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METHODOLOGY OF DIGITAL CONTENT CREATION

Abstract. **The subject of the study** is the individualization of the learning process in the process of assimilating information with different levels of subjective complexity. **The purpose of the study** is to develop a methodology for creating digital content to manage student behavior by changing the objective complexity of the learning material. **The subject of the study** is to develop and theoretically substantiate methods of individualized approach of students to learning professional competences by creating individual trajectories of knowledge acquisition and assimilation. **Used methods:** methods of analytical modelling and artificial intelligence. **The following results** were obtained. It is proposed to determine the complexity of the content by the number of concepts used in a piece of information and the variety of relationships between them, and to present its model in the form of an analytical graph, the vertices of which are concepts and edges that reflect the variety of relationships between them. A method of organizing the learning process using a computer-based learning system, the functioning of which implements a personality-oriented model of a student, has been formed. **Conclusion.** Preliminary structuring of didactic material in the form of a graph, with the vertices being the relevant content sections, and transition management implemented by the learning control system, allows for improved individualization of learning. Moreover, due to adaptation, each student begins to work with the same intellectual load.

Keywords: individualization of learning; personalized learning; computer system; graph-analytical structure.

Introduction

The rapid pace of digital transformation in education is largely driven by the use of digital technologies in both the organization of the learning process and the creation of digital courses. The student-centered approach and individual learning trajectory help to intensify students' creativity and cognitive activity. Their motivation to learn and self-learning will contribute to the formation of relevant digital competencies. By identifying student characteristics, it becomes possible to build individual learning trajectories, taking into account the dynamics and the possibility of changing the learning trajectory to adapt to their individual characteristics. This makes it possible to create parametric models of the student that reflect the peculiarities of their cognitive development, including the level of knowledge acquisition and learning dynamics. In particular, the model makes it possible to predict optimal learning trajectories for a particular individual, to simulate various learning situations that reveal not only the learning process but also the process of personal development.

In automated learning systems, the object of control is the learner who is acquiring certain knowledge. As in any control system, there are two information flows: forward and backward. The direct flow of information, or direct influences, brings learning information to the control object. Feedback describes the changes that occur at the level of the learner's knowledge and are analyzed by the learning system. There is no doubt that the main way to improve the effectiveness of learning is to improve direct influences. This is due to the fact that only direct influences can lead to learning.

Thus, the development of a method for managing student behavior by changing the objective complexity of the learning material in accordance with the subjective complexity that arises during its study is relevant. The aim of this publication is to develop and theoretically substantiate the methodology of individualized approach of students to learning professional competences by creating individual trajectories of knowledge extraction and assimilation based on information technologies.

1. Literature review

One of the ways to manage the learner's activity during the learning process is to change the level of accessibility of the content provided to the learner. This is due to the fact that the same content can be presented with different levels of accessibility, which causes different levels of difficulty when the student studies it. At the current stage of development of information technology, it is virtually impossible to synthesize an arbitrary text with a given accessibility of presentation. Such synthesis is also impossible in real-time learning. Thus, it is necessary to develop learning content that is differentiated by complexity.

The issue of analyzing the complexity of various educational material and the possibility of its differentiation by complexity is partially considered in the work [1], in which the author considers the features of determining the logical structure of educational material. In this case, the complexity of the educational material is measured by some objective characteristics. However, during individual work on the content, learning difficulties arise that are entirely dependent on the subject. The subjective difficulty of learning information while working on content can be assessed by such indicators as the number of errors made by students during control tests and the pace of work [2, 3]. In this case, the object of management is the student, and the managed process is the process of knowledge acquisition by this student. At the initial stage of learning, the course of the learning process is usually not defined. The characteristics of this process cannot be determined experimentally. Thus, the ability to control objects with a high degree of initial uncertainty is based on the use of adaptation, when the initial uncertainty is reduced by using information obtained in the learning process. However, in learning systems, adaptation cannot be used to the fullest extent. This is hindered by the following. Firstly, feedback information does not allow for an effective assessment of the student's thought processes during learning. It is only possible to assess with some probability how the acquired knowledge is being absorbed. Secondly, even if the learning process is assessed reliably enough, it is impossible to effectively influence its changes because the system of controlling influences is created in advance without taking into account the individual characteristics of the student. These limitations are valid for teaching knowledge and lose their meaning when teaching skills [4].

