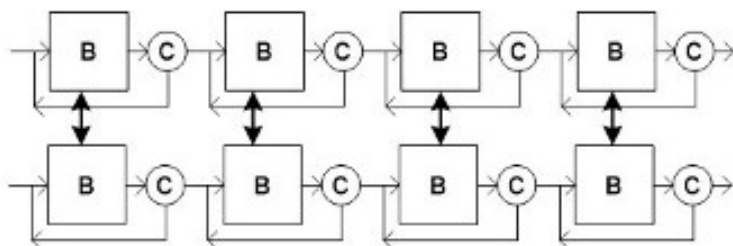


FIGURE 1. The structure of the learning technology consists of four learning modules (B) and four control modules (C), synchronized in two subjects in the presence of interdisciplinary connections, which are shown in the figure with bidirectional arrows

The structure of the  $\mathbf{K}$  matrix for each subject is presented below, while the exponent ( $n$ ) of the learning matrix is used to model interdisciplinary relationships:

$$\mathbf{K} = \begin{bmatrix} -\mathbf{I} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{A} & -\mathbf{I} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & -\mathbf{I} \end{bmatrix}$$

To analyze interdisciplinary connections, two technological chains are included in the model, which correspond to two simultaneously studied disciplines. At the same time, the influence of the degree of interdisciplinary connections on the quality of education is analyzed. In higher education, higher mathematics and computer science can serve as examples of such disciplines. To describe such connections, an indicator of the degree of the learning matrix ( $n$ ) is introduced into the model, the value of which varies from 1 (there are no interdisciplinary connections) to 2 (strong interdisciplinary connections, which are similar to conducting two classes using traditional technology).

#### 4. Results and Discussion

To assess the effectiveness of educational technologies, four criteria are selected: the percentage of excellent students (F1), the percentage of successful students (F2), tuition costs (F3), and unit tuition costs (F4). The results of the computational analysis of these criteria for different values of the indicator of the degree of intersubject relations  $n$  are shown in Table 1.

TABLE 1. The results of a computational study on the influence of the degree of interdisciplinary connections on the criteria for assessing the quality of education

Criteria for assessing the quality of education	The parameter of the intensity of interdisciplinary connections		
	$n = 1$	$n = 1.5$	$n = 2$
Percentage of excellent students (F1)	0.9330	0.9801	0.9897
Percentage of successful students (F2)	0.9419	0.9930	0.9930
Training costs (F3)	10.4557	9.7547	9.4244
Unit cost of training (F4)	10.528	9.8231	9.4905

#### Conclusion

As a result of the computational analysis, it was found that with an increase in the degree of interdisciplinary connections from 1 to 2, the proportion of excellent students increases by 5.67% while reducing tuition costs by 10.4%, that is, the presence of interdisciplinary connections significantly improves the quality of the educational process.

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