Adaptive learning system based on cognitive independence

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Abstract

The authors propose a new approach to building a flexible learning system that adapts to the students' cognitive independence. The approach is based on tuning the technologies of student interaction with the educational environment. The authors use a mathematical model of educational process control to adapt the system. The model's parameters are characteristic of the factors that form the cognitive independence of students. The authors present an information technology for assessing the factors that shape the cognitive independence of students. This technology can be integrated into any educational system due to the universal capabilities that Google services provide. The developed technology is very useful for studying the real picture of individual factors of cognitive independence in the educational process, organized with the help of electronic educational technology. The main functional capabilities and advantages of the developed information technology are: the ability to organize adaptive learning, the ability to organize questionnaires in any electronic educational system, simplicity and ease of use, modular structure, and others.

Keywords

adaptive learning, cognitive independence, educational technology, electronic educational system

1. Introduction

The current educational revolution [1, 2, 3, 4], the rapid technology of e-learning (caused by COVID-19) [5, 6, 7, 8, 9] and the concept of lifelong learning [10, 11] exacerbate the following problems:

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- quality of e-learning environment [12, 13],
- adaptive learning [14, 15, 16, 17, 18, 19, 20],
- ergonomic support of the educational system [21, 22, 23, 24, 25, 26, 27],
- formation of cognitive independence [28, 29, 30].

The analysis of these scientific articles shows that enhancing the cognitive independence of students is crucial for improving and ensuring the effectiveness of e-learning. In modern literature, cognitive independence is defined as follows [30]: "Cognitive independence is an integrative property of a student who learns using a computer, associated with the student's initiative and the search for various alternative ways to solve problems without the participation of tutors".

In this paper, we propose an adaptive learning system based on cognitive independence. The system is built on a new approach to building a flexible learning system that adapts to the students' cognitive independence. The approach is based on tuning the technologies of student interaction with the educational environment. We use a mathematical model of educational process control to adapt the system. The model's parameters are characteristic of the factors that form the cognitive independence of students. We present an information technology for assessing the factors that shape the cognitive independence of students. This technology can be integrated into any educational system due to the universal capabilities that Google services provide. The developed technology is very useful for studying the real picture of individual factors of cognitive independence in the educational process, organized with the help of electronic educational technology. The main functional capabilities and advantages of the developed information technology are: the ability to organize adaptive learning, the ability to organize questionnaires in any electronic educational system, simplicity and ease of use, modular structure, and others.

2. Problem statement

A problem arises: "How to ensure the cognitive independence of students in the conditions of electronic education?".

Lavrov et al. [30] outlines approaches to the analysis of factors that affect the cognitive independence of students. However, the question remains: "How to implement such a study in practice?".

Consider the most well-known digital content management systems designed to organize learning processes using Internet technologies (table 1). For almost all of these platforms, the main goal is to organize access to teaching materials, ensure interaction, testing and reporting between teachers and students.

One of the most common distance learning systems in universities is the Moodle system, an educational platform that aims to connect teachers, administrators and students in a reliable, secure and integrated system to create a personalized learning environment [31].

The technical aspects of the system can be described as follows:

- Moodle is written in PHP using a SQL database,
- Moodle is installation packages and detailed installation files,

Table 1
The most popular educational platforms.

Moodle (https://moodle.org/)	The platform integrates teachers, administrators and students (students) into a reliable, secure and integrated system to create a personalized learning environment
Google Classroom (https://classroom.google.com)	Google's web service, designed for educational institutions to facilitate the creation, distribution and classification of tasks, making them paperless
edX (https://www.edx.org/)	A platform that provides a large number of courses for various purposes from the best universities and colleges in the world
Coursera (https://www.coursera.org/)	An educational platform that provides online courses from the world's leading universities and organizations
FutureLearn (https://www.futurelearn.com/)	Online course platform in the UK
Khan Academy (https://www.khanacademy.org/)	Free online courses and courses
Schoology (https://www.schoology.com/)	A virtual learning environment for schools and universities that allows users to create, manage and share learning content
Classdojo (https://www.classdojo.com/)	A communication platform for distance learning in school, used by teachers, students, and parents
Seesaw (https://web.seesaw.me/)	A platform for creating digital learning resources
Skooler (https://skooler.com/)	Tools for turning Microsoft Office software into an educational platform
CenturyTech (https://www.century.tech/)	A platform that has tools for distance learning

- Moodle represents different categories of users: administrators, teachers-developers, teachers, students, and guests.

