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Cognitive Features of Developing Basic Algorithmic Thinking in Students: Based on Formative Algorithms of Assessment and Feedback in the Digital Environment

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Abstract: In the context of digital transformation in education, formative assessment, along with acquiring new qualities through technological tools, contributes to improving the quality of education. This work is dedicated to studying the characteristics of formative assessment in the digital educational environment, focusing on the role of algorithmic feedback systems in developing students' self-management skills. The evolution of feedback from one-time expert reviews to a continuous, individualized, and data-driven process provided by algorithms is analyzed. It examines how automated, timely, and diagnostically enriched feedback contributes to the formation of metacognitive skills in students: goal setting, self-control, correction of learning directions, and reflection. Particular attention is paid to the dialectics of interaction between external, technologically organized assessment processes and internal self-regulation processes. The study is theoretical-methodological in nature and involves a combination of pedagogical, digital didactics, and cognitive psychology rules. It was concluded that the effectiveness of digital feedback algorithms is determined not by their technical complexity, but by their ability to initiate and maintain conscious learning activities, transitioning formative assessment into a subject-subject mutually regulated process, which is a key factor in the development of academic independence in the digital age.

Keywords: *Formative Algorithmic Assessment, Digital Educational Environment, Algorithmic Feedback, Basic Algorithmic Thinking, Cognitive Development of Students, Self-Regulation of Learning, Metacognitive Skills, Learning Personalization, Adaptive Educational Technologies, Learning Process Analysis, Digital Assessment Tools, Individual Educational Trajectory.*

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I. INTRODUCTION

The current stage of development of educational systems is characterized by the deep integration of digital technologies, which necessitates the reconsideration of traditional pedagogical concepts, including those in the field of assessing learning achievements. Formative assessment, understood as the process of collecting and interpreting data to improve learning and teaching [1], is being transformed in the digital context, acquiring features of continuous, embedded, and often implicit interaction. The key mechanism of this transformation is provided by feedback algorithms—programmed systems for analyzing data on learning activities that are capable of generating diagnostic and corrective messages in a mode close to real time. In contrast to traditional forms, such algorithms offer the potential for “flexible, dynamic, and adaptive pedagogical support” [2].

In the modern context of educational development, the formation of students' basic algorithmic thinking is considered at the intersection of Pedagogy and Cognitive Psychology, where the digital educational environment plays a special role in shaping assessment and feedback. The theoretical foundation is formed by the ideas of J. Piaget and L. S. Vygotsky regarding the gradual development of thinking and the importance of educational support. The concept of algorithmic thinking is linked to "Computational thinking," proposed by J. Wing as a universal competence for problem-solving. The research of D. William and P. Black demonstrates the effectiveness of formative assessment and feedback in developing cognitive skills. In the context of

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digitalizing education, the contributions of D. Ifentaler and E. V. Chernobay, who substantiated the use of "Learning Analytics" for personalized learning, are significant. Also, the works of B. Zimmerman and M. Bukarts emphasize the role of self-regulation in the development of algorithmic thinking. Thus, the integration of competency-based approaches, formative assessment, and digital technologies ensures the effective development of students' basic algorithmic thinking. [3]

Analysis of methodological approaches to developing imperative algorithmic thinking shows that this process must be based on the integration of pedagogy and cognitive psychology. In modern conditions, emphasis is placed on developing skills for step-by-step problem-solving and understanding the structure of algorithms. The theoretical basis is provided by the ideas of J. Piaget and L. S. Vygotsky, which substantiate the gradual development of thinking and the role of pedagogical support. "Computational thinking" is of great importance as a key competence. Learning effectiveness is enhanced through formative assessment and feedback, as well as the application of "Learning Analytics" in a digital environment. Thus, an integrated approach ensures the successful development of students' imperative algorithmic thinking. [4]

Imperative algorithmic thinking is associated with the gradual processing of information and the formation of logical actions within the framework of cognitive psychology. It includes the ability to build a sequence of operations, analyze conditions, and predict the outcome. Abstraction and Computational thinking play an important role. Attention, memory, and reflection are also significant. In the digital environment, development is enhanced through Learning Analytics. [5]

