

# An approach to the formation of adaptive learning paths for students of cybersecurity in e-learning system

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## Abstract

Processing a large amount of educational material requires significant time resources, which prompted us to analyze educational and cognitive activities in the framework of lifelong learning concept and consider practical tasks regarding forming an adaptive path of a student's learning session, with consideration for each student's unique characteristics, learning goals, and available time reserves. We consider the task of forming an adaptive learning path as a task of optimizing the student's educational-cognitive algorithm. For the first time, it was proposed to maximize the Ffed index of probability of answer without errors to one question of final control test with restrictions on execution time. The developed information technology allows you to obtain input data for evaluating student activity algorithms, evaluate learning quality indicators, and create an adaptive path for the learning session depending on specific student characteristics, educational goals, and learning time limitations.

## Keywords

E-learning, adaptation, optimization, learning path, individual characteristics of the student, cybersecurity, information security technologies

## 1. Introduction

Professionals of cybersecurity work for various companies to protect organizations from cyber-attacks and data breaches. Today, statistics show that the demand for professionals of cybersecurity is growing at a rapid rate. Therefore, the training of cybersecurity specialists today is an urgent issue both for higher educational institutions and for companies. But to prepare a universal professional of cybersecurity is a difficult task. So, most of the students, in addition to studying at the university, use external resources for the self-study of cybersecurity. This is facilitated by the large number of available open learning resources, in particular Massive Open Online Course (Coursera, EdX, Udacity, Udemy). Learning independently, you can get certificates for the study of a particular discipline, as well as diplomas in the specialties. A high-level specialist must constantly update his knowledge and skills throughout his life, receive new certificates of conformity and confirm existing ones. For example, cybersecurity certificates CISSP, CISA, and CISM require regular confirmation.

Processing a large amount of learning material requires significant time resources. For a working specialist, the problem of effective time allocation arises. Building information and educational systems

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due to adaptive learning management algorithms will enable pupils to accomplish the desired outcomes using the resources at their disposal.

The creation of the learning session's adaptive path considering the goals of preparation, specific characteristics of the person studying (hereinafter the student), and the available time will allow planning learning activities rationally. Formation of creation of adaptive learning path with the help of the e-learning system (ELS) was considered in the works of many scientists. However, in general, it cannot be considered resolved to the end.

Research aims to optimize models of the adaptive path formation during learning session in the ELS.

## 2. Formulation of the problem

In ELS, the learning material is presented in the form of a sequence of separate electronic learning modules (ELM). Each module can be divided into parts (submodules), depending on the selected levels of complexity of the learning material. By the learning path we will understand the sequence of ELMs and self-control procedures. Various training organization options are achieved with the help of different types of self-control. By self-control, we mean the test procedure that the student completes after doing a part of the course. The number of times of self-checks is not limited. The results of self-control are not taken into account by the system in the final assessment and are only a reflection of the current learning outcomes. Various types of self-control (self-control and re-studying the material, self-control and extra research focusing primarily on challenging aspects of the course materials, etc.) provide a different level of quality of preparation for the final test and need the setting aside of certain time reserves.

The adaptive learning path is formed considering each student's unique qualities and available time reserve for doing ELM. Individual characteristics are taken into account when preparing the initial data.

The issue can be described generally in the following manner: it should be formed specific variant of the learning path  $X$  that will provide the maximum level of assessment of the quality of learning  $P(X)$ , taking into account the limitations on the learning time reserve  $T_0$ , taking into account the level of complexity of the learning material  $U_0$ .

We reduce this problem to the linear programming problem. When the  $j$ -th option of self-control is chosen for the  $i$ -th ELM the variable's  $x_{ij}$  value will be 1. The variable's value will be 0 in all other cases. Here,  $n$  represents the number of ELMs, and  $m$  stands for the possible options for organizing self-control, resulting in  $i = (\overline{1, n})$  and  $j = (\overline{1, m})$ . Let's present the task in the following way:

$$P(X) \rightarrow \max, \quad (1)$$

$$T(X) \leq T_0, \quad (2)$$

$$U(X) \leq U_0, \quad (3)$$

$$\sum_{j=1}^m x_{ij} = 1 \quad (4)$$

$$x_{ij} \in \{0,1\}$$

Thus, we have a problem in which for each ELM in the learning path only one variant of the organization of self-control is determined.

