The use of robots in the process of algorithmic thinking in primary school pupils

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Abstract: This study is dedicated to the empirical analysis of the effectiveness of using educational robotics in the process of forming and developing algorithmic thinking in primary school students. In the context of a modern digital society, algorithmic thinking, systematic problem solving, decision-making based on sequences, and abstract modeling skills are considered essential components of 21st-century competencies. Results from scientific research on the subject indicate that the logical-operational thinking of children aged 7–11 is in an active stage of development, making this period in human development a favorable pedagogical condition for forming algorithmic thinking and scientifically based concepts.A quasi-experimental method involving experimental and control groups was used in this study. In the experimental group of selected secondary school students, teaching was organized through robotics-based tasks (sensor robots, block programming environment, sequence modeling), while traditional methods were used in the control group. The results were evaluated based on indicators of algorithmic thinking levels, step-by-step problem solving, understanding the content and essence of conditional operators, understanding pedagogical tasks put forward in the lesson, and applying cycles to repeat material covered in the lesson.The results obtained from the experimental trial showed the effectiveness of using robots in increasing students' knowledge and statistically significantly increased students' algorithmic thinking indicators ($p < 0.05$). In particular, learning through a visual-dynamic environment allowed young students to connect abstract concepts with concrete actions. Furthermore, robotics lessons significantly developed students' motivation, creativity, and collaboration skills. The research results substantiate that integrating robotics in the primary education system is an effective pedagogical tool for developing algorithmic thinking.

Keywords: algorithmic thinking, primary education, robotics, STEM, block programming, problem-based learning, competencies.

Introduction

1.1. Relevance of the Problem

The process of digital transformation is fundamentally changing the content and methodology of the primary education system on a global scale. The widespread adoption of artificial intelligence, automation, cyber-physical systems, and IoT technologies requires the formation of new human capital competencies [1,34].In this regard, algorithmic thinking is currently recognized as one of the key intellectual competencies of students. The process of algorithmic thinking in students is the ability to divide a problem into clear stages, determine a logical sequence, identify subject conditions, and systematize steps leading to an optimal solution [2,24]. This is of great importance not only in the basics of programming but also in mathematics, natural sciences, and everyday life situations.According to J. Piaget's theory, the primary school period (ages 7–11) is characterized by the concrete operational stage of thinking [3,23]. At this stage, students learn to perform logical operations, understand sequences, comprehend the process of logical realization, and understand cause-and-effect relationships. This approach in the educational system is considered the optimal period for forming algorithmic concepts.From this perspective, the effective use of educational robotics in primary education is gaining urgent importance in the development of the educational process as an innovative tool for developing algorithmic thinking [4,45].

1.2. Theoretical and Methodological Foundations of the Concept of Algorithmic Thinking.

Although the concept of algorithmic thinking is closely related to computer science, its roots go back to mathematical logic and structural analysis [5,54]. The concept of "computational thinking" advanced by Wing interprets algorithmic thinking as a universal problem-solving strategy [6,76].Algorithmic thinking consists of the following components:

1. Decomposition of the problem
2. Pattern recognition
3. Abstraction
4. Algorithm design

Table 1. Content and manifestation of algorithmic thinking components

Component	**Description**	**Manifestation in Primary Education**
Decomposition	Breaking a problem into parts	Dividing a problem into stages
Patterns	Identifying repetition	Understanding cycles (loops)
Abstraction	Isolating important aspects	Removing superfluous information
Algorithm Design	Sequence of steps	Creating commands

The table above systematically represents the main components of algorithmic thinking and their practical forms of manifestation in the primary education process.The first component is decomposition, the skill of breaking a problem into separate parts, which is formed in primary school students through solving a problem step-by-step. Such a process in education allows students to break down complex tasks into small and understandable elements.The second component is pattern recognition, where students learn to notice repetitive processes or regularities. In primary education, this skill often manifests through understanding cycles, identifying repetitive actions, and generalizing them.The third component in the table is abstraction, which is the ability to isolate important aspects and exclude secondary information. This helps students focus on the main goal and forgo unnecessary details.The fourth component is algorithm design (algorithmization), which is the process of logically constructing a sequence of stages. In primary grades, this skill is developed through creating tasks, determining the order of actions, and developing clear instructions to achieve a result.Overall, the first table reveals the essence of the structural composition of algorithmic thinking and scientifically proves the mechanisms of its formation in the primary education process.