Moodle has a wide range of features that are specific to e-learning platforms [31]. This allows you to organize all stages of the learning process: diagnosis, planning, training, management of educational activities, evaluation of results.

To diagnose and assess certain learning phenomena in the Moodle system, the following technologies are provided:

1. Questionnaire module is an activity that provides many proven survey tools used to assess and encourage learning in the Internet environment. Teachers can use them to collect data from students to help them understand the class and think about their own teaching [32]. There are three types of questionnaires:

- ATTLS – Attitudes toThinkingandLearning Survey a questionnaire containing 20 questions, designed to determine the level of students' attitudes to distance learning,
- COLLES – Constructivist On-Line Learning Environment Survey (questionnaire "Learning Environment withEelements of Constructivism") a questionnaire containing 20 questions, designed to determine the level of students' attitudes to distance learning,
- Critical Incidents (questionnaire "Critical Incidents") is a questionnaire in which students are given the opportunity to assess certain events and their attitude to what is happening.

2. Survey module (choice) – in the classroom, you can ask questions and set switches, and students can press these switches to choose from a number of possible answers. They can choose one or more options, and if pre-settings allow, they can update their selection. The options can be used as a quick survey to stimulate reflection on the topic, to allow the class to vote for the direction of the course, or to assess progress [33].
3. Module test is an activity that allows teachers to develop and build tests of knowledge, consisting of many types of questions, including multiple choice questions, right or wrong questions, short answers and correspondence, and numerical questions [34].
4. The provided technologies can diversify distance learning courses and make them "alive" [35].
5. Although these technologies have certain diagnostic capabilities, we believe that the main disadvantage of the questionnaire module is its static nature:

    - you cannot edit the questionnaire,
    - other questions cannot be entered (they can only be used in the same form as specified by the developer).

Therefore, when teachers want to create their own questionnaires to diagnose certain aspects of assessment of learning phenomena, problems arise because this is not provided in the system.

As the analysis of the literature shows, modern e-learning systems do not allow to investigate the importance of factors that affect cognitive independence (in order to increase the effectiveness of learning).

Modern e-learning technologies have a wide range of organizational capabilities at all stages of learning, including diagnostic tools, but they are static in nature, and the scope of assessment of learning phenomena in them is limited.

Thus, despite the large number of studies in the field of adaptive learning, including [22, 36, 37, 38], the practice of most universities has shown a lack of effective online learning in a pandemic. The following facts have been recorded:

- decreased motivation,
- decrease in the quality of the educational process,
- refusal to study,
- stressful situations both among students and teachers.

The main issues are related to the following disabilities:

- operational research of motivational parameters and characteristics of students' cognitive independence,
- customizing the educational process for the characteristics of the student.

In this regard, define the purpose of this study:

- develop information technology for analytical research of factors influencing the effectiveness of distance learning in conditions caused by a pandemic;
- develop the principle of building a model that provides "customization of learning technology for a particular student studying in a particular educational environment".

3. Results

3.1. Development of an approach to building a model of adaptive formation of cognitive independence in the context of pandemic constraints

We will consider a typical situation typical for the organization of the educational process at the university [38]:

1. The working curriculum for the discipline has M topics.
2. Each topic has a basic conceptual part (these are the basic provisions of the topic that are stable for a long time), as well as a variable part (educational material, the content of which may vary depending on the technical process of the educational process, software of the educational process, personal experience, own knowledge, scientific or methodological advantages, etc.).
3. For each i-th topic in the program, the time t_i, which can be represented as $t_i = t_{i1} + t_{i2}$, is allocated, where ti1 is the time allotted to the conceptual part and t_{i2} is the time allotted to the variable part.
4. For each i-th variable part, there are N_i variants j of its presentation.
5. With each i-th variant $(j = 1, N_i)$ of the topic $i(i = 1, M)$, it is possible to connect some function of usefulness of presentation of the maintenance of the j-th variant for formation of cognitive independence. Usefulness cannot be measured directly. Its indirect assessment may be a number – the rank of R_{ijl} – which is attributed by the expert to the j-th variant in the i-th topic from the standpoint of the influence of educational material of the j-th variant on the formation of the l-th component of cognitive independence. Ranks are formed by the method of rank correlations. According to this method, the j-th variant is assigned a rank of 1, if in the opinion of the expert, this variant is the most useful for the formation of the cognitive independence in the i-th topic; the second most important variant of presentation is assigned a rank of 2, etc. Ranking of variants of teaching material is carried out for each l-th informative component of the cognitive independence.
6. To implement the selection process, a logical variable x_{ij}, is introduced, which takes on the value 1 if the j-th option is selected when presenting the i-th topic, and the value 0 otherwise.

