# Using Machine Learning to Analyze the Learning Process for Solving Mathematical Problems

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**Abstract—**The relevance of the research under consideration is due to the need to improve the efficiency of the analysis of the quality, and completeness of the knowledge obtained by students when solving computational problems, the example problems in mathematics. The theoretical argumentation is proposed and the practical implementation of an intelligent automated analytical system for analyzing the quality and forecasting the content of educational material and the trajectories of the student's learning direction is described. The relevance of the research is the creation of neural network algorithms that allow analyzing the dynamics of changes in the student's level of formation of skills to solve arithmetic problems. The methods of analyzing the assimilation of educational information and methods of personalized construction of the curriculum for each student are substantiated.

**Keywords—**artificial intelligence, informatics, mental schemas, pedagogy

## 1 Introduction

From research, it is known that robots take on thousands of routine operations and can displace many low-skilled jobs in developed and developing countries. At the same time, advanced technologies open up new opportunities, creating conditions for the emergence of new and transformed jobs, increasing productivity, and improving the efficiency of public services [1-4].

Studies have repeatedly proved that the quality of teaching and the professionalism of teachers are the most important school factors determining the academic success of students [5,6]. It is the teacher who is the key factor in the process of developing and translating knowledge, skills, and abilities to students. As noted by the British scientist Lawrence Stenhouse, one of the founders of the direction of studying the practice of teachers, "in the end, it is teachers who understand the school world from the inside who will be able to change it". The difference in training between a more capable and a less strong teacher for a student can be an entire academic year. The use of automated intelligent analytical software by teachers in educational activities will allow improving the quality of teaching.

That is why the article emphasizes the fundamental role of an intellectual program in analyzing the learning process for solving mathematical problems – a problem that, by its very nature, does not allow simple and perceptive solutions. An analysis of international experience shows that the success of the education system is guaranteed if teachers use modern intellectual teaching tools [7]. In the era of digital learning, teachers have less and less face-to-face contact with students. This will increasingly happen on digital platforms in the form of online training. This will provide many problems for analyzing the quality of learning material assimilation.

Important principles of education are based on freedom, integrity, and consistency. In particular, it is necessary to observe the consistency concerning growing up [8]. For the most effective educational program, the teacher should devote more time to professional development, and routine teaching tasks such as criterion assessment and analysis of student performance should be done by intelligent software — within the framework of a specific curriculum. As the complexity of the software becomes more complex, the teacher becomes less dependent on the control of the student's knowledge, remaining within the curriculum, and will be able to free up time for a creative approach to the lesson. At the same time, intelligent software for the analysis and control of student performance bears a great responsibility for the quality of the analysis of student performance. But, as always, the principle applies here: the level of freedom cannot increase without a parallel increase in responsibility. These two concepts in consciousness should not be separated from each other.

Forecasting and improving the quality of the results of students ' educational activities is one of the main components of the educational process. Currently, digital learning resources are becoming intellectual, and methods of teaching knowledge that ensure the effectiveness of learning require rethinking [9, 10]. The covid-19 pandemic accelerated this process and proved that the existing expert systems are not yet sufficiently refined for their application during distance education. The most important component of the methods of effective teaching of students in natural science disciplines is the" step-by-step " method of learning to solve computational problems.

Modern trends in education and society indicate the demand for intelligent educational process management systems as a tool for analyzing the educational process and controlling the quality of acquired knowledge [11]. In this regard, the problem of the formation and development of students ' skills and abilities to solve computational problems in natural science areas becomes extremely relevant. Despite the large number of methods of teaching problem solving with different methodological approaches, the issues of formalization and personification of the process of organizing intellectual analysis of students ' progress in solving problems are insufficiently studied and are of considerable interest from the standpoint of intelligent automation of such activities. Indeed, in most cases, the effectiveness of known teaching methods depends on the skill and experience of the teacher, these methods are time-consuming and require a lot of time, especially in terms of diagnosing learning outcomes [12].

In this regard, the creation of computer training, and diagnostic systems that provide the definition, analysis, and assessment of the formation of the ability to solve computational problems is extremely relevant for the theory and practice of digital learning.

