UDC: 372.851
DOI: 10.15587/2519-4984.2025.345529

FEATURES OF THE DEVELOPMENT AND IMPLEMENTATION OF AN ADAPTIVE TEST ON THE TOPIC "INEQUALITIES"

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The article examines the features of preparing and implementing an adaptive test on the topic "Inequalities" within a practice-oriented adaptive technology for reviewing the school mathematics course. It is shown that the usage of an adaptive approach contributes to the development of an individual learning trajectory, taking into account students' cognitive characteristics, learning pace, and possible learning losses. The structure of the "Inequalities" section is described, which includes six topics: linear, quadratic, rational and fractional rational, exponential, logarithmic inequalities, as well as systems of inequalities. The integration of tasks with parameters, inequalities containing the absolute value sign, and those solved graphically is substantiated within the defined six topics.

An algorithm for task coding has been developed to form a test bank that enables the automatic selection of tasks of various difficulty levels (elementary, intermediate, sufficient, and advanced) and forms (multiple choice, matching, and open-ended short-answer tasks). An example of a diagnostic test structure is presented, demonstrating the system's ability to analyze learners' achievement levels and to construct an individual section map. The didactic and technical advantages of using adaptive tests at the stage of review and systematization are identified, including immediate feedback, increased motivation, and student engagement.

It is noted that the results of the approbation confirm the correctness of the task selection algorithm, while also indicating the need for further expansion of the bank of combined tasks. The prospects for further research are related to the implementation of adaptive testing for other content lines of the school mathematics course, the development of profile-level tasks, and the optimization of the software to enhance the system's autonomy and reliability

Keywords: *adaptive learning, adaptive tests, review and systematization, inequalities, item bank, individual learning trajectory, external mathematics assessment, national multi-subject test, school mathematics course, diagnostic test*

How to cite:
Boiko, Y. (2025). Features of the development and implementation of an adaptive test on the topic "inequalities". ScienceRise: Pedagogical Education, 4 (65), 4–9. http://doi.org/10.15587/2519-4984.2025.345529

1. Introduction

The mathematical education domain aims to develop students 'mathematical competence at a sufficient level to ensure effective functioning in the modern world and successful acquisition of knowledge in other educational domains during school learning. However, the results of the state standardized mathematics test within the National Multi-Subject Test (NMT) indicate that even tasks designed to assess the level of mastery of basic skills and their application to solving standard problems pose significant challenges for students [1]. Moreover, the findings of the international PISA study reveal a decline in the level of mathematical competence among Ukrainian students [2]. These results prompt the search for new or the adaptation of existing approaches to mathematics teaching, particularly concerning revision and systematization as integral components of the learning process.

Review and systematization of mathematical knowledge, skills, and abilities acquired throughout the course of complete general secondary education constitute an essential aspect of forming students' holistic understanding of the competencies developed during the study of such subjects as Algebra and the Fundamentals of Analysis and Geometry. One of the means of implementing the learner-centered paradigm of education during the final revision is the use of adaptive learning technologies. An individual revision trajectory makes it possible to account for students' varying levels of topic mastery, their cognitive characteristics – including learning pace and preferred modes of information processing – as well as potential learning losses.

The article "A Conceptual Model of a Practice-Oriented Adaptive Technology for Reviewing the School Mathematics Course" [3] presents the author's approach to implementing final mathematics revision for high school students through the use of adaptive learning technologies. This conceptual model is practice-oriented, with the core of the system's adaptivity grounded in the presence of a task bank structured by topics, levels, and formats.

One of the key content lines of the mathematics course taught within the framework of complete general secondary education is "Equations and Inequalities". In the proposed conceptual model, this content line is represented by two corresponding sections: "Equations" and "Inequalities" [3]. Therefore, we propose to examine in greater detail the specific features of implementing the practice-oriented adaptive technology for revision and systematization of the algebra course, using the section "Inequalities" as an example.

2. Literature Review

The active use of digital technologies by modern adolescents has a range of both positive and potentially problematic consequences. In particular, within the educational process, where students are accustomed to a digital environment rich in stimuli, a number of challenges arise for traditional instruction; however, this also creates new opportunities for the development of adaptive learning environments [4].

