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THE CONCEPT OF INTELLIGENT TRAINING SYSTEM FOR UKRAINIAN SCHOOL FINAL STEM EXAM PREPARATION

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Abstract. The National Multi-subject Test has been prepared and conducted in Ukraine in online learning conditions for several years. Test results show a decline in schoolchildren's performance in mathematics. The article presents a prototype of an intelligent training system for solving mathematical problems that should become an accessible test preparation tool. The system provides a solution to a wide range of mathematical problems in a step-by-step mode. The system is developed in accordance with the principle of rational management by diagnosis, which implies the presence of many diagnostic models. It allows for deep diagnostics of student errors. Artificial intelligence tools will make it possible to implement individual recommendations for each student, taking into account their level of preparation and learning goals.

Keywords: intelligent tutor system, National multi-subject test, math problems.

INTRODUCTION

The traditional education system was formed in the conditions of gradually increasing volumes of information and focused on the formation of a certain critical amount of knowledge, on the basis of which the necessary skills were formed. In modern conditions of digitization and exponential increase in information load, even a highly qualified instructor is not able to effectively adapt the educational process to each pupil or student in the class (group), also taking into account the need for inclusive education.

Intelligent Tutoring Systems (ITS) are effective tools of solving the problem. At the same time, none of the developed ITS has yet approached the effect of individual learning described by the famous American psychologist B. Bloom: the average success rate of a student who learns individually can be better than the success rate of 98% of students who learn in a traditional way: one mentor for thirty students.

Thus, the development of ITS is relevant for improving the efficiency and quality of education, which allow to combine, within the requirements of the modern educational system, the existing methodical and pedagogical experience of leading mentors with an individual approach to the education of each of the

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pupils and students with different basic levels of training, motivation and peculiarities of perception information

The paper proposes the author's scientifically based viewpoint at the technology of creating ITS in exact sciences for preparation for the National multi-subject test (NMT).

LITERATURE REVIEW

The paper [1] proposes a taxonomy of artificial intelligence (AI) methods used in digital tools for teaching mathematics. The taxonomy consists of four categories that cover the entire range of such AI systems:

1. Information Extractors to denote AI technologies that take observations from the real world (test, audio, images) and transform them into a mathematical representation.
2. Reasoning Engine, which includes all software systems capable of automatically solving a mathematically formulated problem.
3. Explainers, i.e., the field of explanatory artificial intelligence research that deals with the development of artificial intelligence methods that produce interpretable models and interpretable solutions.
4. Data-driven Modeling, where methods of intelligent data analysis and machine learning are used to analyze this data and turn it into practical models.

In [2], an intelligent tutoring system for mathematics uses the author's ITSB tool with four modules — domain, learning, student, and user interface — coordinated by the training module. The system collects personal and academic data, tracks student progress, and adapts learning paths based on profiling and activity monitoring.

In [3], an intelligent system teaches fractions multiplication and division via adaptive dialogue, identifies errors in real time, and employs cognitive conflict, problem simplification, and representative learning.

In [4], an AI-based system improves mathematics education strategies in underprivileged regions by integrating rating scales, norms, improvement strategies, and an intelligent assessment program. It diagnoses learner performance in batches and automatically proposes targeted improvements.

Scientists of the National Aerospace University "Kharkiv Aviation Institute" proposed their own approach to the creation of intellectual educational programs. The article [5] discusses the technology of building intelligent computer programs for learning algorithms. The subject area of study is an algorithmic tasks which are characterized by properties of determinism, mass and efficiency. Developments are based on an approach to the rational control of objects in conditions of partial uncertainty. Proposed information technology based on an approach to the rational control of objects in conditions of partial uncertainty.

The process of step-by-step solution of algebraic equations is considered in the article [6]. On the basis of the signal-parametric approach to diagnostics of faults in dynamic systems the mathematical diagnostic models are created which allow detecting classes of errors by comparing the results of Student's calculations and the results of system calculations. The approach to the formalization of the generation of problem situations applicable to the development of tutoring programs consisting of many tasks is considered in [7]. The parametric generation method proposed in the article allows getting the large quantitative variations in task problem situations. Thereby, every learner will get a personal unique set of tasks.

In [8], OnlineMSchool offers math problems of varying complexity and online calculators that show step-by-step solutions.

In [9], IXL Learning provides interactive exercises, personalized recommendations, and real-time diagnostics for math and language skills.

In [10], Khan Academy delivers free, self-paced courses across various subjects, featuring thousands of videos, adaptive exercises, and progress tracking. Its paid AI tool, Khanmigo, uses ChatGPT technology to serve as a personal tutor for students and an assistant for teachers.