Monitoring imperative algorithmic thinking in the educational process based on an activity-based approach involves evaluating students' knowledge and skills through their practical activities. This approach is based on Pedagogy and Cognitive Psychology, allowing for the tracking of students' ability to perform algorithms step-by-step, identifying and correcting errors. As key indicators, the dynamics of task execution, level of independence, and reflection are considered. In the digital environment, monitoring is strengthened through Learning Analytics, which provides personalized control and feedback. This contributes to the more effective development of algorithmic thinking. [6]

The concept of imperative algorithmic thinking as a basic component of computational thinking refers to the ability to construct and execute a sequence of clear step-by-step instructions to solve a problem. It is based on logical operations such as sequence, decomposition, and execution flow management, which are central to cognitive psychology. Unlike more abstract forms of algorithmic reasoning, imperative thinking focuses on procedural activities where every step is clearly defined and executed in sequence. This approach reflects the early stages of developing algorithmic skills, when learners focus on "how" to perform actions rather than just "how" the solution is. It is effectively supported by a structured educational environment and focused practice, where feedback helps clarify the accuracy of procedure execution. Thus, imperative algorithmic thinking serves as a fundamental level for forming more complex computational and problem-oriented competencies. [7]

Diagnostic models for determining the level of imperative algorithmic thinking formation are developed at the intersection of pedagogy and cognitive psychology. Such models are based on assessing students' ability to perform algorithmic tasks step-by-step, follow the sequence of actions, and identify and correct errors. Test tasks, practical tasks, and activity analysis on digital platforms are used in diagnostics. Modern approaches take into account the components of computational thinking, including problem-solving strategy and algorithmic planning. In the digital educational environment, Learning Analytics is widely utilized, allowing for real-time monitoring and automatic diagnostics. Thus, diagnostic models provide a systematic and accurate assessment of the level of development of imperative algorithmic thinking. [8]

Analysis of the reviewed literature shows that the development of imperative algorithmic thinking in modern education is based on the integration of pedagogy and cognitive psychology. Computational thinking and Learning Analytics play a key role in this process, providing the methodological and practical foundation for learning. The use of formative assessment, feedback, and digital educational environments contributes to the gradual development of students' algorithmic thinking. Competence-based and activity-based approaches allow for the formation of logical, sequential, and independent problem-solving skills in students. Overall, a comprehensive approach is the primary condition for the effective development and diagnosis of imperative algorithmic thinking.

The stage of development for modern educational systems is characterized by the deep integration of digital technologies, necessitating a revision of traditional pedagogical approaches, particularly in the field of educational achievement assessment. Formative assessment, as a process of collecting and analyzing data to improve education and learning, is fundamentally changing in the digital environment, taking on a continuous, system-integrated, and often hidden form of interaction. An important mechanism for this transformation is algorithmic feedback systems. They can automatically analyze learning activity data and generate diagnostic and corrective recommendations almost in real time. Unlike traditional forms of assessment, this approach allows for flexible, dynamic, and adaptive pedagogical assistance to students.

Within the framework of this research, primary attention is focused on identifying the cognitive characteristics characteristic of developing basic algorithmic thinking in students. In particular, the influence of formative algorithmic assessment and feedback mechanisms in the digital environment on students' thinking processes is analyzed. This approach contributes to the development of students'

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metacognitive skills, such as step-by-step problem-solving, creating a logical structure, reflection, and self-control. At the same time, in the context of the digital educational environment, the opportunities for forming an individual learning trajectory, increasing the level of self-regulation in learning, and personalizing the educational process are expanding.

The central scientific problem considered in this work is the identification of the relationship between technology-mediated feedback and the development of students' self-regulation abilities. In the educational process, self-regulation is interpreted as an active and constructive process in which students set goals, observe their activities, and regulate and control their cognitive, motivational, and behavioral processes.

The relevance of the study lies in the fact that the digital educational environment, on one hand, may create a risk of excessive external regulation of educational activities, while on the other hand, it creates broad opportunities for independent learning and the development of students' educational autonomy. From this perspective, algorithmic feedback systems serve not only as a means of control but also as an important didactic factor that supports the reflexive activity of students. As researchers note, the effectiveness of digital assessment is determined not by the level of automation in the control process, but by the strengthening of the student's skills in understanding and analyzing (reflecting) their activities. Thus, the purpose of this theoretical analysis is to reveal the didactic potential of algorithmic feedback systems as an important factor in activating self-regulation processes in students. The work analyzes the functional features of such algorithms, their mechanisms of influence on students' metacognitive sphere, as well as the pedagogical conditions necessary for the effective operation of technological feedback.