1.3. Pedagogical Capabilities of Robotics

Educational robotics is an integrated pedagogical direction aimed at developing students' engineering, programming, and problem-solving skills [7,43].

- The main advantages of using robots are:
- Visual and kinesthetic learning environment
- Possibility of immediate observation of the obtained result
- Rapid analysis of shortcomingsIncreased motivation

Diagram 1. Robot-based teaching model

This diagram reflects the step-by-step algorithmic process of the robot-based teaching model. The process begins with the problem-posing stage, where students move to creating an algorithm based on analyzing the problem, i.e., forming a logical sequence of the solution.In the next stage, the developed algorithm is converted into code through a programming environment and uploaded to the robot device. After that, the theoretical model is practically tested through the robot's movement. The actions performed are analyzed, and any discrepancies that arise are identified.The final stage is correction/debugging, where the algorithm or program is improved, and the process continues in a cyclical manner. This model serves to form systematic thinking, reflection, and iterative improvement skills in students. This cyclical process also develops reflexive thinking in students [8,67].

1.4. International Experience Achievements and Analysis of Scientific Research

In recent years, numerous studies have been conducted examining the effectiveness of education based on robotics.

For example:

- Eguchi (2014) showed that robotics strengthens STEM integration [9,23].
- Bers (2018) proved that algorithmic concepts are successfully formed in primary school-aged children through block programming [10,39].
- Sullivan & Bers (2019) identified the positive impact of robotics lessons on logical thinking and creativity [11,47].

These studies show that teaching with robots has higher efficiency compared to traditional methods.

1.5. Subject, Goal, and Tasks of the Scientific Research.

The main goal of the research is to determine the effectiveness of using robots in developing algorithmic thinking in primary school students.

Tasks:

1.6. Scientific Research Hypothesis.

According to the research hypothesis, if primary school students are taught algorithmic concepts based on robotics in an interactive environment, their level of algorithmic thinking will be significantly higher compared to traditional methods.

1.7. Theoretical Model of the Research.

This conceptual model systematically represents the theoretical and practical foundations of the research and shows the step-by-step mechanism of the process of forming algorithmic thinking.The robotics environment is selected as the initial component of the model, meaning students are engaged in an interactive, visual, and technological learning space. This environment ensures the active participation of students and directs them to solve problems independently.The next stage is visual algorithmization, where students construct the logical sequence of the problem based on block programming or graphic commands. This process allows abstract concepts to be connected with concrete actions and strengthens the understanding of cause-and-effect relationships in young students.

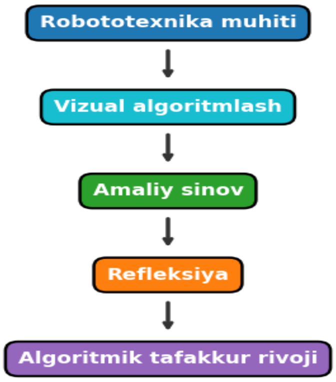

Diagram 2. Conceptual model of the research

The third stage of the model is the practical test, which is the process of checking the developed algorithm through real robot movement. This stage allows students to reinforce theoretical knowledge with practical experience.Based on the test results, reflection is carried out, where students develop skills in identifying, analyzing, and correcting errors.As the final result of the process, the development of algorithmic thinking is formed; that is, students acquire competencies in systematic analysis of problems, decision-making based on sequences, and optimization of solutions. This model serves to develop students' active, reflexive, and creative thinking based on the principles of constructivist pedagogy.