When forming the objective function for ELS, the level of assessment of the quality of learning  $P(X)$ , which is measured in points, must be raised as much as possible.

Important tasks are:

1. provide for the estimation of probability-time characteristics of the learning process by input data;
2. examine the potential for constructing adaptive learning pathways in the ELS using the established model.

## 3. Literature review

The issues of organizing e-learning should be considered as a complex task for the solution of which various approaches are applied:

- ergonomic (e.g. from the point of view of interaction between man and machine considering person's individual psychophysiological parameters) [1-4];
- pedagogical (e.g., in terms of teaching methods);
- psychological (e.g., from the point of view of considering the parameters of information perception when organizing learning);
- technical (e.g., learning automation) [5-6].

The key issue for e-learning systems is to offer courses that are customized for various students with varying levels of knowledge and learning rates. These systems need to be adaptable and efficient.

Basic objective of e-learning technologies realizes in provision of students with training courses that according to his individual parameters (learning rate, knowledge level). Therefore, e-learning systems must also be adaptive. A significant part of modern research emphasizes the need for adaptive e-learning and systems that can provide the conditions for such learning. For example, Carchiolo V., Longheu A. and Malgeri M. propose one of the approaches to constructing an adaptive e-learning system [7]. The authors consider an e-learning system in which adaptability is based on the student profile and teacher profile.

The authors of [8], [19], [20] propose a scheme of selection a learning object by each student individually.

Zhao and Wan proposed to implement an adaptive system [21], [22] for e-learning based on the algorithm for choosing the shortest learning paths. The authors determined that the most time- and effort-efficient learning procedure was the optimum learning path [9].

A study on the variables influencing how differently students learn when employing adaptive e-learning tools was conducted, according to the authors of [10].

The optimization model will be based on the complexity of the ELM and various models of self-monitoring processes on the construction of the adaptive path of student learning in the e-learning system, which is based on the idea of the shortest learning path algorithm [9].

Moreover, the following mathematical tools were used for solving the issue of creating a learning path: graph theory, Petri nets [11], decision trees [12], machine learning [13, 14], fuzzy logic and others. In [15–22], the development of the learning path was viewed as an optimization problem. Despite that, specified studies did not consider a student's personal psychophysiological indications like cognitive comfort [4, 19-22] functional state [2], etc., which significantly affect the quality of education.

In [4], the expediency of using the Human-Computer Interaction methods was proved. The potential and restrictions of current approaches for use in support of e-learning, including for the purpose of planning the ELS's student learning activities, are analyzed, and the use of functional networks (FN) apparatus is justified.



## 4. Materials and methods

### 4.1. The learning process as a functional network

In [4] it was shown that the learning process that implements the learning path can be represented in the form of FM. Designations of typical functional elements are given in Table 1.

**Table 1**

Typical functional elements

Circuit	Explanation
	Working operation - the study of ELM
	Procedure - test self-control (SC)

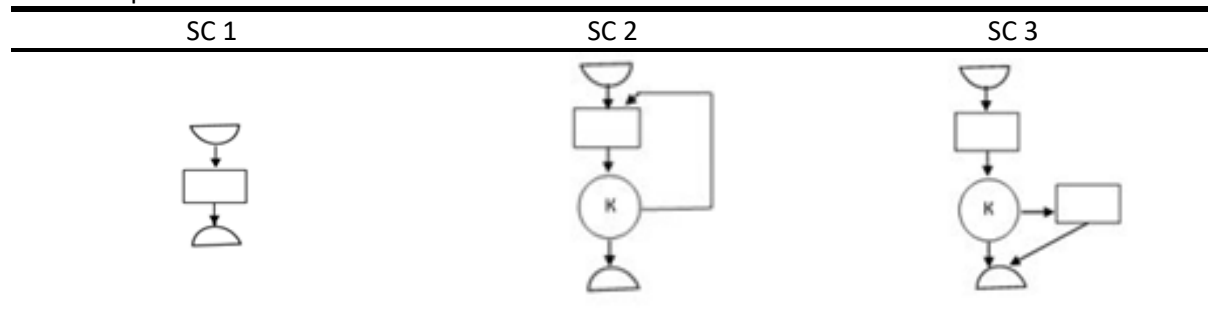
SC 1 corresponds to the consistent development of educational material without self-control of learning outcomes.