In particular, issues are highlighted regarding how technological feedback transitions from a simple means of external control to a form of management (co-regulation) based on cooperation, as well as bringing educational activities from external management to the level of internal self-governance. Thus, the possibilities for developing students' independent thinking, reflection, and the conscious organization of their activities in the digital educational environment are substantiated.

The scientific novelty of the study lies in the systematic consideration of feedback algorithms not as tools for automating control, but as didactic mediators in the formation of self-regulating learning. A model is conceptualized for transitioning from the linear transmission of "assessment-marking" to the cyclic process of "data - diagnostic feedback - action correction - reflection," initiated by the algorithm but purposefully transferring agency to the learner. The innovation also lies in clarifying the conditions under which technological feedback overcomes the limitations of a formalized response and contributes to the development of metacognitive strategies, shaping the digital environment as a space for conscious learning practice.

The scientific novelty of the study lies in considering algorithmic feedback systems based on a systems approach not as a means of automating control, but as a didactic mediator in forming self-management-based education. Within the framework of this approach, a model based on the cyclical process of "information - diagnostic feedback - action correction - reflection" is conceptually substantiated, abandoning the traditional linear "assessment - result" model. Although this process is initiated by algorithms, the priority in it is the student's activity and ability to make independent decisions.

The scientific novelty is also expressed in clarifying which pedagogical conditions allow technological feedback systems to transcend formal response and serve to develop students' metacognitive strategies. As a result, the digital educational environment is considered an effective environment that promotes conscious, purposeful, and reflective learning activities for students.

The relevance of the topic is determined by the contradiction associated with insufficient theoretical development of their formative assessment potential in the context of expanding the scale of using digital platforms in education. The transition to hybrid and distance learning forms requires a revision of traditional assessment principles.

To date, the development of students' self-management (self-regulation) ability is considered one of the important competencies of the 21st century, which is becoming a necessary factor for continuous education in conditions of uncertainty and information abundance. From this perspective, studying algorithmic feedback mechanisms that not only provide information but also develop students' ability to independently manage their learning activities is of current importance. This study meets modern requirements and aligns with the strategic directions for developing personalized and reflexive education.

II. RESEARCH MATERIALS AND METHODS

The methodological basis of the research is a system of comprehensive theoretical methods aimed at conceptualizing the relationship between algorithmic feedback and self-regulation processes in the digital educational environment. A systemic-activity approach has been adopted as the primary approach, allowing for the consideration of formative assessment as an integral part of educational activity and as a pedagogical element transforming under the influence of digital tools.

Within the framework of theoretical analysis, a conceptual modeling methodology was applied, the primary objective of which was to develop a structural-functional model for the interaction of external (algorithmic) and internal (self-regulatory) feedback processes. Also, when analyzing the essence and didactic possibilities of algorithms, a hermeneutic approach was used, based on the interpretation of scientific texts in the field of modern digital pedagogy and educational analytics.

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The study was conducted based on interdisciplinary synthesis principles, integrating the conceptual apparatus of pedagogy, cognitive psychology (specifically, self-regulating reading theory), and computer science (foundations of flexible algorithm functioning). As S.I. Zair-Bek notes, "interdisciplinary analysis allows for the identification of hidden mechanisms behind the impact of technological innovations on deep psychological and pedagogical categories" [2].

The fundamental theoretical works of foreign and domestic authors in the field of assessment (D. William, D. Sadler), research on self-regulated learning (B.J. Zimmerman, M. Boekaerts), as well as scientific works in the field of digitalization of education and Learning Analytics (D. Ifenthaler, E.V. Chernobay) form the source base of this study.

Special attention was paid to scientific works highlighting the pedagogical design of digital educational environments and the cognitive effects of automated feedback. As A.A. Margolis and V.K. Zagvozdkin note, "analysis of research describing specific pedagogical practices allows for the verification of theoretical models in real educational conditions" [10].