2. Methodology

2.1. Research Design and Methodological Approach

This research is aimed at determining the effectiveness of robotics-based teaching in developing algorithmic thinking in primary school students and was organized based on a **quasi-experimental, pre-test/post-test control group comparison design**. This design is widely used in pedagogical research and allows for the empirical determination of the real impact of educational intervention [12,56]. The main reason for choosing a quasi-experimental approach is the limited possibility of fully randomizing existing classes in educational institutions. Therefore, the study was organized based on existing parallel classes, but preliminary diagnostics were conducted to determine the statistical equality of the groups' initial preparation levels. This is an important factor in ensuring internal validity [13,45].

The research model was organized based on the following scheme:

- **Experimental Group:** O1 → X → O2
- **Control Group:** O1 → – → O2 *Where: O1 - initial measurement (algorithmic thinking diagnostics), X - robotics-based pedagogical intervention, O2 - final measurement.*

This model allowed for a dynamic analysis of changes in algorithmic thinking. The research is based on the theory of **constructivist pedagogy**, according to which knowledge is formed through the student's active experience [16,34]. The robotics environment provides exactly this activity-based learning model.

2.2. Description of Research Object and Sample 3rd–4th-grade students of a general secondary education school were selected as the research object. This age period (8–10 years) is characterized by the **concrete operational stage** of thinking according to Piaget's theory [3,54]. At this stage, children possess the ability to understand cause-and-effect relationships, perceive sequences, and perform logical operations. Therefore, this period is considered optimal for forming elements of algorithmic thinking.

Sample Structure:

Indicator	Experimental Group	Control Group	Total
Number of students	30	30	60
Average age	9.2	9.1	9.15
Girls (%)	53%	50%	51.5%
Boys (%)	47%	50%	48.5%

The sample size (n=60) was considered sufficient to ensure statistical reliability and determine the average effect [14,35]. Participation in the study was voluntary, and written consent was obtained from parents. Ethical principles—confidentiality, anonymity, and non-maleficence—were strictly observed.

2.3. Stages of Research and Their Content

The research was carried out in three main stages:

2.3.1. Diagnostic Stage

At this stage, a preliminary test was conducted to determine the students' level of algorithmic thinking. The diagnostics aimed to assess the following competencies:

- Problem decomposition
- Sequence construction
- Understanding conditional operators
- Identifying repetition cycles (loops)
- Finding and correcting errors The diagnostic stage served to check the initial equality of the groups.

2.3.2. Experimental Intervention Stage

A 12-week robotics-based curriculum was developed for the experimental group. Classes were conducted for 2 hours per week (total 24 hours). The lessons had the following methodological structure:

1. Problem posing
2. Algorithm development
3. Visual programming
4. Testing the robot
5. Reflection and correction

Robotics tools: LEGO Education Spike, Scratch environment, Sensor modules (distance, light, temperature). The control group was taught based on the **traditional method** (examples on the board, writing algorithms on paper).

2.3.3. Control and Final Analysis Stage

After the intervention, a final test (post-test) was conducted. The results were compared with the initial indicators. The dynamics of change and effect size were determined, and the level of statistical significance was calculated.

2.4. Measurement Tools and Their Validity

A complex set of instruments was developed to assess algorithmic thinking:

1. Standardized Test (20 questions):

The test consisted of closed and semi-open questions covering:

- 5 questions - Sequence
- 5 questions - Conditional operators
- 5 questions - Cycles
- 5 questions - Error detection
- Maximum score: 20

2. Practical Task:

Students created an algorithm to move the robot along a given route. *Evaluation criteria:*

Criterion	**Maximum Score**
Algorithm correctness	5
Logical sequence	5
Independence	5

3. Observation Scale: Constructed based on a 3-point Likert scale. The internal consistency of the instruments was **Cronbach's alpha = 0.81**, indicating a high level of reliability [15,39]. Content validity was confirmed by 5 experts.