2. Developing a criterion for the complexity of a piece of information

Quantifying the level of complexity of a piece of information is necessary to make a decision on how to present it to the user.

Regardless of the type of content, its complexity, which has an objectively determined level, should be proportional to the amount of information provided. For this purpose, it is proposed to determine the complexity of the content by the number of concepts used in a piece of information and the variety of relationships between them. The most convenient way to present the model of information content is in the form of an analytical graph, the vertices of which are the concepts used in the fragment of information, and the edges reflect the variety of connections between them. This creates a formal problem of determining the complexity of the graph, in other words, finding the next function:

$$C = f(n, t, m, \phi, p), \tag{1}$$

where n – the number of vertices in the graph; t – number of types of graph vertices; m – number of edges; ϕ – number of types of edges; p – number of different degrees of the graph.

This function should satisfy a number of conditions, one of which is that the domain of the function must coincide with the set of positive numbers. At the same time, the function should grow monotonically depending on the number of vertices, edges, their number and types. It is assumed that one undirected edge is equivalent to two directed edges. Thus, it is proposed to measure the complexity of the information content **C** by the number of its elements **n**, and to take into account the diversity of elements using the entropy formula used in the statistical theory of information [5, 6]. In this case, assume that the probability p_i of the occurrence of the *i*-th element is determined by the following relation:

$$p_i = n_\mu / n,$$

where n_μ – number of elements; μ – the type to which the *i*-th element belongs.

Based on this, it is proposed to quantify the complexity of a graph:

$$C = n(1 - \sum_{\mu=1}^{t} (n_\mu / n)\log_2(n_\mu / n)). \tag{2}$$

The following conditions should be met:

$$n = 0 \Rightarrow C = 0;$$
$$m = 0 \Rightarrow C = n(1 - \sum_{\mu=1}^{t} (n_\mu / n)\log_2(n_\mu / n)); \tag{3}$$
$$m = 0 \quad t = 1 \Rightarrow C = n.$$

Taking into account the assumptions made, the quantitative measurement of the complexity of a fragment of information (2) will take the following form:

$$C = n\left(1 - H^t_{n_\mu} - H^\phi_{m_\beta} - H^t_{n_\lambda}\right), \tag{4}$$

where $H^t_{n_\mu} = \sum_{\mu=1}^{t} (n_\mu / n)\log_2(n_\mu / n)$

is an entropy measure of the variety of graph vertex names;

$$H^t_{m_\beta} = \sum_{\beta=1}^{\phi} (m_\beta / m)\log_2(m_\beta / m)$$

is an entropy measure of the variety of graph edge names;

$$H^t_{n_\lambda} = \sum_{\lambda=1}^{t} (n_\lambda / n)\log_2(n_\lambda / n)$$

is an entropy measure of the variety of degrees of vertices in a graph.

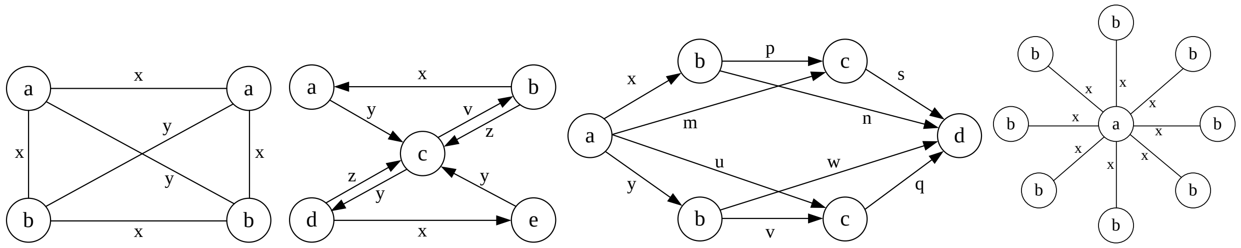
In these expressions, n_μ is the number of vertices of the same name; m_β is the number of edges of the same type; n_λ is the number of vertices of the same degree.