LearnBop [11] is a virtual system guiding children step-by-step through math problems, pinpointing gaps in foundational knowledge. Uses images, graphics, and video hints (via LearnZillion). Teachers can customize lessons, track progress, and assign interventions with the built-in LMS. Children enjoy the panda mascots during lessons.

Mangahigh [12] is a web platform offering math games, tutorials, and tests aligned with Common Core standards, covering fundamentals from counting to early algebra and geometry. Learning adapts to the learner's level, and wrong answers come with explanations. More practice variety could further enhance skill depth.

GeoGebra [13] is a free program enabling students to create, visualize, and manipulate mathematical models in algebra, geometry, and more. It has browser and mobile versions, with a vast library of ready-made resources. Though there's a learning curve, its interactive approach helps students explore and understand math concepts hands-on.

CueThink [14] introduces Thinklets: four-step solutions — Understand, Plan, Solve, and Revise. Students view teacher assignments, create videos showing their solutions, and share them with peers for feedback. Tools like markers and notebooks support each step, fostering collaboration and deeper problem-solving skills.

WeBWorK [15] is a free Perl-based system (launched in 1995) for online math homework, developed at the University of Rochester. Gives students immediate feedback, encouraging multiple attempts. Distinguishes itself by integrating LaTeX with Perl for flexible problem generation.

In turn, IMathAS [16] is an internet-based math assessment system generating algorithmic questions with numeric or symbolic answers. Includes learning-control tools, shows math and graphs accurately, and accepts simple calculator-style inputs..

WirisQuizzes is a tool for creating STEM assessments with equations, graphs, or text answers, automatically graded. Random parameters help prevent cheating. It integrates seamlessly with different systems, allowing dynamic question generation in real time.

Recently, many math-focused educational resources have begun using generative AI (e.g., ChatGPT). While machine learning has advanced significantly, including ChatGPT, it lacks a "true understanding" of math and can struggle with structured computation. Though ChatGPT may generate plausible explanations, it is often unreliable for precise answers. A solution involves connecting ChatGPT to Wolfram|Alpha, whose computational "superpowers" rely on Wolfram Language [17] for exact code and computations.

Another interesting study in the direction of the application of AI for mathematics was presented by the division of the Google company Deepmind. AlphaGeometry [18] solves complex geometry problems at near — Olympic gold medalist level, a notable breakthrough in AI. In testing with 30 Olympiad geometry problems, AlphaGeometry solved 25, compared to 10 by the previous best system and 25.9 by the average gold medalist. AI often struggles with complex geometry due to limited reasoning and training data. AlphaGeometry tackles this by merging a neural language model's predictive power with a rule-based deduction engine.

Thus, the possibilities of preparing for the NMT in mathematics are quite powerful, schoolchildren and teachers can choose the tools at their discretion and estimate the effectiveness of learning on trial tests that have been developed by the Ukrainian Center for Education Quality Evaluation. On the other hand, we will analyze the results of last year's testing of Ukrainian students within the NMT, using data from the official report [19].

The certification work contains tasks of various forms:

1. Tasks 1–15 with the choice of one correct answer (1 point).
2. Tasks 16–18 for matching, determining "logical pairs" (3 points).
3. Tasks 19–22 open form with a short answer (2 points).

The maximum number of points that could be obtained by correctly completing all the tasks of the certification paper in mathematics is 32.

The mathematics test was included in the main block of the NMT, the subjects of which were mandatory for all test participants. Fig. 1 shows the distribution of mathematics test participants by the number of test points scored. The diagram shows that the vast majority of participants scored less than 10 points, which is a very low indicator for the possibility of further study at a university.