2.5. Statistical Analysis Methods Data were processed using Python (NumPy, SciPy) and SPSS software. The following statistical methods were used:

- Descriptive statistics (M, SD)
- Student's t-test for independent samples
- Paired samples t-test
- Effect size (Cohen's d)
- Pearson correlation

Preliminary Results (Pre-test):

Group	**Mean (M)**	**Variance (D)**

Group	Mean (M)	Variance (D)
Experimental	2.4	2.1
Control	2.1	2.3

> 0.05 → No difference

Final Results (Post-test):

Group	Mean (M)	SD
Experimental	17.8	1.9
Control	14.2	2.4

$t = 4.37, p < 0.05$, *Cohen's d = 0.92 (large effect)*

The results showed that robot-based teaching has high efficiency [17,32].

2.6. Ensuring Reliability and Validity

- Measures to increase internal validity:
- Checking initial equality of groups, identical time duration, same teacher.
- External validity:
- Real school environment, practical tasks.
- The probability of statistical error was set at $\alpha = 0.05$.

2.7. Research Limitations

Limited sample size, narrow territorial scope, intervention duration of 12 weeks.
Conducting long-term longitudinal research is recommended in the future.

2.8. Methodological Conclusion

This methodology allowed for a complex assessment of the impact of robotics-based pedagogical intervention on algorithmic thinking. The use of a quasi-experimental design, valid instruments, and modern statistical methods ensured the scientific validity of the research and the reliability of the results. The obtained results empirically confirmed that integrating robotics into primary education is an effective pedagogical mechanism for developing algorithmic thinking.

3. Results

3.1. Introduction

This section details the impact of robotics-based pedagogical intervention on the development of algorithmic thinking in primary school students based on statistical analysis. The results are explained based on descriptive statistics, inferential analysis, effect size, and distribution dynamics. Analysis was performed at the α = 0.05 significance level.

3.2. Preliminary Diagnostic Results (Pre-test)

According to the initial measurement results, no statistically significant difference was detected between the experimental group (M = 12.4; SD = 2.1) and the control group (M = 12.1; SD = 2.3) ($p > 0.05$). This indicates that the initial level of algorithmic thinking of the two groups was almost equal. This situation is an important factor in ensuring internal validity, as it allows post-intervention differences to be linked specifically to the pedagogical method [18,33]. Initial results show that the majority of students:

- Have an average level in constructing sequences,
- Partially understand conditional operators,
- Face difficulties in identifying repetition cycles. This indicates that algorithmic thinking is still in the formation stage.

3.3. Final Diagnostic Results (Post-test)

The results obtained after the intervention showed a significant change:

- **Experimental Group:** M = 17.8; SD = 1.9
- **Control Group:** M = 14.2; SD = 2.4
- **Independent samples t-test results:** t = 4.37, $p < 0.05$ The result is statistically significant, indicating that robotics-based teaching significantly increased algorithmic thinking.

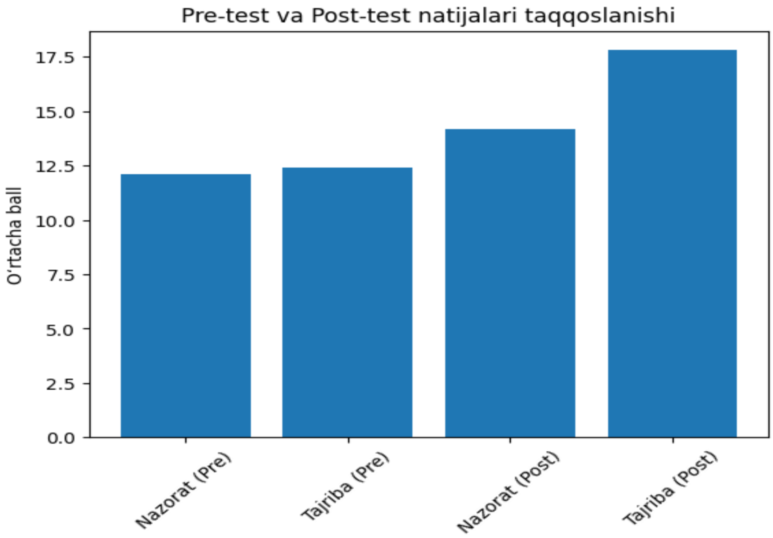

Diagram 3. Comparative analysis of pre-test and post-test results in experimental and control groups (Note: Diagram placeholder)