As an example of the practical application of the proposed criterion of the complexity of information content (4), consider the examples shown in Fig. 1, and summarise the data in Table 1.

Table 1 – **Examples of complexity calculation**

Figure number	n	t	m	ϕ	p	C
a	4	2	12	2	1	11,67
b	5	5	8	4	3	33,76
c	6	4	10	10	2	42,95
d	10	2	18	1	2	19,37

The results of calculating the level of complexity in the above examples of information models make it possible to take into account the features of each model [7, 8]. Thus, when creating digital content, the didactic material of an academic discipline should be structured in the form of a graph, the vertices of which correspond to concepts, and the edges to the connections between concepts, which together determine the complexity of the content.



a b c d

Fig. 1. Model of the structure of a fragment of information

3. The method of organizing the learning process

The proposed criterion for assessing the objective complexity of a fragment of content is the basis for building digital content. To manage the learner's activity in the process of knowledge acquisition, the level of accessibility of information content should be varied. In this case, the learner acts as an object of management, and the process under management is the process of knowledge acquisition by this learner. The learner's behavior is managed by changing the objective complexity of the learning material in accordance with its subjective complexity, which arises during its study. At the same time, the learning system performs partial adaptive control of the learner, making the process of learning content assimilation more optimal.

Usually, some learning content is contained in a learning information source in the form of a set of portions of material that make up the information content and control questions. Based on the results of work on the preliminary data, some *i*-th level of objective complexity of the information content is determined. The student is given a fragment of information containing the text T_i and a set of control questions $\{K_i\}$. The answer analysis block evaluates the student's answers on a true/false basis. And with the help of the block for determining the pace of answers, the time spent working on the content is compared with the permissible time limit, and a true/false decision is made. The values from these blocks are transferred to the memory, where information about the results of the last three tests is stored. This information allows us to judge the subjective difficulties caused by the learning content. Based on this analysis, the level of difficulty of the next new material is selected in accordance with the learning algorithm. Adaptation to the individual characteristics of students leads to the fact that each of them starts working with a level of content complexity that is accessible to them. Experimental studies [9] have shown that there is no significant difference in the time it takes to learn the information material. This indicates that different categories of students had approximately the same intellectual load. Based on the results of the time spent studying the content and the correctness of answers to control questions, the content is moved to content of greater or lesser complexity, providing an individual learning trajectory for each student.

4. The algorithm for building digital content

First, the structure model of the individual fragment of information that will be provided to the learner is formed. Given that the complexity of a piece of information depends on the model of its structure, the content developer first calculates its primary value. Its complexity is reduced by dividing it into several component sub-fragments of a simplified structure, which together fully cover the amount of information of the primary piece of information. Moreover, during the breakdown and creation of each of the sub-fragments, their complexity is calculated and correlated with the level of the overall complexity of the fragment [10, 11]. To do this, a model of the structure of each of the sub-fragments of information is built and their complexity is calculated. The complexity of each of the created sub-fragments of this simplified level should be within 50–25% of the calculated complexity of the main separate piece of information.

The next simplified level is created in the same way, but each of the created fragments of the higher level is taken as the basis for the calculation.

This way, depending on their subjective characteristics, each user can automatically choose their own learning path while mastering the training material, moving from level to level of varying degrees of difficulty. The structure of the application that helps the developer create structured information content is shown in Fig. 2.