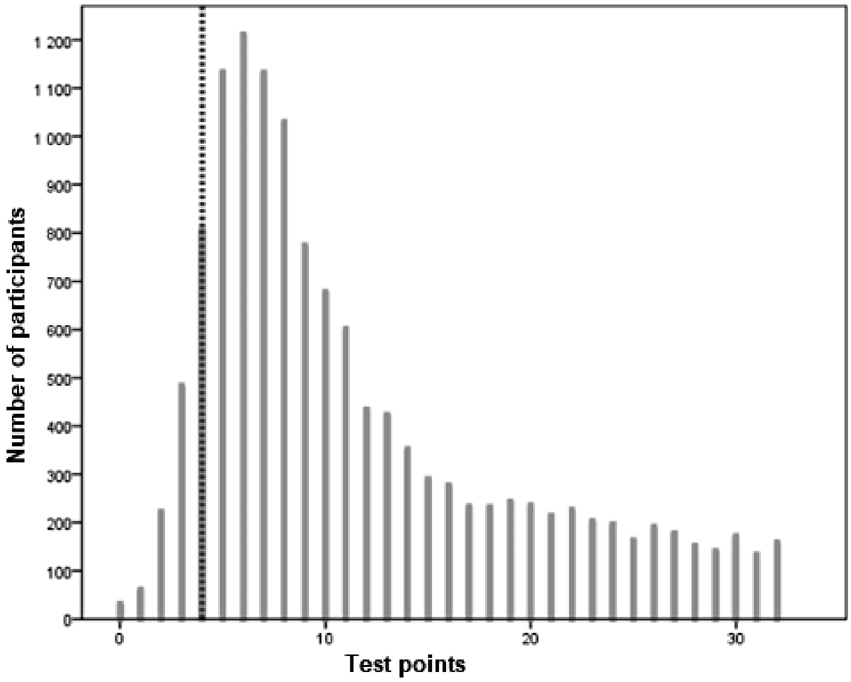

Fig. 1. Distribution of mathematics test participants by the number of test points scored

The share of competence tasks, namely: the task of constructing a pie chart according to a known distribution, calculating the percentage of a number, classifying a body formed as a result of the rotation of a geometric figure around an axis, and the combinatorial task of determining the number of options using combinations and multiplication rules — was 23 % of all test tasks.

The analysis of the results of the tasks of the certification work showed that even the tasks for checking the level of formation of basic skills and abilities and their application when solving standard problems cause difficulties for the participants. The number of such tasks was two-thirds of the total number of certification work tasks. For example, 48% of participants successfully coped with task 6 on the reproduction of facts (determining the zero of the function according to the given graph). Problem 20 from combinatorics caused the greatest difficulties, only 12.7% of those tested gave the correct answer.

The statistical indicators of the NMT tasks have slightly deteriorated compared to the corresponding indicators of the VET tasks of previous years. Thus, in 2020, more than two-thirds of the participants completed the task of determining the zero of the function according to the given figure, and in 2023, less than half. In 2020, 60% of the test subjects completed a short-answer task to check the financial literacy of participants, which involved finding percentages from a number, and in 2023, only 53.6% completed a similar task with choosing the correct answer from five offered [20].

The analysis of the statistical indicators of the certification work revealed a high distributive ability of the test tasks with an average score of 56.7, which made it possible to single out the participants prepared for study in higher education institutions.

The analysis of the results of the NMT in mathematics for the past year, as well as the tendency of deterioration of performance indicators in previous years, makes the task of improving the methodology of preparing for the NMT in mathematics with the help of intelligent computer training programs an urgent and important task.

THE LEARNING PROCESS FROM THE POINT OF VIEW OF CONTROL THEORY

There are three classical control principles: impact control, disturbance control, and deviation control. They allow you to achieve the goal in different ways.

Many destabilizing factors — well-being, mood, motivation, and a student's initial preparation — affect progress toward learning goals. We can't effectively manage these without identifying them through interaction with the student. A different approach, the principle of control by diagnosis, is needed to address these challenges.

Let's consider the application of various control principles in the educational process.

When teaching calculation skills (e.g., in math, physics, or chemistry), two types of teachers illustrate how control principles are applied: Schematically, such a learning process can be represented by the following diagram (Fig. 2).

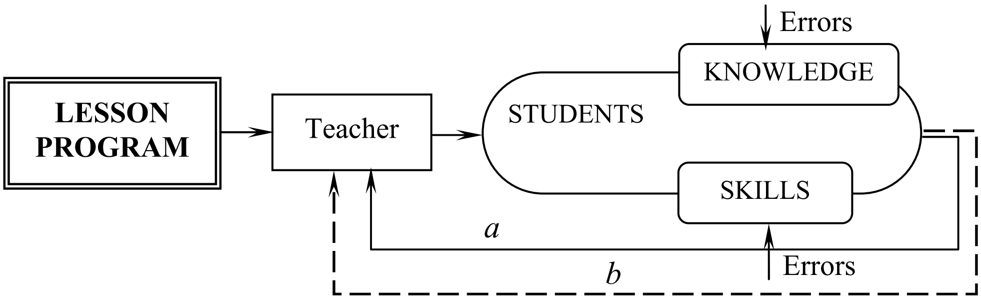

Fig. 2. Scheme of training control: *a* — regular; *b* — irregular

Teachers (Fig. 2, *b*) follow formal procedures and schedules without deeply checking each student's work, feedback is irregular, only at control points or at the end of class, quality and efficiency suffer because errors are not addressed quickly

Professional teachers (Fig. 2, *a*) provide ongoing, personalized feedback. They regularly identify errors, clarify misunderstandings, and strengthen student motivation. This "vector feedback," or continuous monitoring and correction, aligns with personalized training methods and achieves the highest efficiency and quality of learning.