Given the assumptions made, the task of forming cognitive independence can be formulated as follows:

Known:

- the number M of topics of educational material of the discipline,
- the time t_{ij}, allocated for each j-th variable part in each i-th topic,
- the number N_i of j variants of the presentation of each variable part,
- the structure of the properties l (l = 1, k) of the student's personality, the list of which is customary to explicate cognitive independence (in other words, personality properties that form cognitive independence),
- R_{ijl} ranks assigned by experts to the j-th variant of presentation of the i-th topic according to the level of its influence on the l-th parameter of cognitive independence.

It is necessary to choose the following options j for each topic i to maximize the total effect of the educational material on the formation of cognitive independence.

Thus, it is necessary to maximize the sum of ranks, which determines this effect:

$$\sum_{i=1}^{M}\sum_{j=1}^{N_i}\sum_{l=1}^{k} R_{ij}^{l} x_{ij} \to max, \tag{1}$$

with restrictions:

- on the study of the discipline

$$\sum_{i=1}^{M}\sum_{j=1}^{N_i} t_{ij} \le T, \tag{2}$$

- on the obligatory presentation of all topics

$$\sum_{i=1}^{N_i} x_{ij} = 1, (i = 1, M), \tag{3}$$

- on the obligatory choice of at least one version of the presentation in each topic

$$\sum_{i=1}^{M} x_{ij} = 1, (j = 1, N_i), \tag{4}$$

- for integer variables

$$x_{ij} \in 0, 1, \tag{5}$$

Explication of the concept of "cognitive independence" allows us to identify a list of personality traits that form a complex quality of personality "cognitive independence", which can be called components of cognitive independence (factors).

Consider an example of a fragment of a set of such factors (determined by experts of Sumy National Agrarian University and the Ukrainian Academy of Engineering and Pedagogy):

- the need and desire to master the knowledge and methods of activity,
- cognitive motive and interest,
- interest in the results of their independent cognitive activity,
- interest in the future profession,
- initiative,
- basic knowledge (possessed by the individual),
- acquired basic skills and abilities, computer skills and possession of previously learned software,
- acquired knowledge of the discipline of the computer cycle being studied,
- acquired skills and abilities in the discipline of computer cycle, computer skills and possession of learned software,
- use of scientific and methodological literature, means of communication, the Internet,
- attentiveness,
- strong-willed efforts,
- purposefulness,
- persistence,
- contact with the teacher during independent cognitive activities in order to obtain information,
- contact with other students during independent cognitive activities in order to obtain information,
- ability to set and achieve the goals of cognitive activities,
- ability to plan their cognitive activities,
- ability to assess their potential in performing cognitive activities,
- ability to evaluate the results of their cognitive activities.

In the notation of the above model, a list of k properties of the student's l personality is formed ($l = 1, k$).

Such sets of factors will be different:

- for different universities,
- for different groups of students,
- for different age groups,
- for different learning technologies, etc.

Therefore, it is necessary to be able to model them in each problem situation.

The main problems of this model are:

- Pr1 – how to embed the model in the distance learning system;
- Pr2 – how to generate source data that really reflects the current problem situation.

We solved the Pr1 problem by creating a special technology of intelligent agent-manager, which is built into any system of distance education [37]. To solve the Pr2 problem, we offer a special online survey technology, which is described below.

3.2. Information technology for the analytical study of the factors influencing the effectiveness of distance learning in the context of constraints caused by a pandemic

Basic principles of technology:

- use of modern Google Script technology familiar to students and teachers,
- online questionnaire for all categories of participants in the learning process:
  - all teachers,
  - all students
- preliminary formation of factors to be considered (special expert group of teachers and students),
- embedding the questionnaire in the educational process management system,
- formation of results:
  - for each student,
  - for all teachers together.

The results are processed in a special way [30]. Based on expert data, the average value of the degree of P_{avi} manifestation in the structure of cognitive independence, the variance of $S_i$expert assessments, the confidence interval V_i, as well as upper confidence limit P_{upi} values of the informativeness of cognitive independence parameters, lower confidence limit P_{lowi} values of the informativeness of cognitive independence parameters, and the R_{Pupi} rank of the values of the upper limits of the confidence intervals are calculated for each factor. In addition, a line graph for R_{Pupi} and P_{lowi} is built.

Figure 1 and figure 2 show the results that are automatically generated by the system after

- conducting a survey,
- processing questionnaires and determining the informativeness of the parameters of cognitive independence.

It is clear that for each student we receive the individual estimations (figure 1), and it allows system to adjust educational process.

