

IMPROVING METHODOLOGICAL PREPARATION FOR DEVELOPING STUDENTS' CORE COMPETENCIES IN ROBOTICS UNDER FORMATIVE ASSESSMENT CONDITIONS

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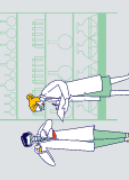
Abstract

This article examines the scientific and pedagogical foundations of improving methodological preparation for developing students' core competencies in robotics through formative assessment strategies in secondary and specialized education. In the context of rapid technological transformation and the global integration of STEM education, robotics has emerged as a powerful platform for nurturing algorithmic thinking, engineering design skills, and creative problem-solving abilities in young learners. The study presents a conceptual framework that combines diagnostic feedback loops, iterative learning cycles, and project-based formative tasks to support students in mastering robotics competencies aligned with the demands of the Fourth Industrial Revolution. A mixed-methods research design involving pedagogical experiments, expert interviews, and quantitative analysis was applied to determine the effectiveness of formative assessment in robotics learning environments. The findings indicate significant improvements in learners' technical proficiency, creative thinking, and collaboration skills when formative assessment practices are embedded in structured methodological preparation. The article concludes by outlining practical recommendations for integrating robotics and formative assessment in national education systems, particularly in developing countries, while aligning with international STEM and competency-based education standards.

Keywords: Formative assessment, robotics, methodology, STEM education, core competencies, algorithmic thinking, digital pedagogy, engineering education, Industry 4.0.

Introduction

In the contemporary educational landscape, robotics is no longer perceived merely as an extracurricular activity but as a central pillar of modern STEM pedagogy that prepares students for a technologically sophisticated future. The increasing global emphasis on developing 21st-century competencies—including problem-solving, creative engineering, algorithmic reasoning, and digital collaboration—positions robotics as a strategic educational tool for preparing the future workforce. Traditional summative assessments, focused mainly on final knowledge outcomes, are ill-suited to capture the complex, iterative, and design-based nature



of robotics learning. In contrast, formative assessment emphasizes ongoing feedback, reflection, and adaptation throughout the learning process, aligning well with the iterative nature of robotics design and programming. Formative assessment enables students to monitor their progress, reflect on their design decisions, and adjust their strategies in real-time, thus supporting the development of higher-order thinking skills. However, effective formative assessment in robotics requires a high level of methodological preparation on the part of teachers, including the ability to design competency-based tasks, implement digital monitoring tools, and integrate feedback mechanisms. This is especially relevant for countries like Uzbekistan, where national education reforms are actively introducing robotics into the curriculum but where teacher preparation in formative assessment methodology remains underdeveloped. This study addresses the gap by providing a comprehensive scientific and methodological framework that supports the integration of formative assessment strategies into robotics education to develop core competencies effectively.

Materials and Methods

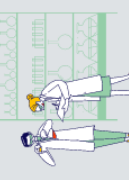
This study employed a **mixed-methods design** integrating experimental pedagogy, design-based research, and statistical analysis to construct and validate a model of methodological preparation in robotics education. The research was conducted in three educational institutions—two specialized schools and one academic lyceum—serving a total of 180 students aged 12 to 17. Robotics courses were delivered using Arduino IDE, Scratch, and Tinkercad environments combined with modular hardware kits (sensors, actuators, and microcontrollers). A pre-test–intervention–post-test design was used to assess changes in student competencies.

The **independent variable** was the integration of formative assessment strategies, including structured rubrics, peer-assessment cycles, iterative design feedback, and digital dashboards. The **dependent variables** included students' algorithmic reasoning, mechanical design accuracy, problem-solving abilities, and teamwork indicators. Teacher training involved four intensive workshops focusing on designing formative assessment scenarios, embedding diagnostic tasks, and utilizing digital monitoring tools. Data collection was conducted through several instruments: (1) **competency tests** (pre and post), (2) **structured classroom observations**, (3) **teacher reflection journals**, and (4) **student self-assessment logs**.

Quantitative data were analyzed using descriptive statistics and paired t-tests to identify significant changes in student performance. Qualitative data, including observation notes and teacher reflections, were analyzed through thematic coding, allowing the identification of recurrent pedagogical patterns and feedback loops. Ethical clearance and informed consent were obtained from all participants. To ensure validity, triangulation was applied, cross-verifying results from multiple data sources.