High efficiency and significant quality of skill training are achieved with individual training. With such training, the teacher has the opportunity to identify "gaps" in knowledge, reasons for misunderstanding the theory, errors in the ability to apply theoretical knowledge in the practice of calculations, weak motivation and a number of other reasons for imperfect ability to solve calculation tasks, as well as to quickly increase the level of knowledge and the necessary skills to overcome the difficulties found in the student. The learning control process in this case is based on operational system diagnostics of the student's knowledge and skills (Fig. 3).

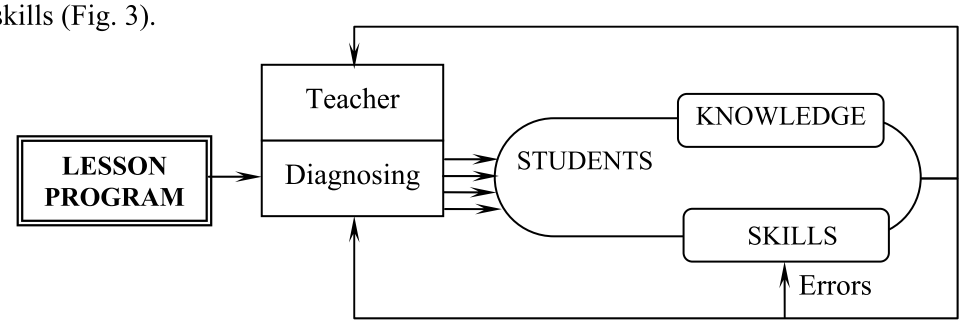

Fig. 3. Scheme of rational training control

In such a learning process, the teacher has more opportunities to diagnose the causes of errors made when solving the calculation task, as well as more opportunities to eliminate them with help the involvement of additional material that is more accessible to this student with the help of an insightful explanation of the causes of errors and ways to eliminate them. Diagnosing errors in this learning process is a highly intellectual type of teaching activity that allows you to identify weaknesses in the student's training in the ability to acquire new knowledge and use it in practical activities, in motivation.

Productive control of skill training is based on the use of the principle of diagnosis control [22].

Based on the results of the analysis of the above principles, and taking into account the work created by Professor A.S. Kulik approach to the rational control of objects in conditions of partial uncertainty was formed by the block diagram of the system of rational control of education with the help of ITS, depicted in Fig. 4.

As shown in figure the 6 main blocks in the learning control system with the help of ITS are the student diagnosis and modeling block (BDMO), as well as the learning action selection block (BBBV). Through the feedback channel, the data entered by the students in the IKOP are sent to the BDMO. In addition, as input actions on the BDMO, the necessary KZU and reference data are required in the ITS. BDMO affects BVOV by transferring the diagnosis, and even the model of the student.

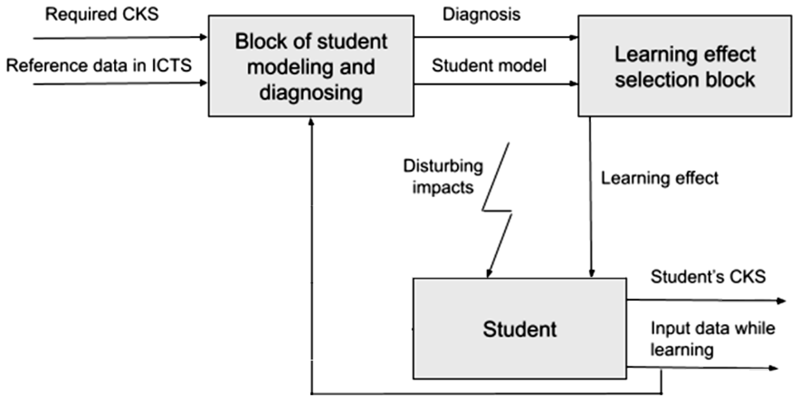

Fig. 4. Block diagram of the system of rational control of training with the help of ITS

PECULIARITIES OF THE COMPUTER IMPLEMENTATION OF THE PRINCIPLE OF CONTROL BY DIAGNOSIS

The principle of control by diagnosis has been applied in various projects focused on rational control of physical objects, using diagnostic models and knowledge bases on emergency behavior. Its computer-based implementation for training involves breaking down calculation tasks into stages, each producing intermediate numerical results for verification. Since mistakes can occur at any operation, each stage's result is compared with a reference outcome. Errors are then diagnosed by locating the incorrect operation and identifying the specific error. This step-by-step diagnostic process relies on a detailed solution model, making a production knowledge base and dichotomous tree structure ideal for implementing diagnostic control.

The consolidated structure of the curriculum, which implements the principle of diagnosis control, can be presented graphically in the following way (Fig. 5).