Most often, adaptation is carried out based on students' current performance results and contributes to increasing their engagement and motivation. The effectiveness of such an approach also depends, among other factors, on the level of pedagogical reflection demonstrated by the teacher and on the alignment of technological tools with the intended educational goals [5]. These considerations lead to the conclusion that, despite the predominantly automated nature of adaptivity, the teacher remains an integral component in the implementation of this learning technology, as it is the teacher who defines the learning objectives. Nevertheless, delegating routine processes enables the teacher to devote more time to developing learning strategies. For example, AI-based adaptive learning systems significantly enhance the effectiveness of revision and systematization of knowledge through instant feedback and flexible control of task difficulty [6]. In addition to providing instant feedback, an important aspect of using adaptive technologies lies in their extensive capabilities for learning analytics and the development of students' cognitive models [7]. Furthermore, the integration of visual, auditory, and kinesthetic elements within e-learning environments enhances student engagement and promotes more effective knowledge acquisition [8].

According to the research by Simon and Zeng, teachers' attitudes toward the use of adaptive learning technologies are generally positive. However, despite acknowledging the potential of adaptive technologies to enhance learning effectiveness, a number of challenges are also identified, including a lack of time, insufficient technical training, and limited methodological guidance [9]. Similar tendencies can be observed in communication with teachers in Ukraine regarding their perception of adaptive technologies. The need for appropriate software tools and methodological support encourages the development of technical and didactic means of adaptive learning that align with the current mathematics program for upper secondary school.

3. Research aims and objectives

The purpose of the study is to describe the didactic and structural features of training tasks for the section "Inequalities" in the system of practice-oriented adaptive technology for reviewing the school mathematics course.

To achieve this goal, the following objectives were set:

1) To specify particular content aspects within the structure of the "Inequalities" section in accordance with the selected thematic division;

2) To specify the general task-encoding algorithm for the "Inequalities" section, including for combined tasks;

3) To conduct a pilot implementation of adaptive testing for the "Inequalities" section and analyze the accuracy of task selection according to the described technology.

4. Materials and Methods

The study utilized methodological materials, such as algebra and geometry textbooks for grades 7–9 (standard level), mathematics textbooks (algebra and the fundamentals of analysis, and geometry) for upper secondary school (standard level), the current External Independent Evaluation (EIE) mathematics program, certification test items from previous EIE exams, and sample mathematics test materials from the National Multi-Subject Test (NMT) in 2023 and 2024, as presented in the official reports of the Ukrainian Center for Educational Quality Assessment (UCEQA). Additionally, collections of mathematics problems developed for EIE (NMT) preparation were used.

Among the technical tools employed were the Classtime testing platform, a prototype of the developed software for adaptive tests, the Canva graphic design platform, and artificial intelligence tools used for creating adaptations of certain tasks.

The study employed a combination of methods, including analysis of scientific and methodological sources, synthesis, comparison, systematization, generalization, and modeling. The theoretical and didactic foundations of the development include the technology of structural-logical schemes and reference outlines, information and communication technologies, microlearning, interactive and adaptive approaches, as well as elements of gamification.

5. Research Results and Discussion

The development of the skill to solve inequalities is important not only for tasks that directly require finding the solution set of an inequality, but also for analyzing the properties of functions, particularly when determining their domains of definition — for example, in the case of logarithmic functions or those involving even-degree roots. Since the "Inequalities" section within the practice-oriented adaptive revision system is introduced after the study of functions, it is logical to include tasks on determining the domain of functions within the system of inequality-related exercises.

The “Inequalities” section includes six chapters:

1) Linear inequalities;

2) Quadratic inequalities;

3) Rational and fractional-rational inequalities;

4) Exponential inequalities;

5) Logarithmic inequalities;

6) Systems and sets of inequalities.