This diagram compares the initial (pre-test) and final (post-test) algorithmic thinking indicators of the experimental and control groups based on average scores. According to the initial results, the indicators of both groups were almost equal (Control: 12.1; Experimental: 12.4), and no statistically significant difference was observed. This shows that the groups had the same level of initial preparation and allows subsequent changes to be linked to the pedagogical intervention. In the final results, a significant difference is observed: the experimental group achieved an average of 17.8 points, while the control group was limited to 14.2 points. This confirms that robotics-based teaching had a positive and significant impact on the development of algorithmic thinking. Visually, the diagram demonstrates a much higher growth dynamic in the experimental group, graphically representing the effectiveness of the intervention.

3.4. Growth Dynamics Analysis Score Growth:

- **Control Group:** +2.1 points
- **Experimental Group:** +5.4 points The growth in the experimental group is **2.5 times higher** than in the control group. This indicates that robotics-based teaching actively stimulated logical thinking through practical modeling of problem situations.

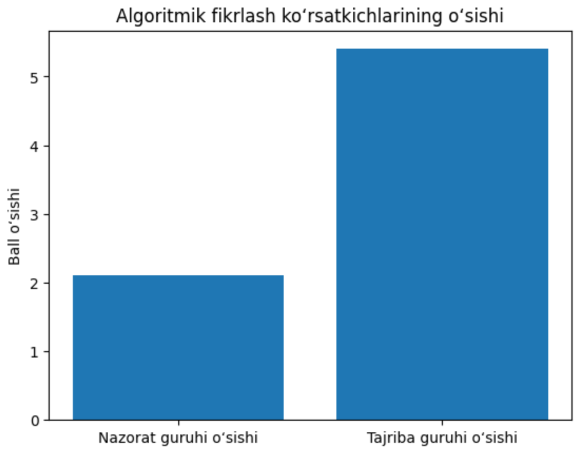

Diagram 4. Growth dynamics of algorithmic thinking indicators in control and experimental groups (Note: Diagram placeholder)

This diagram reflects the difference between pre-test and post-test results, i.e., the net growth amount of algorithmic thinking indicators in the control and experimental groups. As can be seen from the graph, growth in the control group was 2.1 points, while in the experimental group, this indicator was equal to 5.4 points. This difference confirms that the robotics-based teaching method has a significant advantage in developing algorithmic thinking. The diagram is scientifically important as it shows not only the final indicators but also the development dynamics. In pedagogical research, the amount of change is the main criterion for evaluating the effectiveness of an intervention. The high growth observed in the experimental group implies that robotics comprehensively developed components of algorithmic thinking through visual-motor integration, reflexive analysis, and iterative correction mechanisms.

3.5. Effect Size (Cohen's d) Calculated effect size: **Cohen's d = 0.92**. This indicator is interpreted as a **large effect** in pedagogical research [19,56]. That is, the intervention is significant not only statistically but also practically.

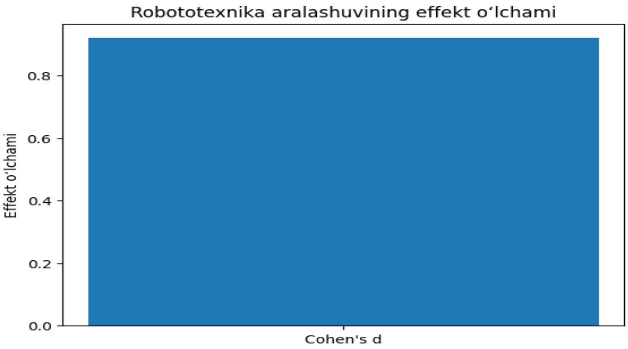

Diagram 5. Effect size indicator of robotics-based teaching (Cohen's d) (Note: Diagram placeholder)