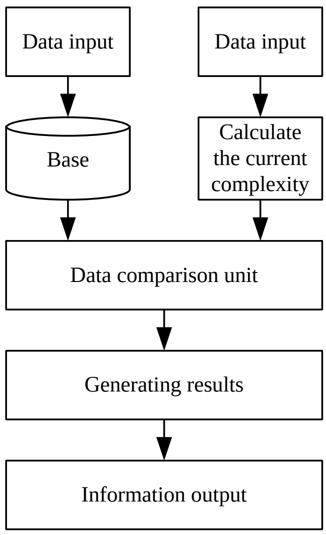


Fig. 2. Algorithm of the program for creating a fragment of information of a given complexity

In the input data entry block, the number of vertices and links between them is entered directly. Based on the data obtained, the program calculates the initial complexity of the piece of information and the data obtained is recorded in the knowledge base for further comparison with the initial value of the complexity of the piece of information. The data comparison block compares the data obtained from the current content complexity calculation block with the data in the knowledge base. Then the system proceeds to the block of generating results and then to the block of information output. To organize a multi-level approach, a complex task is divided into several simpler tasks, and all information content fragments are divided and grouped at the appropriate levels, which form a hierarchy. Content fragments belonging to one particular level request only the content fragments of the neighboring level to perform their tasks. Fig. 3 shows a scheme of organizing an individual learning trajectory. Based on the results of mastering some information content of the appropriate level, taking into account such components as the time spent mastering a piece of information and the correctness of answers to test questions, the student can move to a higher or lower level of information presentation, the level of which characterizes the complexity and volume. It is not possible to move from one level to another bypassing the intermediate level. A summary assessment of the level of information assimilation is the number of transitions from the beginning of the learning process to the final fragment of the cycle.

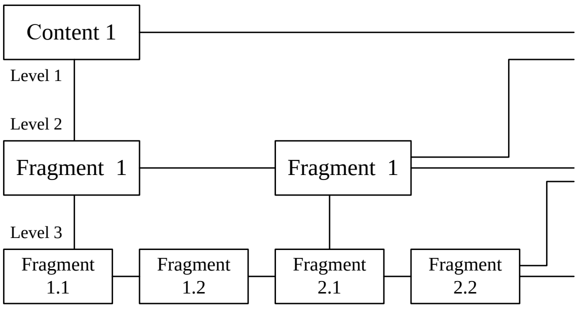


Fig. 3. Method of organizing an individual learning trajectory

Thus, the lowest number of transitions from one content to another will be in the case when a student masters the material at a higher level of difficulty and answers the control questions correctly. Therefore, in this case, the student's grade will be the highest. In the other case, when the student is constantly mastering information material at a lower level, the number of transitions will be maximum and the student's grade will be lowest. The intermediate values of the scores depend on the specific content and are determined by the content developer.

Analysis

The development of a personalized learning system was implemented and underwent experimental testing [3, 4]. During the experiment, a learning program with three levels of difficulty and various error correction methods was studied. Two methods of error correction were employed. In the first method, the student independently identified the cause of the incorrect answer by studying the same material but in a more detailed presentation. The second method involved the student receiving a full explanation of what the correct answer should be.

Fig. 4 shows the change in the average time spent on a dose of educational material (dependencies 1, 2) and the percentage of correct answers to the control questions for one dose of material (dependencies 3, 4) for a group of students. Dependencies 2 and 4 correspond to the second method of error correction, while dependencies 1 and 3 correspond to the first method. Based on the analysis of the presented graphical materials, it can be concluded that the second method of error correction, unlike the first, reduces student activity towards the end of the work on the content. This is due to the decreased time spent on one dose of material and the increased number of errors.

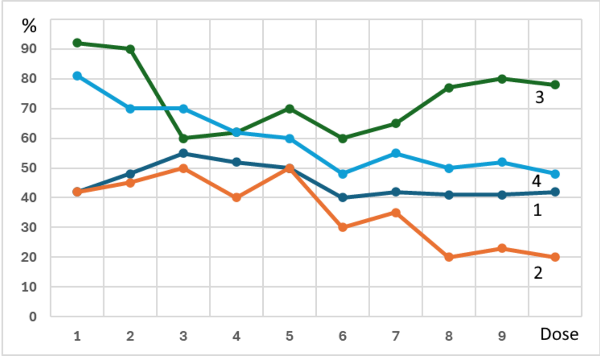


Fig. 4. Average time spent on material dose and percentage of correct answers: 1 – time with error correction using method 1; 2 – time with error correction using method 2; 3 – percentage of correct answers with error correction using method 1; 4 – percentage of correct answers with error correction using method 2