Although irrational inequalities are not included in the current mathematics curriculum at the standard level, it is assumed that such inequalities as $\sqrt{x} \geq 0.5x$ could be solved using the graphical method. However, since the graphical method is not presented as a separate topic, tasks of this kind are assigned to the “Functions” section, while also linking them to the lesson on the graphical approach to solving inequalities.

It should be noted that such types of inequalities as inequalities with a modulus, parameter-based inequalities, and inequalities solved by the graphical method are not identified as separate topics. The reason is that these types of problems are integrated throughout and can be traced across all previously defined topics.

Inequalities with a modulus. Within the topic “Linear inequalities”, we consider the simplest cases of inequalities containing an absolute value. Other types of inequalities with a modulus are approached through their reduction to simpler cases or by applying the absolute value definition rule.

If students make systematic errors when solving inequalities with a modulus, even though they confidently handle analogous inequalities without it, it is advisable to review the properties of absolute value, revisit the absolute value definition rule, and reinforce practical skills in transforming expressions that contain a modulus.

Parameter-based inequalities. In this regard, we adhere to the position that it is advisable to introduce parameters at the initial stage of studying the section [10], in particular by examining the simplest linear and quadratic inequalities with parameters while discussing the algorithm for their solution.

The graphical method is also integrated into each of the identified topics. Tasks involving its application can be conditionally divided into two groups:

1) those that use pre-drawn graphs, where students are not required to construct or recognize function graphs;

2) those that require the ability to plot or identify graphs of elementary functions.

In the first group, it is sufficient to focus on explaining the algorithm for solving inequalities graphically and, if necessary, to clarify the concept of coordinates and the names of the coordinate axes. In the second group, if systematic errors are observed (provided that tasks of the first type are performed correctly), it is advisable to return to the material covered in lessons on the properties and graphs of elementary functions and to reinforce the required skills through targeted practice exercises.

Note that during the revision of rational and fractional-rational inequalities, we focus on using the interval method as the main method for solving them.

When studying exponential and logarithmic inequalities, attention is drawn to the similarity of their solution algorithms, which are based on the monotonicity properties of the corresponding functions. Special emphasis is placed on the domain of the logarithmic function and the range of the exponential function.

The task encoding algorithm used to construct the task bank was presented in the article describing the conceptual model of the adaptive revision technology [3]. According to this algorithm: Latin letter represents the section (D – “Inequalities”); Arabic numeral following it indicates the chapter number within that section; the Latin letters p, q, r, s correspond to the levels of learning achievement (p – elementary, q – intermediate, r – sufficient, s – advanced); the Latin letters x, y, z denote the task format (x – single-choice tasks, y – matching tasks, z – open-ended tasks with a short answer); the number at the end of the code designates the item number within that group of tasks in the bank.

It should be noted that some tasks, particularly those of sufficient and advanced levels of achievement, have a combined nature and may simultaneously belong to several chapters. Exercises of this level of complexity should be offered only when a student has achieved the corresponding level of mastery in all types of inequalities related to the given task.

For example, a high-level task involving the solution of a fractional inequality with a parameter, where the numerator contains an exponential expression and the denominator – a logarithmic one, may be proposed only after the student has successfully completed sufficient-level exercises on fractional-rational, logarithmic, and exponential inequalities.

During the creation of single-choice or matching tasks, we consider it necessary to document the logic of forming options. This makes it possible to subsequently “clone” similar tasks with other numerical or letter data using artificial intelligence tools and obtain correct and equivalent original distractors.

Let us consider an example of the diagnostic test structure and the corresponding summary output, which is displayed on the section map. Table 1 presents the sequence of test items, divided into three stages: the first stage is automatically generated from the bank of intermediate-level tasks; the second stage is generated based on the results of responses to the first set of tasks; the third stage depends on the responses to the second set.

If a correct answer is given to an intermediate-level task (first cycle) within a certain topic, the corresponding second-cycle task for that topic will be of sufficient level. Conversely, if the answer is incorrect, the system will propose an elementary-level task. For topics, in which a student has answered sufficient-level tasks correctly, the third-cycle task will be of high level. If no sufficient-level performance is achieved in any topic, the third cycle will not be generated.