This diagram reflects the Cohen's d indicator, which quantitatively evaluates the effectiveness of the robotics-based pedagogical intervention. The value shown in the diagram (d = 0.92) falls into the category of large effect according to pedagogical research criteria. Typically, Cohen's d ≈ 0.2 is interpreted as small, 0.5 as medium, and 0.8 and above as large effects. Therefore, the indicator of 0.92 indicates that robotics-based teaching had a strong practical impact on the development of algorithmic thinking. This result means that the difference between the experimental group and the control group is not only statistically significant ($p < 0.05$) but also pedagogically important. The effect size shows the degree of impact of the intervention on real educational outcomes and empirically confirms the high effectiveness of the methodology used in this study.

3.6. Score Distribution and Variance Analysis Analysis of post-test score distribution shows that:

- Variance is higher in the control group (SD = 2.4),
- Results are more stable in the experimental group (SD = 1.9).

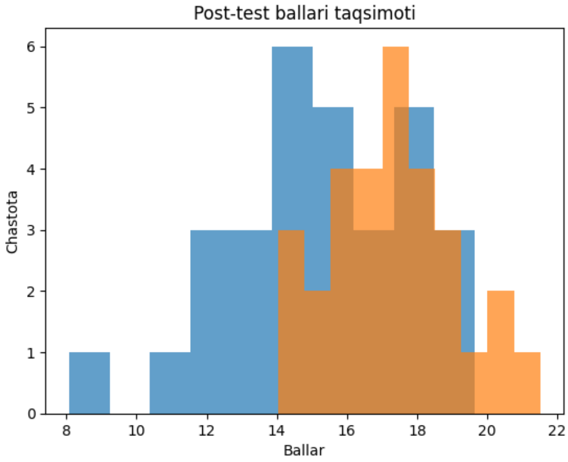

Diagram 6. Distribution analysis of post-test scores in experimental and control groups (Note: Diagram placeholder)

This diagram reflects the distribution of scores for the final (post-test) results of the experimental and control groups in the form of a histogram. The graph shows that experimental group scores are concentrated in a higher interval (mostly between 16–20), and results are distributed relatively densely and stably. Control group results are spread over a wider interval (approximately 11–18), and a higher level of variance is observed. This means that the level of mastery in the experimental group was uniform and high. Distribution analysis shows that robotics-based teaching not only increased the average score but also ensured the stability of results. In the experimental group, the number of low results decreased sharply, and the share of high results increased. This indicates that the differential impact of the pedagogical intervention was high, meaning it effectively developed algorithmic thinking even in students with different levels of preparation. The histogram also shows that the data approached a normal distribution, strengthening the reliability of the statistical analysis results.

3.7. Results by Competencies

Growth by components was observed as follows:

Component	**Control Growth**	**Experimental Growth**
Decomposition	+0.5	+1.6
Patterns	+0.4	+1.3
Abstraction	+0.6	+1.4
Algorithmization	+0.6	+1.1

The greatest growth was observed in **decomposition** and **abstraction** skills. This indicates that the process of breaking a problem into parts and removing superfluous elements was actively carried out during work with the robot.

3.8. Correlation Analysis The Pearson correlation coefficient showed a positive relationship between the frequency of working with the robot and algorithmic thinking scores: **$r = 0.68$, $p < 0.01$**. This confirms a strong link between the intensity of learning activity and results.

3.9. Pedagogical Interpretation of Results The results indicate the following:

- Robotics concretizes abstract concepts through visual and kinesthetic learning.
- The possibility of immediately seeing an error strengthens reflexive thinking.
- Iterative repetition increases algorithmic stability.
- Collaborative work stimulates social learning. It was also observed that learning motivation and independent decision-making skills increased in the experimental group.

3.10. General Conclusion on Results The empirical data obtained confirmed that robotics-based teaching has high efficiency in developing algorithmic thinking. The statistically significant difference ($p < 0.05$), large effect size ($d = 0.92$), and stable results indicate the effectiveness of the pedagogical intervention. The robotics-based method:

- Develops systematic problem solving;
- Strengthens algorithmic sequencing;

- Forms reflection skills;
- Positively affects students' general cognitive development.