Despite the significant technological and didactic potential of modern information and communication technologies, their use in training students to solve problems is unsatisfactory for several reasons [13-15]:

- Firstly, Digital means of forming the ability to solve problems are traditionally more instructive, reference in nature, and controlling means, as a rule, assess the level of formation of this skill according to the final result, according to the "black box" model.
- Secondly, the existing automated training systems are poorly connected with the principles of personality-oriented, personalized learning.
- Thirdly, the motivation and effectiveness of students ' independent work on solving computational problems significantly depend on flexible, adaptive, and unobtrusive external management, as well as on convenient and visualized self-management of educational activities according to the "white box" model.
- Fourth, the teacher makes a physical analysis of the progress of each student based on their qualifications. As a result, as students grow and deepen into the educational material, the teacher loses the objectivity of the student's progress in mastering the educational material.

The purpose of this article is the theoretical substantiation of the model of personalized work of students on the formation of the ability to solve computational problems from the standpoint of a mental approach and the practical implementation of an automated training and diagnostic system with a visualized mechanism of self-management of educational activities on a mirror subject-object-subject interaction.

### 1.1 Review of the scientific literature on the problem

With the development of digital technologies and their application in the life of society, the problem of assimilation of knowledge in solving computational problems in the natural science field is becoming more acute. Problem-solving is a highly individualized skill, which largely depends on abstract thinking and previously learned educational materials [16].

The analytical work of the teacher in the educational activities of students plays a significant role in the learning process. Its effectiveness largely depends on the didactic qualities of digital learning tools. As a rule, most of these educational resources are aimed at teaching according to the principles of modern didactics, forming and developing the required abilities and competencies [17].

Recently, researchers are increasingly paying attention to innovative methods and means of teaching in the context of digital learning (e-learning) [18]. However, as real practice shows, digital learning is not always successfully and effectively implemented in the educational process [19]. Many teachers have high hopes for the personification of learning from the perspective of a student-centered paradigm of education [20-24]. Also, teachers are in urgent need of intelligent analytical assistants who could facilitate their work and allow them to devote more time to the learning process itself.

The quality of the student's assimilation of educational material for solving problems depends on several factors, including the following:

- student independence is expressed in the responsibility of students, not teachers, for educational results;
- personification of the educational process — the teacher models the individual educational trajectory of each of his students based on his capabilities;
- orientation to significant achievements in independent learning is a psychological and pedagogical phenomenon that contributes to the manifestation of interest and internal motivation;
- self-diagnosis and comparison of the achieved learning results with reference ones is also a psychological and pedagogical phenomenon that enhances self-expression and the importance of one's personality.

The effectiveness of training students in the educational process depends not only on the ability of teachers to competently manage the training of students and on the degree of preparation of students for this type of activity but also to a greater extent on the appropriate means of teaching [25].

By transferring pedagogical functions to oneself, a person thereby masters the system of appropriate "meta-cognitive skills" [26]. It is more convenient to provide conditions for the organization of personalized learning based on a cognitive or mental approach. From a cybernetic point of view, the student can be considered a "black box" model. The teacher exerts training influences on him, trying to form the required properties (learning outcomes). It is advisable to carry out coordinated training with the help of feedback control. Traditionally, the control is implemented by analyzing the protocol of observations of the "black box". At the same time, the protocol is understood as a list of effects on the "black box" and the corresponding reactions. Well-known methods of learning, including innovative e-learning methods, are based on the analysis of the protocol (Figure 1a). The cognitive approach allows us to model the mental structure of thinking, and to study the issues of its development, which can provide the opportunity to build an educational process according to the "white box" model. In this case, the learning process is reduced to the formation of the required mental structures in the student (Figure 1b).

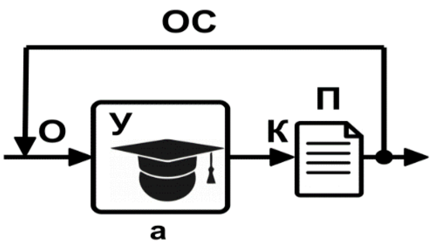


**Fig. 1a.** Training on the "black box" model with the analysis of the protocol

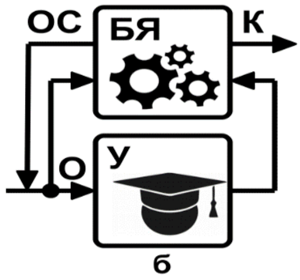


**Fig. 1b.** Training on the "white box" model

*Designations: O-training, Y-student, OS-feedback, K-control, P-protocol, BYA-white box

The central concept in the mental approach to learning is the concept of "mental schema", introduced by W. By Neisser[13]. At the physical level, the mental circuit is a set of structural elements and processes in the nervous system that control thinking and activity. There are mental schemes that are formed when solving computational problems and managing this activity. The purpose of training in this case is the purposeful formation of mental schemes responsible for solving computational problems. At the conceptual level, the mental schema model is represented as a graph containing terminal (data objects and goals) and non-terminal vertices (a lower-level mental schema) [27].