SC 2 corresponds to the consistent development of educational material and the control procedure. If the test result is at a low level, the topic is re-studied.

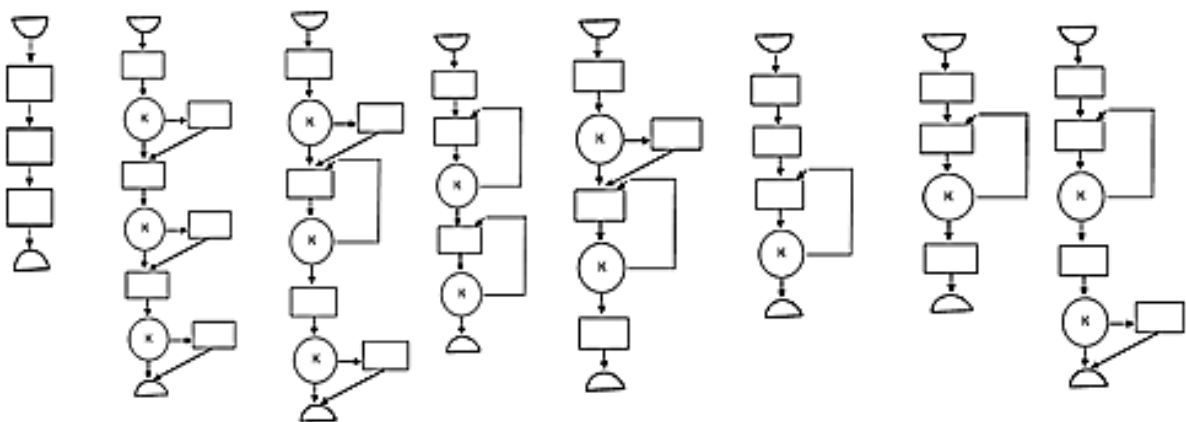
SC 3 corresponds to the consistent development of educational material and the control procedure. If the test result is at a low level, only the problematic fragments of the topic are studied.

There are different ways of organizing learning that can be implemented through different models of self-control procedures. Possible options for self-control are given in Table 2.

**Table 2**  
Possible options for self-control



Some possible options for the learning path with the number of difficulty levels  $k = 3$ , corresponding to three submodules, are shown in Figure 1. The learning path options differ in the quality of the learning outcomes and the time resources that are spent. To assess these indicators, the qualimetric method is used [18].



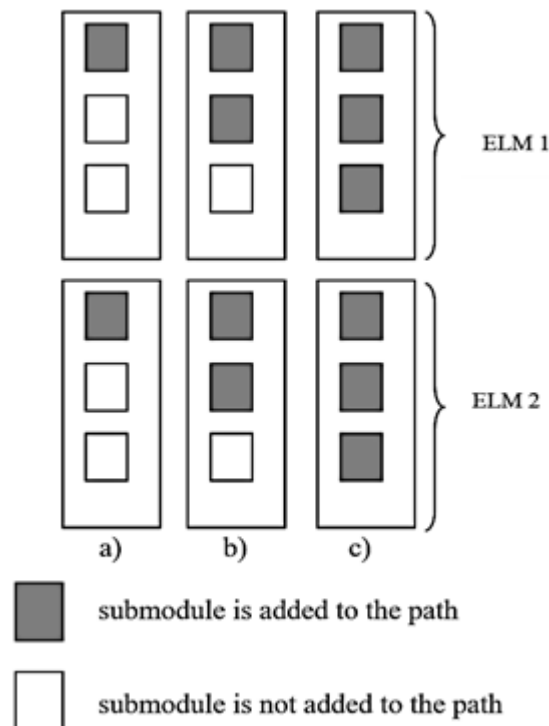
**Figure 1:** Possible options for the learning path