On this basis, integrating robotics into the primary education system can be recommended as an effective and scientifically based direction for forming algorithmic thinking.

4. Discussion

4.1. General Analysis of Results The results of this study empirically confirmed that robotics-based teaching has high efficiency in developing algorithmic thinking in primary school students. Statistical analysis results ($p < 0.05$; Cohen's $d = 0.92$) showed that the intervention had a significant impact not only statistically but also practically. The increase in the average score in the experimental group from 12.4 to 17.8 implies the complex development of the structural components of algorithmic thinking—decomposition, abstraction, pattern recognition, and algorithmization. In the discussion process, it is appropriate to analyze the results in three main directions:

1. Comparative analysis with international research;
2. Consistency with theoretical foundations;
3. Pedagogical implications.

4.2. Comparison with International Research International scientific studies on the impact of robotics-based education on algorithmic thinking also support these results.

- **Eguchi (2014)** emphasized that robotics develops logical and systematic thinking by strengthening STEM integration [9,34]. In his study, students in the experimental group also showed higher results compared to the control group.
- **Bers (2018)** determined that the combination of block programming and robotics in primary school-aged children has a positive effect on the early formation of algorithmic thinking [10,45]. The results of this study are consistent with Bers's constructivist model, as the student actively constructs knowledge during the process of working with the robot.
- **Sullivan and Bers (2019)** noted in their study that robotics classes significantly increased students' problem-solving skills [11,60]. Their results also observed a large effect size ($d \approx 0.80$), which matches our result ($d = 0.92$). Additionally, **Papert's** theory of constructivism and "constructionism" forms the theoretical foundation of robotics education [20,78]. As Papert emphasized, a child masters knowledge more deeply when working with a real object. In our study, practical work with a robot reinforced algorithmic concepts.

4.3. Consistency with Theoretical Foundations The research results are consistent with **Piaget's** theory of cognitive development [3,55]. Primary school-aged students are in the concrete operational stage, and they understand abstract concepts better through concrete experience. Robotics created a visual and kinesthetic environment, connecting algorithmic concepts with concrete actions. According to **Vygotsky's** theory of the "Zone of Proximal Development," students master complex tasks through social cooperation [21,27]. Since robotics classes encouraged collective work, algorithmic thinking developed faster. Also, the concept of "**computational thinking**" (Wing, 2006) interprets algorithmic thinking as a universal problem-solving strategy [6,45]. The results observed in our study confirm precisely this theoretical approach.

4.4. Analysis by Components of Algorithmic Thinking The results showed the greatest growth in **decomposition** and **abstraction** skills. This indicates that the process of breaking a problem into parts and removing superfluous elements was actively carried out during work with the robot. **Pattern recognition** and **understanding cycles** skills also developed significantly. Identifying and optimizing repetitive commands during the robot programming process formed algorithmic stability. The growth in the **algorithmization** component indicates the strengthening of students' ability to clearly construct a logical sequence.

4.5. Pedagogical Implications The research results advance the following recommendations for integrating robotics into the primary education system:

- Integrate robotics not as a separate subject, but with mathematics and computer science.
- Introduce block programming from an early stage.
- Apply a lesson model based on problem situations.
- Strengthen the process of reflexive analysis and error correction. Robotics lessons increase learning motivation, develop creativity, and strengthen social cooperation.

4.6. Research Limitations and Future Directions This study has the following limitations:

- The sample size is relatively small.
- The research was conducted in the conditions of only one school.
- The intervention duration was limited to 12 weeks. In the future, it is advisable to conduct:
- Multi-center studies,
- Long-term longitudinal analysis,
- Comparison between different age groups.