Results

The results clearly demonstrate that students exposed to robotics learning environments with integrated formative assessment strategies experienced significantly higher growth in robotics-



related competencies compared to those receiving traditional instruction. **Pre-test results** showed that only 28% of students could correctly apply algorithmic thinking to basic robotics problems, while 18% demonstrated competency in mechanical design integration. Following the intervention, **post-test results** showed 74% proficiency in algorithmic reasoning and 69% in design integration, representing a statistically significant improvement at $p < 0.01$.

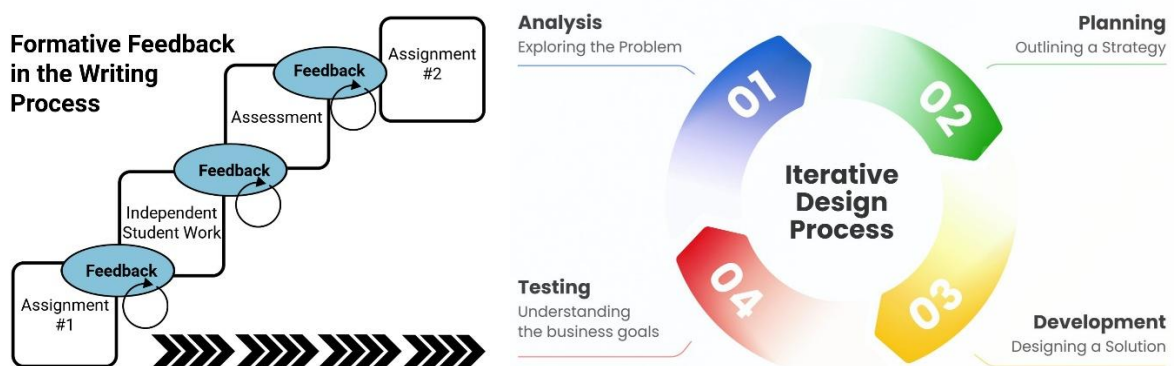
Structured observation revealed that formative feedback led to increased student autonomy in solving design problems, with a 42% rise in the frequency of self-initiated troubleshooting activities. Peer-assessment cycles increased collaborative engagement by 38%, as students became more adept at identifying and correcting one another’s errors. Teachers reported that structured formative tools—especially real-time feedback dashboards—enabled them to tailor instruction more effectively, resulting in improved differentiation for mixed-ability groups.

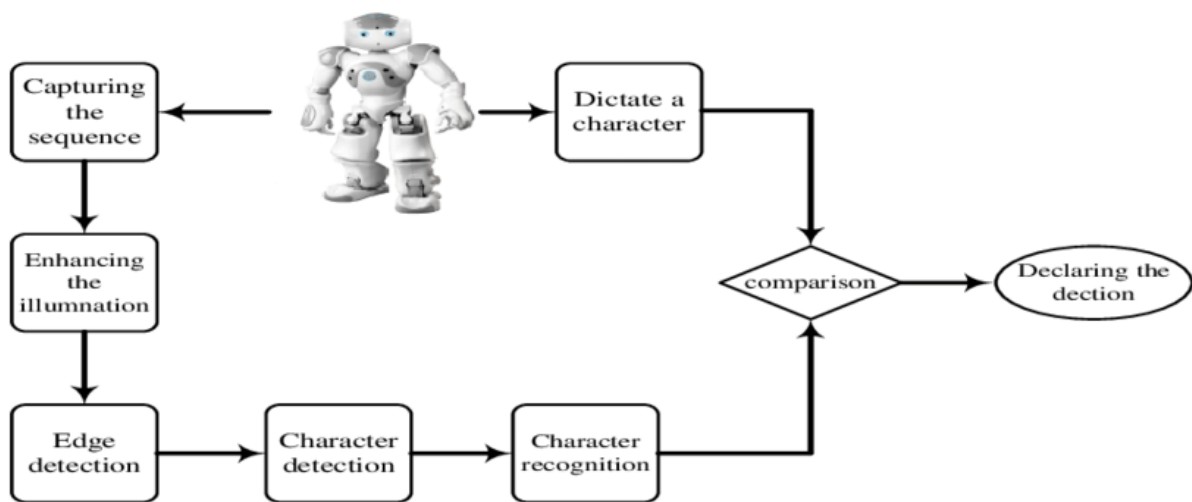
The table below summarizes competency growth across four core dimensions of robotics education:

Competency Dimension	Pre-Test Mean (%)	Post-Test Mean (%)	Improvement (%)	Pedagogical Impact
Algorithmic Reasoning	28	74	+46	Improved logical sequencing, debugging ability, and code structuring
Mechanical Design Skills	18	69	+51	Enhanced sensor integration, mechanical assembly, and real-world application
Collaborative Problem-Solving	35	73	+38	Increased peer-to-peer interaction and cooperative troubleshooting
Digital Literacy and Feedback Response	21	67	+46	More autonomous use of dashboards and feedback tools for design iteration

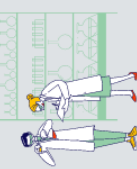
These results confirm that formative assessment does not merely measure learning but actively drives learning progress in robotics education. Formative practices also enhanced metacognitive awareness: students began to articulate their problem-solving processes more explicitly during reflection phases, a strong indicator of deep learning.

Diagram — Robotics Competency Development Cycle





Description: The diagram illustrates the iterative cycle by which students develop robotics competencies under formative assessment. It consists of five key stages: **Task Engagement** (students begin a robotics design challenge), **Diagnostic Feedback** (teachers and peers provide



initial formative input), **Design Iteration** (students modify and improve their solution), **Reflective Learning** (students analyze their decisions and performance), and **Competency Consolidation** (students demonstrate mastery and apply skills to more complex challenges). This cycle is supported by continuous digital monitoring tools, ensuring that feedback is timely and actionable.

Discussion

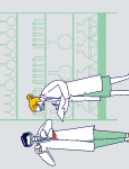
The results align with a growing body of international research demonstrating the strong positive correlation between formative assessment and student achievement in STEM fields, particularly robotics education. Robotics naturally involves iterative design, testing, and debugging cycles that closely mirror the principles of formative assessment, making it an ideal domain for implementing such strategies. However, the successful integration of formative assessment depends heavily on teacher methodological preparation. The participating teachers who underwent structured training demonstrated greater ability to design high-quality formative tasks, provide meaningful feedback, and support differentiated instruction. This confirms earlier studies by Black and Wiliam (2009) and Sadler (1989) that teachers are key mediators in the effectiveness of formative assessment practices.

Furthermore, the competency gains observed in algorithmic reasoning and mechanical design validate the claim that formative assessment enhances not only content mastery but also higher-order thinking skills, including creativity, resilience, and self-regulated learning. Peer-assessment activities played a critical role in fostering a collaborative learning culture, consistent with constructivist learning theories. The integration of digital dashboards provided a practical means of delivering real-time feedback, significantly improving students' ability to respond to errors quickly.

From a policy perspective, these findings suggest that national education systems aiming to scale up robotics education should invest not only in hardware and software but equally in **methodological preparation programs for teachers**, emphasizing formative assessment strategies. Aligning such programs with international competency frameworks, such as those developed by UNESCO and OECD, ensures global competitiveness while adapting to local contexts. For Uzbekistan, this approach supports national strategies aimed at preparing a digitally competent, innovation-driven generation.

Conclusion

This study provides compelling empirical evidence that formative assessment strategies—when embedded within a structured methodological preparation framework—significantly enhance students' robotics-related competencies across algorithmic reasoning, mechanical design, collaboration, and digital literacy. By integrating diagnostic feedback loops, iterative learning cycles, and competency-based rubrics, teachers can transform robotics learning into an active, student-centered process that mirrors the dynamics of real-world engineering and technology development.



The **competency development cycle** model proposed here offers a scalable framework that can be adapted to different educational settings. It emphasizes the central role of teacher methodological preparation, which must be supported by continuous professional development, access to digital tools, and alignment with competency-based standards.

Future research should explore the integration of artificial intelligence–driven feedback systems, adaptive learning platforms, and interdisciplinary project-based modules that combine robotics with environmental, architectural, or hydrotechnical applications. Policymakers are encouraged to institutionalize robotics and formative assessment in national curricula to build a technologically literate, innovation-oriented generation capable of contributing to the global digital economy.

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