For matching tasks, the table also indicates the topic affiliation of each item; for combined open-ended tasks, the links to specific topics are provided in the column containing the task code breakdown.

Table 1

Example of the diagnostic test structure for the section "Inequalities"

No.	Code	Explanation	Result	Comment
Stage I (intermediate-level tasks automatically generated from the task bank)				
1.	D0qy_5 1) D0{1}qy_5 2) D0{4}qy_5 3) D0{5}qy_5	Intermediate-level matching tasks that include the following types of inequalities: 1) linear 2) exponential 3) logarithmic	1) Correctly 2) Correctly 3) Correctly	In the second cycle of tasks, students will be offered linear, exponential, and logarithmic inequalities of the sufficient level of complexity.
2.	D2qx_2	A quadratic inequality presented as a multiple-choice task.	Mistake	In the second cycle of tasks, students will be offered a quadratic inequality of the basic level.
3.	D3qx_7	A rational inequality presented as a multiple-choice task.	Mistake	In the second cycle of tasks, students will be offered a rational or fractional-rational inequality of the basic level of complexity.
4.	D6qx_q	A system of linear inequalities presented as a multiple-choice task.	Correctly	In the second cycle of tasks, students will be offered a system of inequalities of the sufficient level. This system will include inequalities of the types that were solved correctly in the first cycle of tasks.
Stage II (tasks selected based on the results of responses from Stage I of the test)				
5.	D0py_2 1) D0{2}py_2 2) D0{3}py_2 3) D0{3}py_2	Elementary-level matching tasks that include the following types of inequalities: 1) quadratic 2) rational 3) fractional-rational	1) Correctly 2) Mistake 3) Mistake	For the chapter" Quadratic Inequalities," the student has previously demonstrated an elementary level of learning achievement, while the topic "Rational and Fractional-Rational Inequalities" has not yet been mastered.
6.	D6rx_3	A system of inequalities of the sufficient level, presented as a multiple-choice task.	Mistake	For the chapter "Systems of Inequalities," the student has previously demonstrated an intermediate level of learning achievement, since the sufficient-level task was solved with an error.
7.	D0ry_4 1) D0{1}ry_4 2) D0{4}ry_4 3) D0{5}ry_4	Sufficient-level inequalities, presented as matching tasks: 1) linear 2) exponential 3) logarithmic	1) Mistake 2) Correctly 3) Mistake	For the chapter" Linear Inequalities" and "Logarithmic Inequalities," the student has demonstrated an intermediate level of learning achievement. For "Exponential Inequalities," a high-level task will be offered.
Stage III (high-level tasks selected for the topics, in which a sufficient level has been achieved based on the results of Stage II of the test)				
11.	D4sz_1	A high-level exponential inequality	Mistake	For the chapter "Exponential Inequalities," a sufficient level of learning achievement has been determined, since the high-level task was not completed successfully.

Thus, based on the results of this diagnostic test, it has been determined that the student does not possess the skills to solve rational and fractional-rational inequalities, solves quadratic inequalities at the elementary level, demonstrates an intermediate level of achievement in solving linear and logarithmic inequalities, and system of inequalities, also has mastered the chapter“ Exponential Inequalities” at the sufficient level.

It should be noted that the identified levels of learning achievement will be displayed on the section map and represent preliminary conclusions. These results will be further refined through thematic assessments within the individual topics of this section.

Analyzing the sequence of tasks in this test, we can note the appropriateness of the task types proposed based on the results of previous items. However, it should be pointed out that this particular test generation did not include tasks requiring the application of the graphical method for solving inequalities.

Moreover, despite the previously identified sufficient level in the topic “Exponential Inequalities,” it can be assumed that the student may experience difficulties with sufficient-level tasks that require the substitution method, since quadratic inequalities posed challenges for this learner. This conclusion is considered logical and expected, yet it is not currently generated automatically by the software.

Furthermore, when independently reviewing the test results, the student would not identify this gap in their knowledge and skills, which emphasizes the necessity of pedagogical reflection and analytical interpretation to create an effective individual trajectory of revision and systematization.