The level of complexity determines the structure of the ELM. For example, with a complexity level of  $k = 3$ , there are three distinct submodules that correspond to the exploration of the subject matter at a basic, intermediate, and high levels. The choice of difficulty level is determined by the goals of the student. If it is necessary to quickly obtain a basic level of knowledge, then the path is formed with a submodule of the basic level ( $k = 1$ ).

To obtain intermediate level knowledge, a path is formed with submodules of the first and second difficulty levels ( $k = 2$ ).

If it is necessary to obtain high-level knowledge, then the path is formed with a submodule of all levels of complexity.

An example of the choice of components of an adaptive learning path for two ELM with different levels of complexity is shown in Figure 2.



**Figure 2:** Options for adding submodules to adaptive learning paths, taking into account the learning objectives (a)  $k = 1$ ; b)  $k = 2$ ; c)  $k = 3$ )

Thus, the sequence of actions is as follows: select submodules for the learning path that correspond to the desired level of complexity of the module; check the quality of learning material, apply self-control procedure options that will provide the necessary level of quality and satisfy the time limit for learning.

Therefore, for the purpose of solving the problem it is important to choose the level of complexity, generate input data for assessing the quality indicators of the path options and conduct optimization.

## 4.2. Formation of input data

The solution to the task of developing an adaptive ELS's learning path provides an assessment of the quality and reliability of the options for organizing the learning process. To assess the characteristics of the quality and reliability of the learning process in ELS related to probability and time, the models and methods described in [4] are used. The major objectives are to calculate the mathematical expectation of time for studying the ELM as well as the likelihood that a final test control question will be answered without error.

The parameters that mainly determine the probabilistic-temporal indicators of the quality of ELS's activity of the student are the level of motivation, the results of input control, functional state, cognitive comfort and time reserve. Statistics compiled from observations of student activities in the ELS allows you to obtain data for analysis and forecasting - how similar students acted in similar conditions.

The developed intelligent models [4] and the software for their implementation allow us to obtain input data for evaluating student activity algorithms in the ELS and further forming an adaptive path.

## 4.3. A model for optimization of the development of individual learning paths

To be able to apply optimization methods, we will develop a new objective function that allows you to maximize the value of the learning quality assessment in points  $P(x_{ij})$ .

Let  $p_{ij}$  be the probability of the answer without error to one question of the final test control of the  $i$ -th ELM. In this case, if the number of ELMs is  $n$  and the number of options for organizing self-control is  $m$  the value of  $i$  and  $j$  will be accordingly  $i = \overline{(1, n)}$  and  $j = \overline{(1, m)}$ . As well,  $s_i$  is structure of the control procedure for summing up the learning outcomes (number of questions) for the  $i$ -th ELM;  $g_i$  is the number of points that are calculated for one correct answer to the question, which corresponds to the  $i$ -th ELM;  $p_{ij} \cdot g_i \cdot s_i$  is the mathematical expectation of the total quantity of points awarded for correct responses for the final self-control that corresponds to the  $i$ -th ELM;  $T_{ij}$  is the mathematical expectation of the studying time for the  $i$ -th ELM with the  $j$ -th self-control option, and  $U_0$  is the highest allowable level of complexity.

Then, the problem of forming an adaptive path at a certain  $i$ -th learning step can be formulated as follows:

$$\sum_{i=1}^n \left( \sum_{j=1}^m p_{ij} \cdot x_{ij} \right) \cdot g_i \cdot s_i \rightarrow \max \quad (5)$$

$$\sum_{i=1}^n \sum_{j=1}^m T_{ij} \cdot x_{ij} \leq T_0 \quad (6)$$

$$\sum_{i=1}^n x_{ij} \leq U_0 \quad (7)$$

$$\sum_{j=1}^m x_{ij} = 1 \quad (8)$$

$$x_{ij} \in \{0,1\}$$

The solving of the issue (6) - (9) enables to identify the ideal plan  $X$  for organizing self-control of the ELM and  $T_0$  to foresee the outcome of achieving total final control.