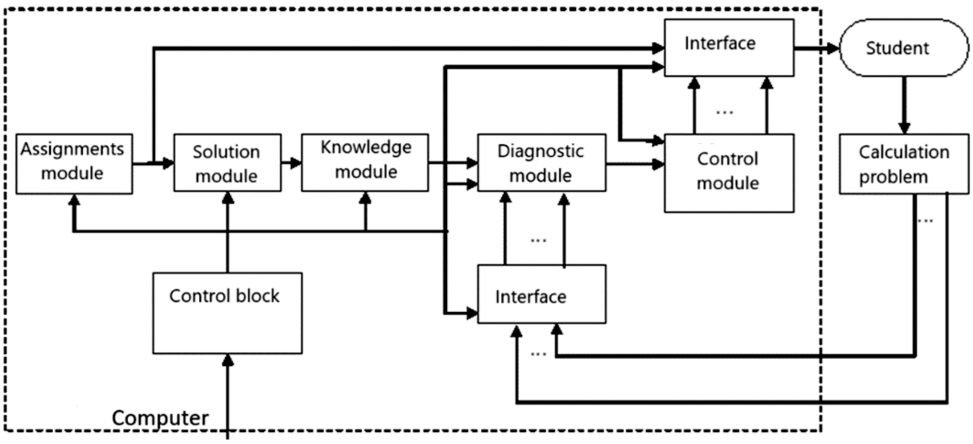

Fig. 5. Scheme of learning skills using the principle of diagnosis control

The scheme presents the functionally necessary software modules for the implementation of the principle of control based on the diagnosis. In the key module — the diagnostic module, a step-by-step program for diagnosing the results of student problem solving is implemented.

The module receives data from the knowledge base (machine solution) and the student's solution. After diagnosing the student's errors, it sends the results to the resource control module, which provides explanations and guidance for correction. The student then recalculates the problematic stage, iterating until their results match the correct solution. A control unit synchronizes all modules, and upon completion, generates performance indicators and an assessment of the student's ability. This iterative process arises due to insufficient preparation and the inevitable calculation errors.

A GENERAL APPROACH TO COMPUTERIZED LEARNING

The learning process is realized by a combination of internal and external cycles. The process of problem solving forms an internal learning cycle.

The student receives a task. He can immediately go to the answer or choose a step-by-step mode. In the step-by-step mode, he receives hints previously created by the teacher and implements his solutions. In this, it performs both calculations and symbolic or graphic transformations. If the answer is correct, it is highlighted in green and the student can proceed to the next task. If an incorrect solution is entered at the next step, the system issues the message "Think!" without specifying what the error is. The student can correct the error himself or ask for a hint. In the case of a repeated error, the input field is highlighted in red, visualizing the incorrect component of the solution. At the next error, built-in models are included to search for the cause of the error and generate an individual prompt. If the student could not complete the task, he can request a solution to this step. The correct solution is filled in by the system and highlighted in orange, after which the Student is prompted to proceed to the next step. The internal cycle is schematically presented in Fig. 6, 7.