One of the shortcomings identified during the testing process is the insufficient number of combined tasks in the task bank, particularly matching tasks. For example, in this test, there were three matching tasks included; however, there have been cases where, at the second or third stage of the test, tasks of this type could not be generated due to the absence of the necessary combination of topics at the corresponding level in the task bank. Therefore, there is a clear need to expand the number of tasks, especially those of a combined nature.

The practical significance of the development lies in the possibility of its application in mathematics lessons in institutions of complete general secondary education or pre-professional education at the stage of reviewing and systematization of knowledge, skills and abilities from the content line “Equations and inequalities”. In addition, given the compliance of the content with the external assessment program in mathematics, the development can be used in preparation for the NMT.

The limitations of the study are related to both didactic and technical aspects of implementation. In particular, the content of the section “Inequalities” corresponds to the requirements of the standard level and therefore does not meet the needs of students studying mathematics at the advanced level.

The software tool developed for implementing adaptive testing requires further validation on a larger sample to confirm its reliability; at present, teacher involvement remains necessary for monitoring and adjustment. For this reason, it is currently difficult to cover a large number of students; however, when used within a single class, the proposed system effectively supports the construction of individual learning trajectories for students.

The prospects for further research include the implementation and validation of adaptive testing for other content lines of the school mathematics program, the expansion of the task bank for the identified chapters, and the addition of new topics tailored to the advanced level of mathematics study. Another important aspect involves the continued validation and optimization of the software tool to enhance its reliability and autonomy.

6. Conclusion

1) The tasks within the “Inequalities” section are divided into six chapters that correspond to the content of the current standard-level algebra program. Parameter-based inequalities and inequalities with a modulus are not designated as separate topics, as such tasks are integrated across all defined topics. The same applies to inequalities solved using the graphical method; however, tasks of this type are also linked to lessons from the “Functions” section.

2) Some tasks have a combined nature, meaning they relate to several chapters within the section. These include matching tasks, where each individual item corresponds to a specific chapter of the section, as well as tasks that require the application of knowledge and skills from multiple topics during their solution.

In the first case, both the task as a whole and each of its individual items are coded as combined, with clarification of their thematic affiliation. In the second case, the task is coded as belonging to the section as a whole, but is programmatically linked to the chapters whose application is required. Each higher-level task of this kind is proposed only if the learner has achieved the previous level of learning achievement in all related chapters.

3) During the pilot implementation of the tests, it was determined that the sequence of task selection generated according to the described algorithm was satisfactory but not always optimal, primarily due to the limited size of the task bank. Accordingly, to conduct large-scale validation of the developed adaptive tests, it is necessary to continue expanding the task bank, particularly by adding combined tasks. The proposed adaptive testing system serves as a tool for learning personalization, but it is not yet fully autonomous and still requires teacher involvement.

Conflict of Interest

The authors declare no conflict of interest, including financial, personal, authorship, or any other influence that could affect the research or its outcomes, presented in this article.

Funding

This research was conducted without any financial support.

Data Availability

This manuscript has no associated datasets.

Use of Artificial Intelligence

The authors employed artificial intelligence technologies within acceptable ethical boundaries to support the provision of their own verified data, as described in the research methodology section. Specifically, the ChatGPT-5.1 and Gemini (Flash 2.5) models were used at the preparatory stage of the study to develop and adapt selected tasks intended for inclusion in the item bank. The accuracy and validity of the generated tasks were reviewed and approved by the author of the article. The use of artificial intelligence tools made it possible to expand the task pool, which increases the likelihood of retaking the test without repetition of identical items and enables the generation of equivalent-difficulty tests with varying content. Thus, the use of artificial intelligence enhanced the diversity of task content but did not alter the research findings.

Authors' contributions

Yuliia Boiko: Conceptualization, Methodology, Investigation, Data curation, Software, Visualization, Writing – original draft, Validation, Project administration.

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Received 30.09.2025
Received in revised form 16.10.2025
Accepted 06.11.2025
Published 30.12.2025

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