If we analyze the ranks of the factors obtained as a result of the analysis of teachers and students of Sumy National Agrarian University, the most important (fragment) for the conditions of the pandemic (a total of 20 factors were estimated) were identified:

- rank 1 – contact with other students during the performance of independent cognitive activities in order to obtain information,
- rank 2 – the ability to evaluate the results of their cognitive activity.
- rank 3 – contact with the teacher during the performance of independent cognitive activity in order to obtain information.

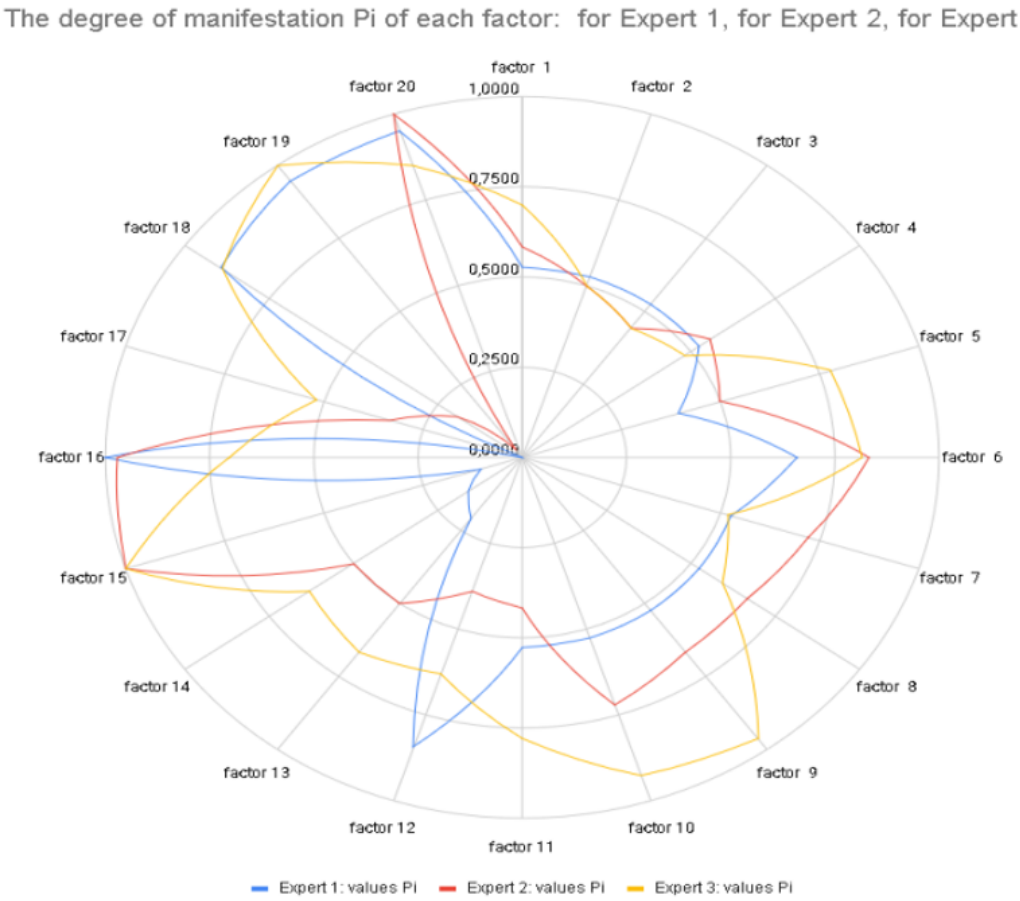

Figure 1: Results (fragment) of data processing by three experts (students) – the degree of manifestation of the components of cognitive independence.

Such studies allow us: a) to change the general technology of training organization; b) to adjust the learning process for each student.

The main functional capabilities and advantages of the developed information technology are:

- the possibility of organizing adaptive learning,
- the possibility of organizing a questionnaire in any electronic educational system to determine the level of factors in the study of any discipline,
- an opportunity, for example for educational institutions, to introduce disciplines in solving problems related to the quality of teaching,
- simplicity and ease of use,
- modular structure,
- the ability to reach a wide audience of test takers, with access to the Internet,
- the ability to store answers in Google spreadsheets,
- survey results are stored on Google Drive,

Figure 2: Results (fragment) of data processing: R_{Pupi} and P_{lowi} – upper and lower confidence limits for the informativeness values of the factors of cognitive independence (obtained during the survey of teachers for the conditions of studying the discipline "Information Technology", Faculty of Management, Sumy National Agrarian University).