The results of the experiment, which was carried out using the Emotiv EPOC neurointerface [12, 13], proved that adaptation to individual student characteristics led to each of them working on the material available to them. There was no significant difference in time, which can be interpreted as approximately the same intellectual load for different categories of students. At the same time, a clear structuring of the didactic material in the form of a graph, in which the vertices correspond to the sections of the material, and transition management is implemented using a test system for monitoring the mastery of the unit's material, which allows for a fully personalized learning experience.

The implementation of the developed approach clearly demonstrates the process of motivating students during training. The availability of several levels of difficulty allows individuals with different skills to move to higher levels after sufficient practice and become an expert. Allowing access at different levels of difficulty means that not all learners are at the same point in the learning trajectory. Learning at the most appropriate level of difficulty helps to prepare for the next, higher level of difficulty as experience is gained.

The complexity of the task depends on the content and such fundamental capabilities as spatially selective attention, working memory, and other sensory and perceptual abilities. In addition to basic operations, it requires additional cognitive processes, such as search, comparison, and symbolic problem solving.

Simultaneous tracking of several objects, visiting several places in the gambling space, or solving more than two tasks at the same time requires the distribution of attention. In turn, the distribution of attention reduces the speed and accuracy of decisions made by the player. This imposes restrictions on the number of objects, their location, and the number of tasks that need to be solved simultaneously. Usually, a person cannot simultaneously hold more than 4 elements in RAM and visit more than 4 objects at the same time. Memory allows you to store, maintain, and later retrieve information. There is a distinction between working and long-term memory. The working memory stores information for the current manipulation and is closely linked to the attention system. Instead, long-term memory receives information through the learning process and vice versa. Working memory retrieves information from long-term storage in accordance with the requirements of the current task and under the control of executive processes in the human brain. In this way, working and long-term memory complement each other. The inability to efficiently store and process information in RAM leads to poor performance in many tasks.

The executive processes of spatial attention monitor the content of working memory and coordinate other brain systems that are necessary for the maintenance and selection of object features.

Effective spatial selective attention and working memory are important for solving complex spatial tasks.

In addition to the distribution of attention, it is often necessary to switch attention from one location of an object or task to another. Such switching also entails costs in terms of information processing speed because it takes some time to unlock and restart the task. Quickly switching attention from the current task to a new one requires additional time, especially for beginners. On the other hand, spreading attention over a wide field of vision allows you to see the peripheral world without focusing on most of the objects in the periphery. However, the visual system cannot process all information. Most of the unprocessed visual information is not important for achieving the goal of the game and can be ignored. At the same time, in order to attract attention and reduce information processing time, the visual system must be sensitive to changes in object position, brightness, and color. Attention is directly directed to the place where a sudden change has occurred, which is associated with a sudden onset or change that attracts attention. Sudden events are rapidly analyzed by the brain using processes that require identification, recognition and decision-making. The processes usually involve eye movements and motor actions. The next step is to recognize the object that has attracted attention, discarding information that is not relevant to the object. This is visual selective attention. Thus, improving this basic skill improves performance on other tasks by supporting functions that depend on this ability.

Conclusions and Future Work

The research clearly demonstrated the need to manage learning processes. This is due to the need to maintain focused attention when studying a certain amount of information content and control the level of learning. Moreover, the use of neurointerfaces [14, 15] capable of receiving bioelectrical signals from the human brain during learning and transmitting them to technical devices in real time has made it possible to control the learning process.

The main criterion for the optimization of the learning process is to stabilize the time period that allows for full implementation of personalized learning. The use of optimal time when working on a certain amount of information is evidence that the learner is actively working with the content available to him or her. New methods of cognitive learning help to develop, maintain and improve spatial cognition. All tasks in spatial cognition are supported by attention and the level of working memory, which are closely related to each other. Complex spatial tasks require rapid extraction, separation, and redistribution of attention across a variety of object qualities. At the same time, during several stages of information processing, attention should be selectively switched between the qualities of the object in the RAM to maintain their activity.