## 2 Methodology

Digital learning tools of the new generation should carry the functions not only of presenting educational information but also of developing mental operations and their analysis. They allow the student to independently manage the learning process. They should provide different options for adjusting the text to the psychological preferences of the student. Due to the hierarchy of cognitive qualities of a person, it is important to provide a graph structure and collapsibility of certain text fragments that are of a clarifying nature in the interface of a digital publication. Such a view will allow you to simulate different training routes for mastering a given topic. At the same time, the student can change and adjust the route of study in the course of educational activities, depending on his motivation, acquired experience, and claims for the result of training [28].

The main advantage of digital cognitive learning tools is interactivity and visualization. All sessions of working with trainees should be remembered in a special database with a statistical mechanism. This is necessary for the subsequent stages of training, in particular, it will be possible to generate more often those tasks in which most users had difficulties, and where they made more mistakes. It is preferable to use a mental approach to build adaptive and independent teaching of students and schoolchildren to solve problems using the "white box" model [29]. The experience of developing and using training tools using mental schemes has shown their high efficiency in the educational process [30].

In our model, the initial data set contains linear algebra data from the 7th-grade program, as well as the name of topics and scientific problems for each row. For a more accurate analysis, it was decided to use the Pandas library. To get the right result, converting training data to the right level of detail for analysis or a machine learning project is a common task and often requires some level of pre-processing and experimentation.

One of the difficult aspects of designing natural language processing is that all the analyzed texts will contain a lot of words and elements that do not provide any meaningful information in terms of identifying the underlying structure or topic. These can be general words, such as "I" or "my", as well as specific words that are often found in the entire collection of the text being studied. Another very difficult problem is the recognition of mathematical formulas written in the MathType editor.

### 2.1 Making a model

To solve the problem of binary classification of objects, it is proposed to use various machine learning methods, as well as their combinations (an aggregated classifier). It is impractical to talk about the effectiveness of any of the methods considered, since we can get different results for different samples, even for different parts of the same sample. You can only introduce several restrictions on the selection related to the peculiarity of a particular method or field of research, for example, the logistic model is sensitive to correlation between factors, so the presence of strongly correlated input variables is unacceptable in the model; the support vector machine is sensitive to noise and data standardization; to apply the Bayesian approach, it is necessary first to bring the initial data to an interval scale, so that the variables are discrete, otherwise, this may lead to the loss of significant information, etc. As a result, the developed program will select the best (in the sense of the specified criteria) combination of the methods involved, that is, the optimal aggregated classifier [31].

To analyze the curriculum, which in a certain period will analyze the tasks solved by the student, a thematic model was created based on the curriculum for the 7th grade. "Thematic modeling" is the process by which we find hidden topics in a series of documents. This means that according to the data presented from several documents—in this case, the mathematics curriculum for the 7th grade — we find sets of words, and formulas that often coexist, forming coherent "topics". After determining these topics, formulas, and words, we trace how common these topics are in the student's work over time, indicating the progress of the student's academic performance in a given curriculum.

The first step to building a topic model is to extract objects from the corpus for modeling. In the process of natural language processing, the preferred technique is the "bag of words" model. The "bag of words" model summarizes the frequencies of each word in a document, with each unique word being its characteristic, and its frequency being the value [32].

An even better feature extraction tool that does a deep analysis is the term "frequency-inverse frequency" of the document. This method shows the number of words that appear very often in the corpus, since they should be less likely to give an idea of specific topics of the document, given how common this word is. Using its tf-idf, we can determine the features for each element of the training material, which can represent how important each word is for our analysis program.

```
tfidf_vectorizer = TfidfVectorizer(stop_words = list_of_stop_words, min_df = 0.1)
    tfidf_freq = tfidf_vectorizer.fit_transform(documents)
```

**Fig. 2.** The "frequency-inverse frequency" method of the document

After we have defined the methods for analyzing the text in the curriculum, we create a thematic model! The modeling method that was used for this project is NMF. NMF, or non-negative matrix factorization. We will use this algorithm to identify our topics or groups of words and formulas that occur, as well as to determine the prevalence of these topics in each student's decision.