Within the framework of methodological reflection, key concepts such as "algorithmic feedback," "pedagogical design of feedback," "interpretation of self-management as a metacognitive process," and "digital educational environment as a mediator" were analyzed and revised.

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Formative assessment develops as a continuous, integrated phenomenon into the educational process within the digital educational environment, transcending the boundaries of episodic control. Its central element is feedback, which when implemented through algorithmic systems acquires qualitatively new characteristics: continuity, personalization based on data, speed, and partial secrecy for the reader.

Algorithms, as cognitive artifacts, not only provide information about the result but also actively structure the learning situation, providing "specific supports (scaffolding) for cognitive activity" [1]. This fundamentally changes the didactic nature of feedback: it becomes not only a message transmitted after the action, but also an element embedded in the action itself that directs and corrects it in real-time.

The main direction of this change is determined by the influence of algorithmic mechanisms on the process of student self-regulation. According to the social-cognitive theory, self-regulation is interpreted as a cyclical process that includes a forecasting stage consisting of goal setting and planning, an execution stage consisting of applying strategies and self-control, and self-reflection stages consisting of analyzing one's own activities [2].

When a digital educational environment is equipped with analytical tools, it provides specific "supporting pillars" for each stage. For example, algorithms that analyze students' previous activities can visualize progress in achieving a goal, which serves as external support during the self-control stage.

However, as researchers note, the primary risk is that "excessive algorithmic orientation can lead to a weakening of students' ability to independently set goals and develop strategies, replacing internal motivation with external signals" [9].

Thus, the central pedagogical problem is that it is necessary to design algorithmic systems that do not replace the role of the student's active subject (agent), but rather purposefully develop it. Effective feedback in the digital environment must be designed in such a way that it gradually transfers management functions from the system to the student.

This process can be interpreted as a transition from external regulation to full self-regulation through correlation. At the same time, the algorithm performs the role of an "intellectual intermediary": it does not provide ready-made answers, but asks diagnostic questions, suggests metacognitive guiding signals, and visualizes patterns in the student's learning activity, turning them into an object of analysis.

This approach aligns with the idea of "help for self-help," meaning the technology serves to make the student's mental process visible and understandable, primarily to themselves [10].

The personalization provided by algorithms also has a dual nature. On one hand, it allows for the adaptation of task content, difficulty levels, and feedback form to individual educational trajectories. On the other hand, in the context of self-regulation development, authentic personalization should encompass not only the content level but also the metacognitive level, which should help the student realize and optimize their learning strategies. In this case, the student should not move only along the optimal path determined by the algorithm but hidden from it. As noted in research on modern educational analytics, "the value of information is manifested not only in predicting the result of its assimilation but also in creating feedback that develops reflexive thinking and responsibility for the educational process" [11]. Accordingly, the developmental potential of digital formative assessment is realized only when its tools—algorithmic feedback systems—are designed in such a way that they are aimed at the gradual transfer of regulatory competencies to the student. This approach turns algorithms into a catalyst that activates students' internal processes, such as goal setting, observation, and correction of their activities, and consequently leads to the formation of academic autonomy in the digital environment.

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III. RESULTS AND DISCUSSIONS

The conducted theoretical analysis allowed for the formulation of a number of conceptual provisions that reveal the features of formative assessment in the digital educational environment and its connection to the development of basic algorithmic thinking in students. The research results show that algorithmic feedback transforms the traditional linear model in the form of "teacher - assessment - student" into a complex system of network interactions, whereby the algorithm acts as an active didactic mediator.

It has been established that the primary didactic effect of such feedback is the creation of an opportunity for the continuous diagnosis of the educational process. This makes the educational process "transparent" not only for the teacher but, more importantly, for the student themselves [1].

Within this approach, the development of basic algorithmic thinking in students is ensured precisely through transparency and the possibility of constant analysis. Students master the logical sequence, algorithmic structuring, and systematic methods of problem-solving during the gradual observation of their activities, identifying errors, correcting them, and re-evaluating the results.

Thus, algorithmic feedback systems serve not only as a means of assessment but also as an important pedagogical mechanism that supports students' cognitive development and forms basic algorithmic thinking.