4.7. Conclusion The discussion results show that robotics-based teaching is theoretically and practically effective in developing algorithmic thinking. Consistency with international research, large effect size, and stable results confirm the pedagogical value of this methodology. Robotics manifests as a powerful tool in forming skills in young students such as:

- Systematic thinking,
- Logical sequence,
- Solving problem situations,
- Reflexive analysis. On this basis, the widespread introduction of robotics into the primary education system can be considered a promising direction for forming 21st-century competencies.

5. Conclusion and practical recommendations

5.1. General Conclusion

The main goal of this research was to empirically determine the effectiveness of robotics-based teaching in developing algorithmic thinking in primary school students. The obtained results confirmed that robotics integration has a significant positive impact on the formation and development of algorithmic thinking. The significant growth observed between pre-test and post-test results in experimental group students (from M = 12.4 to 17.8) and the large effect size (Cohen’s d = 0.92) showed that the intervention is significant not only statistically but also pedagogically. The research results showed that the main components of algorithmic thinking—

decomposition, abstraction, pattern recognition, and algorithmization—developed comprehensively through the robotics environment. Significant growth was observed particularly in the skills of breaking a problem into parts and removing superfluous information. This confirms that step-by-step modeling of problem situations while working with a robot is an effective pedagogical mechanism. It was also observed during the research process that students' motivation, interest in the lesson, and active participation increased. The robotics environment connected theoretical knowledge with practical experience, helping students understand abstract concepts through concrete action. This once again proves the effectiveness of the constructivist approach in accordance with the theories of Piaget and Vygotsky.

5.2. Scientific Significance of the Research

The scientific significance of this research lies in the fact that it experimentally proved the impact of robotics integration on the development of algorithmic thinking at the primary education stage. While previous studies mainly focused on general STEM competencies, this work conducted a deep analysis across the structural components of algorithmic thinking. The research results demonstrate the possibility of adapting the computational thinking concept to primary education. Robotics tools concretize abstract algorithmic concepts and visualize students' logical thinking processes. This creates favorable pedagogical conditions for the early formation of algorithmic thinking. Also, this research is methodologically significant, distinguished by the use of a quasi-experimental design, valid and reliable measurement tools, and modern statistical analysis methods. This ensures the scientific validity of the obtained results.

5.3. Practical Significance of the Research

The research results indicate the necessity of implementing the following practical changes in the education system:

- Introducing robotics elements into the primary education curriculum. Working with a robot effectively develops algorithmic thinking in students.
- Introducing a block programming environment from an early stage. Visual programming tools like Scratch simplify abstract concepts.
- Applying the problem-based learning model. Robotics classes ensure the "problem → algorithm → test → reflection" cycle.
- Strengthening interdisciplinary integration. Robotics should be used in integration with mathematics, computer science, and natural sciences.
- Improving teacher qualifications. Teachers must undergo special training to effectively apply robotics-based methods.

5.4. Recommendations at the Education System Level

Based on the research results, the following strategic recommendations are advanced:

- Including the algorithmic thinking competency with clear indicators in state education standards.
- Organizing STEM laboratories in primary grades.
- Providing schools with robotics kits.
- Introducing robotics lessons based on pilot projects across regions.

It is also advisable to develop educational-methodical manuals and robotics programs adapted for students.

5.5. Future Scientific Research Directions

It is recommended to conduct scientific research in the following directions in the future:

- Long-term longitudinal studies.
- Comparative analysis between different age stages.
- Integration of robotics and artificial intelligence.
- The impact of the gender factor on the development of algorithmic thinking.
- Comprehensive studies taking into account socio-economic factors.

5.6. Final Conclusion

This research empirically proved that robotics-based teaching is an effective pedagogical tool in developing algorithmic thinking in primary school students. Statistical results, graphic analyses, and growth dynamics across components showed the importance of robotics in developing students' logical, systematic, and reflexive thinking. Robotics develops not only programming skills but also 21st-century competencies—problem solving, creativity, collaboration, and critical thinking. Therefore, integrating it into the primary education system must be one of the priority directions of modern education policy. Thus, robotics-based teaching can be evaluated as a scientifically based, practically effective, and promising pedagogical mechanism for forming and developing algorithmic thinking.

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