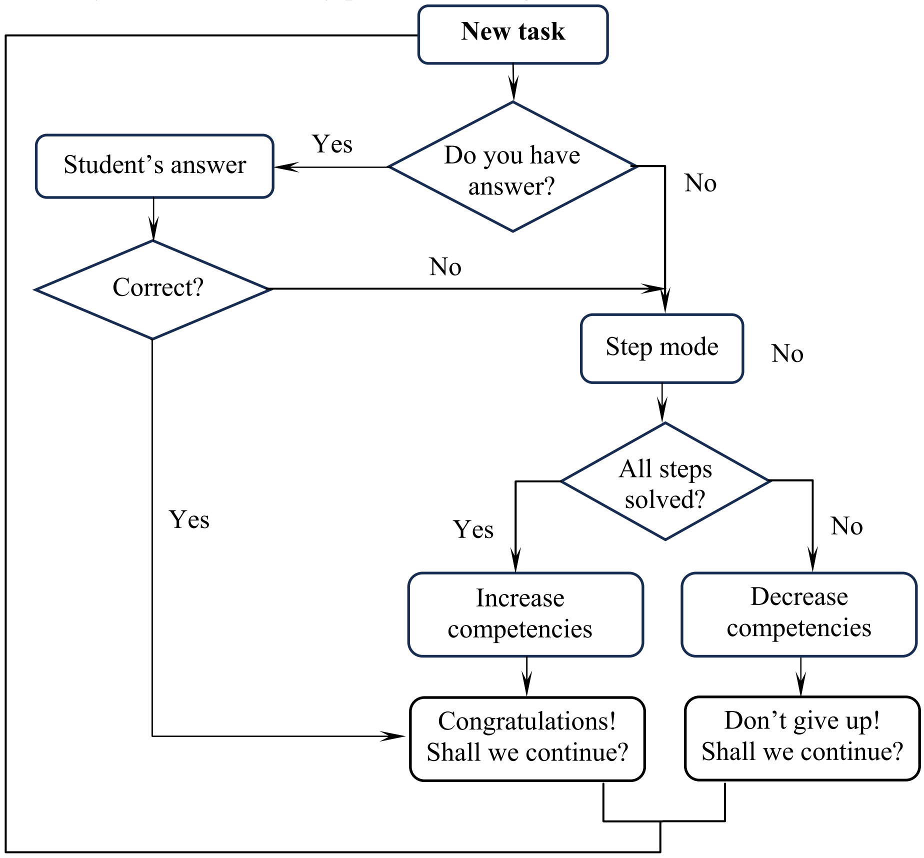

Fig. 6. Internal cycle of solving the task

The external cycle manages the learning process depending on the achieved competencies and the results of solving tasks. It can be presented schematically in the form of a Table 2.

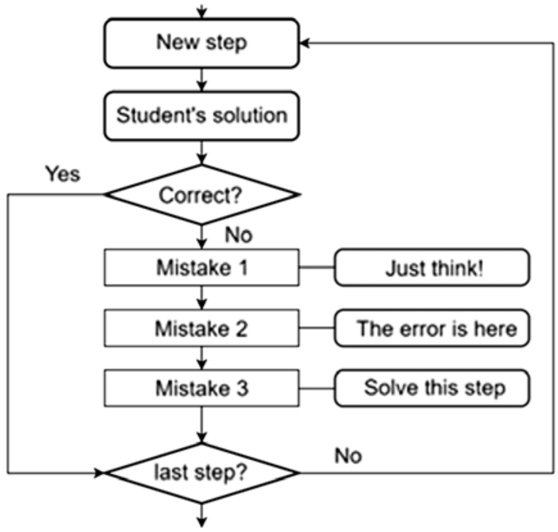

Fig. 7. Step mode

T a b l e 2 . External cycle of task selection

		Last task solved	
		Correct	Incorrect
Competencies level	High	Suggest a high difficulty problem or move on to the next section	Decrease the competency level and suggest the next task
	Low	Increase competency level and offer a more complex task	Decrease the competency level and: – offer work in demo mode; – recall theoretical material; – propose a simple task

The choice of the next task depends on the results of solving the previous one and previously achieved competencies. If the student successfully coped with the task, he is offered a more difficult task or a transition to the next chapter. If he made a mistake, and before that he had a high level, another task is offered. If he had a low level of competence and made mistakes again, he is offered a simpler task, as well as an opportunity to familiarize himself with the solution of tasks in a demonstration mode, that is, without evaluation. In addition, links to the theoretical material, which is desirable to repeat, are offered.

Based on the results of solving the problem, the student's level of competence is assessed on a probability scale (the probability of mastering this competence ranges from 0 to 1). Initially, it is equal to 0.5. Successful decisions increase this possibility, and mistakes decrease it. Achieving a level of 0.95 means mastering this competency.

Systematically modeling effective pedagogical activity, we will get three modes of operation of ITS: demonstration, training and test (Fig. 8). Thus, first the instructor explains the new material, demonstrating how new tasks for the students are solved, then calls the students to the blackboard and formulates tasks from the considered class of tasks, while helping the students in case of difficulties or wrong actions. Finally, to test the acquired knowledge and skills, the mentor gives homework or a control work, which the students solve independently, without prompts.