## 5. Experiments

Consider the problem of forming an adaptive learning path of the ELM's third complexity level ( $k = 3$ ). Table 2 presents possible options for self-control of submodules.

Calculation results of the probability-time quality indicators for the options for organizing self-control from Table 1 according to the method [18] are presented in Table 3. These results are input data for the optimization problem.

**Table 3**

Data for the task of optimization

ELM №	Quality indication	SC 1	SC 2	SC 3
1	P	0.79	0.98	0.95
	T, min	19	30	25
2	P	0.74	0.96	0.91
	T, min	20	32	25
3	P	0.77	0.95	0.90
	T, min	20	33	28

Let  $s_1 = 20, s_2 = 20, s_3 = 20, g_1 = 1, g_2 = 1, g_3 = 1$ , that is, the test self-control contains 20 questions for each submodule, and for each correct answer one point is awarded.

The outcomes of addressing the input data optimization problem (Table 3) with different reserves of time  $T_0$  are shown in Table 4.

The learning paths shown in Figure 3 correspond to the obtained matrices.

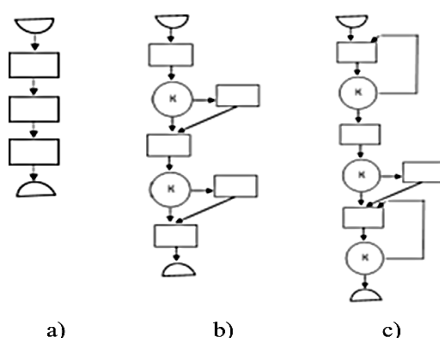
The  $X_1$  path is proposed for small reserves of time, offers less knowledge and no means of exercising self-control.

**Table 4**  
Findings from tackling the optimization issue (U0=3)

Path	Reserves of time, min	Optimal plan	Estimated number of scored points / amount of possible scores	Time, min
X <sub>1</sub>	60	$x_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$	46/60	59
X <sub>2</sub>	71	$x_{ij} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$	52/60	70
X <sub>3</sub>	88	$x_{ij} = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$	56/60	87

Although the X<sub>2</sub> path takes more time, it offers the chance to modify the problem-learned blocks of educational content and raises the standard of learning.

Due to the model of recurrent studying in cases of poor self-control, the X<sub>13</sub> path offers the maximum level of preparation quality.



**Figure 3:** Adaptive learning path for U0=3 with various time reserves (a - X<sub>1</sub>, b - X<sub>2</sub>, c - X<sub>3</sub>)

The larger time reserves, the greater the level of quality of education can be achieved.

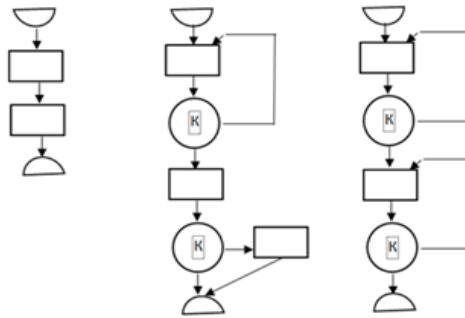
There are cases when a student has less time to study and does not purport to excellent rating. In this case, an adaptive path can be formed with an ELM of the first and second complexity level (Figure 3b).

The results of solving the optimization problem with U0 = 2 are given in Table 5.

**Table 5**  
Findings from tackling the optimization issue (U0=2)

Path	Reserves of time, min	Optimal plan	Estimated number of scored points / amount of possible scores	Time, min
X <sub>1</sub>	40	$x_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$	30/40	39
X <sub>2</sub>	55	$x_{ij} = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$	37/40	55
X <sub>3</sub>	65	$x_{ij} = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}$	38/40	62

The corresponding learning paths in Figure 4.