It has been established that the development of self-regulation under conditions mediated by digital means is carried out through a mechanism of gradual transfer of regulatory functions. At the initial stage, the algorithm is compiled, provides frequent and accurate signals, and performs the function of an external regulator.

As the student develops basic metakognitive skills, the nature of feedback becomes more complex, the level of reflexivity increases, and it begins to stimulate the independent implementation of goal-setting and strategy evaluation. This process corresponds to the idea of a "zone of immediate self-regulation development," in which technological means serve as "a means of ensuring the transition from joint, distributed activities to independent and self-managed activities" [2].

Within this approach, basic algorithmic thinking in students is also developed through step-by-step support: first, actions directed by the algorithm, and then transformed into logical sequences, planning, and analysis processes compiled by the student themselves. Thus, the digital formative assessment system not only monitors knowledge but also becomes a pedagogical tool that forms algorithmic thinking and independent learning strategies.

As one of the important results, it was conceptually substantiated under which conditions algorithmic feedback can perform a developmental function, and in which cases the educational process can transition into a "substitutional" role. Among such conditions were: a design aimed at explaining and directing feedback rather than a ready-made answer; providing the student with the opportunity to work with information about their activities (for example, visualizing progress); and integrating selection and goal setting elements into the digital environment interface.

As E.V. Chernobay notes, "a tool becomes pedagogical only if it includes the possibility of developing new ways of action and thinking in the user; otherwise, it simply automates old practices" [12].

Therefore, the research results show that effective formative assessment in the digital environment is built not only around algorithms but also around a pedagogically grounded design of the entire educational interaction. At the same time, algorithmic feedback serves as a flexible tool that supports gradually growing educational autonomy and metacognitive competence, as well as creating conditions for the formation of basic algorithmic thinking in students.

IV. CONCLUSIONS

The conducted theoretical research demonstrated a dialectical relationship between algorithmic formative assessment and the development of students' self-regulation in the digital educational environment. It has been established that algorithmic feedback is not merely the automation of traditional assessment processes, but a new pedagogical tool that qualitatively changes the own structure of educational activity.

Its potential is manifested in providing a continuous, personalized, and diagnostically rich control circuit. This creates external "supports" for the formation of internal metacognitive processes in students and gradually develops their thinking activities.

Based on this, it can be said that formative assessment in the digital environment plays an important role in developing basic algorithmic thinking in students. Algorithmic feedback allows students to analyze the problem in stages, construct a logical sequence, identify and correct errors, and evaluate their activities in a reflexive manner.

As a result, algorithmic assessment systems are manifested not only as a means of knowledge control but also as an effective means of supporting cognitive development and the formation of metacognitive competencies.

The main conclusion of the study is that the developmental effect of digital formative assessment is determined not by the technical complexity of the algorithms, but by their pedagogical design. That is, the system must be oriented in such a way as to ensure a gradual transition from the regulatory agency to the reader.

An effective algorithmic environment begins with external control and evolves to a level of support for full self-governance (self-regulation) through a stage of joint (co-regulation) activity. Such a transition is only possible if

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feedback is designed as a means of prompting the student to reflect, set goals, and independently adjust their learning strategies.

At the same time, the feedback system should be viewed not as a system of commands or automated instructions, but as a pedagogical tool that develops students' basic algorithmic thinking, forming skills in problem analysis, creating logical sequences, and developing solutions independently.

Thus, formative assessment in the digital educational environment achieves its full pedagogical value only if algorithmic feedback systems become not only a means of diagnosing and adapting content but also a catalyst for forming conscious learning behavior.

In this context, algorithmic systems serve to develop basic algorithmic thinking in students, as they activate the processes of analyzing the educational process, identifying errors, constructing logical sequences, and developing solutions in stages. Through this, the student becomes not only a recipient of knowledge but also an active subject who analyzes and manages their learning activities.

As a perspective for future research, the issue of developing specific didactic models and design principles for metacognitive-oriented algorithmic systems remains relevant. Such systems must combine the analytical capabilities of digital technologies with the primary goals of education—the formation of an autonomous, reflective, and responsible personality. Thus, digital formative assessment is being improved as an effective pedagogical mechanism for developing basic algorithmic thinking.

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