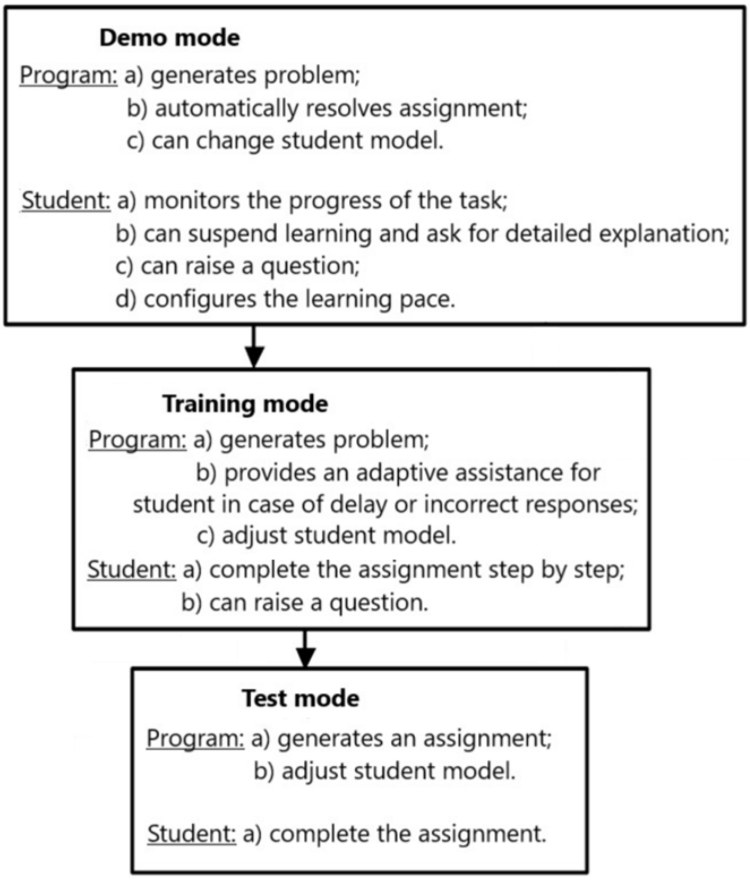

Fig. 8. Operating modes of education al programs

In the second mode, the task is formulated by the program, and the learner must complete it step by step. In case of mistakes or substitutions of the student, the ITS can give him a hint. The student can also ask questions to the program.

In the third mode, the task is formulated by the program, and the learner has to complete it. Unlike the previous mode, hints are not available. Also, the student does not have the opportunity to ask the program questions.

In order to develop stable skills for solving mathematical problems, the student must solve a number of problems of a certain class, which differ in conditions and numerical parameters. This increases the degree of assimilation of competencies, and also prevents memorization of answers to improve results when retaking tests. For this, it is necessary to ensure:

1) a set of meaningful statements for individual classes of mathematical problems (if possible);

2) the possibility of generating random numerical parameters for all classes of tasks.

To store problem templates in the system, the LATEX format is used — the data markup language and the TeX macro package, which is considered the de facto standard for preparing mathematical and technical texts for publication in scientific publications [109].

When the task template is entered, the teacher will have several fields assigned to different areas on the student's screen, which he can use to fill out in LATEX format. Numerical parameters are generated according to the scenario defined by the teacher.

For example, a hint template for one of the steps of a vector algebra task looks like this:

```
step_21_2.Text_Sample ="We got the equation \n\n"+ \
"$\overrightarrow{{AB}}({task21.xab}; {task21.yab};
{task21.zab}) = \overrightarrow{{(({task21.xb})- xa;
{task21.yb}) – ya; ({task21.zb}) - za)}}$ \n\n" + \
"Deduce from it equations for individual coordinate compo-
nents in the form: \n\n"+ \
"$xab=xb-xa$, \n\n"+ \
"$yab=yb-ya$, \n\n"+ \
"$zab=zb-za$, \n\n"+ \
"where $\overrightarrow{{AB}}(xab; yab; zab)$ -
coordinates of the vector $\overrightarrow{{AB}}$"
```

After its interpretation by the program and generation of numerical parameters, we will get the prompt shown in Fig. 9.

We got the equation

$\overrightarrow{AB}(-3;8;1) = \overrightarrow{((7) - xa; (-2) - ya; (0) - za)}$

Deduce from it equations for individual coordinate components in the form:

$xab = xb - xa$,

$yab = yb - ya$,

$zab = zb - za$,

where $\overrightarrow{AB}(xab; yab; zab)$ - coordinates of the vector $\overrightarrow{AB}$

Fig. 9. A hint for a step-by-step solution of the problem with generated numerical parameters.

By storing parameter-generation and calculation functions as scripts in the database, the system can dynamically create a new, unique set of problems each time a student takes the test. This not only prevents students from memorizing fixed question sets but also promotes deeper understanding and problem-solving skills through repeated exposure to varied task scenarios.

Thus, each time the student passes the test, he receives a unique set of tasks generated just for him.

To increase the motivation of students in the programs, it is advisable to implement the game principle. The prototype uses playful, step-by-step interaction to keep students engaged. By "peeling the nuts" (solving each part of the problem in sequence) and assembling correct answers like puzzle pieces, learners gain a sense of exploration and achievement. Game elements such as immediate feedback, hints, and visual cues transform the learning process into an enjoyable experience.

Students have the option to either enter the final answer directly or work through each stage of the solution. This approach fosters incremental learning: students can pinpoint exactly where they go wrong and receive immediate guidance on how to correct it. Over time, these targeted corrections reinforce strong problem-solving habits.

By tracking each step and offering just-in-time assistance, the system helps students identify and rectify misconceptions before they become entrenched. This ultimately leads to more stable competencies in arithmetic, algebraic manipulations, and other targeted math skills.