- allows you to set a deadline for receiving answers to questions,
- has sufficiently reliable protection, this applies to both the content of the surveys and the results of the surveys.

3.3. Use of technology for the formation of individualized training focused on the conditions of the pandemic. Experimental studies

The technology of revealing individual features of students and the model of individual customization of the educational process "for the student" during the spring semester of 2019–2020 academic year and the autumn semester of 2020–2021 academic year were studied, implemented and tested at the Department of Cybernetics and Informatics of Sumy National Agrarian University (SNAU).

The content of the questions (20 questions in total) that were asked to students is described in clause 3.1 and complies with the recommendations [30] (however, it is possible to formulate arbitrary questions that are relevant for a particular university).

The main advantage of the proposed method is the ability to flexibly adjust the training to the characteristics of the student and the recommendations of teachers (see table 2).

Table 2
Development of approaches to learning technologies (example based on materials of computer cycle disciplines, teacher V. G. Logvinenko, SNAU, Ukraine).

Traditional learning (F1 – Form 1)	Distance learning (F2 – Form 2)	Flexible online learning in a pandemic (adaptive technology) (F3 – Form 3)
Lectures – 18 hours	Study of lecture materials (on the website) – 18 hours	The volume and forms are adjusted individually according to the results of the online research: • online lecture of the teacher, • video lecture (record), • study of materials for the lecture (text, presentation), • discussion of problematic issues of the lecture with the teacher, • discussion of problematic issues of the lecture in microgroups of students, • games and debates based on lecture materials
Laboratory work – 36 hours	Virtual laboratory work – 36 hours	The volume and forms are adjusted individually according to the results of the online research: • online preparation for laboratory work, • video to study the technology of laboratory work (record), • modeling problem situations “what will happen if”, • discussion of problematic issues of laboratory work with the teacher, • discussion of problematic issues of laboratory work in microgroups of students, • games, • passing a laboratory course

Satisfaction with the forms of educational process (percentage of positive assessments of the quality of technology, according to materials of the Department of Cybernetics and Informatics of Sumy National Agrarian University) in the pandemic is presented in figure 3.

4. Conclusions

Existing e-learning technologies do not offer the possibility of flexible operational analysis of factors that determine the quality of the educational process from the point of view of teachers

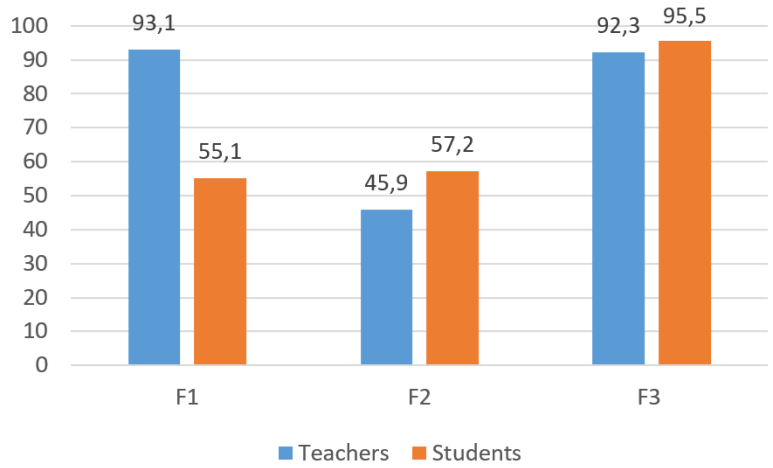

Figure 3: Satisfaction with the forms of educational process (percentage of positive assessments of the quality of technology, according to the Department of Cybernetics and Informatics of Sumy National Agrarian University) in the pandemic.

and students, in particular the factors that shape the cognitive independence of students.

In today's e-learning environment, including due to COVID-19 and war restrictions [39], this is a critical limitation. In this regard, a modern management system of the educational process requires a fundamentally new information technology developed as a result of this study, which includes models and software:

- online surveys of students and teachers,
- prompt processing of survey results with the possibility of ranking the factors influencing cognitive independence in different learning conditions (including pandemics),
- adjustment of learning technologies to the parameters of students identified as a result of online surveys.

The scientific novelty of the result lies in the fact that in contrast to the existing models of adaptive management of the learning process, focused on expert (or selective) assessment of student parameters and learning technologies, built adaptation models use online assessment technologies that allow you to quickly configure the system to a "problem situation".

Testing under COVID-19 constraints has proven the effectiveness of the approach. The practical significance of the results lies in the possibility (thanks to the use of Google services) of embedding into any learning process management system.

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