A method of organizing the learning process using a computer-based learning system has been formed, the functioning of which implements a personality-oriented model of the student. The results of the experimental study have proved that due to adaptation, each student begins to work with the same intellectual load for different categories of students. Structuring the didactic material in the form of a graph with the vertices of the relevant content sections and transition management implemented by the learning control system allows to improve the process of individualization of learning. Thus, the methods used in digital content development technologies have the potential to revolutionize the teaching of spatial skills and concepts. In turn, this will have significant social and economic implications in basic education.

Further research should be directed towards identifying the increase in students' creativity and cognitive activity, their motivation to learn and self-learning, facilitated by fundamentally new technologies of human learning based on the use of virtualization and augmented reality. They make it possible to form relevant digital competences [16, 17], to learn information images of real natural phenomena and processes by experimenting with various digital tools and technologies (simulations, computer modelling, virtual and augmented reality), and to ensure the restoration of lost and development of new intellectual abilities [18, 19]. The proposed means of virtualization and augmented reality will contribute to the emotional involvement of students, create additional opportunities to make tasks more understandable, illustrate the nature and effectiveness of the phenomenon in action, increase the visualization of results, and strengthen the vector of students' mental development [20, 21]. It is emphasized [22] that the introduction of new technologies provides increased motivation for the systematic mastery of practical skills, increases students' concentration and attention, increases their cognitive experience and promotes the development of creative abilities.

An analysis of current views on the problems of introducing a synthetic learning environment into educational practice [17, 23] has proved the need to consider it in two aspects: artificial and formed by synthesizing the physical world and computer modelling. For example, study [24] describes a hybrid learning model to support virtual and offline student learning. With the development of virtualization techniques [25], new types of environments are being created, such as augmented reality, which allows you to observe an object from any angle. Moreover, an analysis of the scientific literature [26] revealed a shortage of appropriate applications for teaching science, technology, engineering and mathematics subjects in higher education institutions. In particular, work [27] notes that the choice of innovative learning depends on a person's access to certain types of technology. At the same time, the organization of the educational process in educational institutions is directly influenced by the features of user access, namely the permissible number of users. In this case, an important aspect is the methods of evaluating the results of the implementation of augmented reality applications, which are based on the ISO 9241-11 standard.

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Методологія створення цифрового контенту

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Анотація. Предметом дослідження є індивідуалізація процесу навчання під час засвоєння інформації з різним рівнем її суб'єктивної складності. **Мета** – розробка методології створення цифрового контенту для управління поведінкою учня за допомогою зміни об'єктивної складності навчального матеріалу. **Задача** – розробка та теоретичне обґрунтування методів індивідуалізованого підходу студентів для навчання професійним компетенціям шляхом створення індивідуальних траєкторій вилучення та засвоєння знань. Використані **методи**: методи аналітичного моделювання та штучного інтелекту. Отримані наступні результати. **Запропоновано** визначати складність контенту числом понять, які використані у фрагменті інформації та різноманіттям взаємозв'язків між ними, а його модель надавати у вигляді графа-аналітичних структур, вершинами якого є поняття та ребра, які відображають різноманіття зв'язків між ними. Сформовано метод організації процесу навчання із використанням комп'ютерної навчальної системи, функціонування якої реалізує особисто-орієнтовану модель учня. **Висновки.** Попереднє структурування дидактичного матеріалу у вигляді графу, вершинами якого є відповідні розділи контенту, а управління переходами реалізує система контролю засвоєння матеріалу дає змогу удосконалити процес індивідуалізації навчання. Причому, за рахунок адаптації кожен з учнів починає працювати з однаковим інтелектуальним навантаженням.

Ключові слова: індивідуалізація навчання; особисто-орієнтоване навчання; комп'ютерна система; графа-аналітична структура.