**Figure 4:** Adaptive learning path for  $U_0=2$  with various time reserves (a -  $X_1$ , b -  $X_2$ , c -  $X_3$ )

## 6. Results

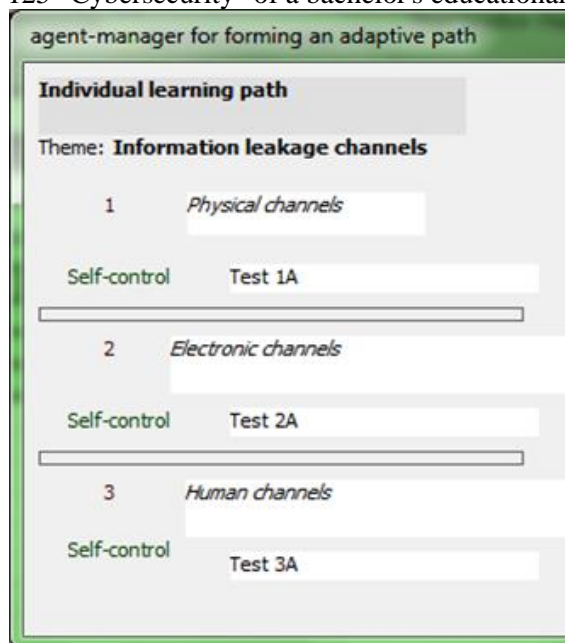
The developed information technology was implemented as part of the program and was researched to provide a solution to the issue of creating an adaptive learning path when studying the discipline "Information Security Technologies" for the preparation of bachelors in the specialty "Cybersecurity".

When developing the software package for the agent-manager of e-learning assistance, the specified methodology was used. Software package's main tasks are:

- determination of the values of individual psychophysiological parameters of students that affect the level of cognitive and educational work;
- development of an adaptive learning path of the learning session, weighing the ELS's capabilities as well as the unique traits of each student.

To study the effectiveness, experiments were conducted based on Sumy State University.

Figure 5 shows an example of the use of an agent-manager for forming an adaptive path when studying the electronic learning course "Information Security Technologies" for applicants of higher education with a specialty 125 "Cybersecurity" of a bachelor's educational level.



**Figure 5:** An example of a window fragment of the formation of an adaptive learning path

The system provides an option for the formation of an adaptive path without self-control. Such a model slightly reduces the learning time, but significantly affects the quality of assimilation of the material. In some cases of low student motivation and significant time constraints, such a model may be appropriate.



## 7. Conclusions

The developed model allows us to implement the task of forming an adaptive path of a learning session in the ELS. It provides maximization of the evaluation of the learning process's quality in points, with consideration of the students' individual psychophysiological parameters and restrictions on the available learning time.

The development advantages are that, in contrast to the well-known methods for optimizing human activity algorithms, which are designed for averaged indicators, models provide an account of individual characteristics at the stage of input data formation.

It was used the indicator of probability of error-free execution as opposed to the common optimization models. A proposed indication offers the chance to get a point-based evaluation of the learning's level of quality.

Possible disadvantages and limitations of the method include the following:

- the possibility of use only for algorithmized discrete activities in modular ELS;
- the assumption of the invariability of the indicators of learning quality during work with ELM that are probabilistic-temporal.

The urgent task of creating adaptive learning path for an ELS learning session is completed.

Proposed approach allows considering the student's unique characteristics during formation of an adaptive learning path when there is a limitation on the time of learning in the ELS and taking into account the goals of the student and the complexity of the module which makes scientific novelty of the results.

Development of information technology to support e-learning makes practical value of the results. Experimental results allow us to offer developed software for learning specialists.

Future studies could address the issue of creating an adaptive path that consider the actual learning outcomes in the ELS.

As you know, actual results may differ from forecast results. This discrepancy should be considered in the model for optimizing the formation of the path. The path correction should occur each time the actual results of quality and learning time are received.

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