The first part of the NMF output is the text. At this stage of the machine learning process, we get the opportunity to use the data of the training program for analysis. After checking the text in each topic, you can make a responsible decision about which topic or idea is represented by words and we can post a visual analysis of the learned material.

Another part of the NMF output is the "Document-topic" matrix. In this matrix, each row is a topic of a section, each column is a task, and the value is a relative assessment of how much this topic exists in a particular student's work and how it was completed.

In the course of the work, the task was to see how often the materials of a certain section are used in each student's work, and it was also necessary to identify the criteria assessment and identify the most successful descriptors for each topic. During the analysis of the algorithms used with the threshold for evaluating the student's work, it was decided to set the threshold at the level of 0.1. After the training, we had a transformed matrix of the topics of the sections and their corresponding tasks ready. At the next stage, it was necessary to train the program to effectively evaluate and determine the descriptors in the database.

## 3 Results

To develop a mental scheme of skills to solve computational physical problems, we will highlight elementary phenomena and processes. We will describe each phenomenon by an appropriate physical model, which is generally characterized by several quantities. They, in turn, will be interconnected by some mathematical law, formula, or equation (mathematical model). Let's call the combination of physical and mathematical models a computational primitive.

After building and teaching a complete thematic model, for a more accurate analysis of problem solutions by the student, it was necessary to create a new model that would consider deeper relationships between individual objects, rather than general topics of the curriculum. To do this, a modeling method called "word2vec" was used. With this model, we can match each object that appears in the texts of the curriculum. As a result of the program, you can look at the similarity of objects. Such a mapping of a word into a vector space is called an embedding of a word. With the help of this model, we can see how similar some words are to each other in terms of the style of writing problem solving by the student and the model embedded in the knowledge base.

By observing the words and objects that are grouped in the tSNE below, we get an idea of how well the problem was solved and reveal how complete the student received knowledge on a given topic [33, 34]. It should be remembered that the words are grouped based on the similarity of their attachments in the knowledge base of the intellectual program for analyzing the correctness of the tasks being solved by the student.

## 4 Discussion

The possibilities of natural language processing are endless, and the idea is that it can give us a deeper understanding of how it will be possible to improve educational activities in the future [20]. The proposed method of creating an intelligent automated training and diagnostic system for learning how to solve computational problems has several advantages over existing analogs.

Firstly, the system ensures the implementation of the principles of personalized learning and has a high degree of adaptability for each individual user. Secondly, the system motivates the effectiveness of teaching students to solve computational problems due to flexible and unobtrusive external control, as well as due to a convenient and visualized mechanism for analyzing the development of educational material according to the "white box" model [15]. Thirdly, the system provides for the forgetting factor and assumes its repeated use to achieve the planned learning result by the student. Tasks are generated based on statistical data accumulated during the work of all users of the system.

## 5 Conclusion

The proposed method can be used to create structural-mental schemes not only for sections of the mathematics course but also for other disciplines in which solving computational problems is a common activity (chemistry, physics, computer science, etc.). The representation of structural-mental schemes in the form of a graph is very convenient for software implementation. The level of formation of the ability to solve problems using structural-mental schemes is determined by the superposition of particular structural-mental schemes of individual tasks that the student has solved. In the case when private schemes completely cover the general structural and mental scheme, we can talk about the formation of the ability to solve computational problems in the subject area represented by this scheme.

The rating, unlike the methods for determining latent characteristics developed in IRT, allows you to determine the difficulty of tasks and the readiness of the student dynamically, in the learning process. Its use does not imply the presence of a large bank of calibrated tasks and estimates of various parameters that appear in other models. This allows you to organize an adaptive selection of tasks quickly, simply, and cheaply.

An intelligent analytical diagnostic system for teaching elementary mathematics problem-solving was implemented under the Windows operating system. It will be posted on the Internet after full approbation and receipt of the author's certificate. The analysis of the system will allow us to further modernize the methodology for creating cognitive tools for analyzing the learning process and achieve more effective results of mastering the educational material by students for the formation of skills to solve computational problems.

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