In Fig. 10 shows screen forms of the process of step-by-step solution of one of the NMT problems. The student has the opportunity to immediately enter the answer, or to solve the problem step by step, peeling the “nuts”. At each step, he assembles the correct answer, like a puzzle, by dragging the pieces of the answer (correct or incorrect) into the corresponding fields. If necessary, he can get additional information.

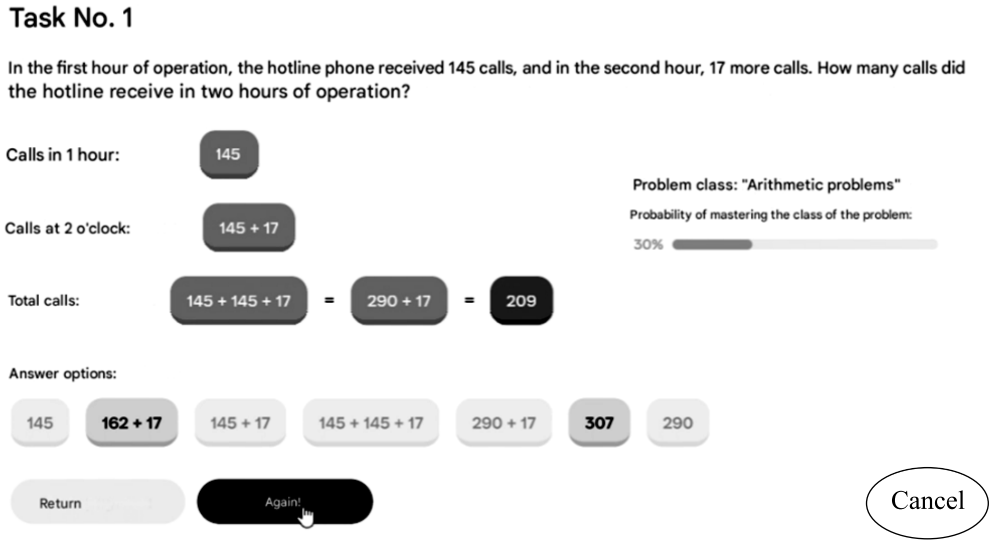

Fig. 10. An example of a screen for a step-by-step solution to a mathematical problem

In this way, the student in a playful way solves a number of tasks of a certain class, forming and consolidating the relevant competencies.

CONCLUSIONS

We have presented an author’s vision of a modern Intelligent Tutoring System (ITS) for exact sciences, particularly mathematics, aimed at preparing Ukrainian schoolchildren for the National Multi-Subject Test. A functional prototype has been developed to demonstrate how diagnostic control, real-time feedback, and adaptive guidance can be effectively combined.

Our prototype employs structured knowledge bases, algorithmic problem generation, and iterative error diagnosis. This design ensures that each step of a student’s solution can be systematically monitored and corrected, demonstrating a high level of scientific rigor in both pedagogy and software engineering.

Through an analysis of existing tools and research, we identified critical gaps in personalized learning and feedback mechanisms within mathematics education. The prototype addresses these gaps by incorporating specialized modules for real-time assessment and targeted remediation.

Based on the prototype’s initial success, the future goal is to refine and deploy the ICNP software throughout Ukraine. Further development will focus on expanding the system's capabilities, integrating additional educational resources, and conducting large-scale trials to validate its effectiveness and scalability.

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КОНЦЕПЦІЯ ІНТЕЛЕКТУАЛЬНОЇ КОМП'ЮТЕРНОЇ НАВЧАЛЬНОЇ СИСТЕМИ ДЛЯ ПІДГОТОВКИ УКРАЇНСЬКИХ ШКОЛЯРІВ ДО НМТ / А.С. Кулік, О.П. Зеленяк, А.Г. Чухрай, О.В. Прохоров, О.С. Яшина, О.В. Гавриленко, О.О. Євдокимов, А.А. Торжков, О.В. Заярний

Анотація. Уже кілька років підготовка та проведення національного мультипредметного тесту (НМТ) в Україні відбувається в умовах онлайн-навчання. Результати тестування показують зниження успішності школярів у математиці. Подано прототип інтелектуальної навчальної системи для розв'язування математичних задач, яка має стати доступним засобом підготовки до тестування. Система забезпечує вирішення широкого кола математичних задач у покроковому режимі. Систему розроблено відповідно до принципу раціонального керування за діагнозом, що передбачає наявність багатьох діагностичних моделей. Це дає змогу поглиблено діагностувати помилки учнів. Інструменти штучного інтелекту дозволять реалізувати індивідуальні рекомендації для кожного учня з урахуванням його рівня підготовки і цілей навчання.

Ключові слова: інтелектуальна репетиторська система, національний мультипредметний тест, задачі з математики.