The Pedagogical Effect of Using Electronic Stands in Teaching the Discipline "Robotics"

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***Abstract*—This study examines the pedagogical effectiveness of electronic training stands in teaching the Robotics course in Kazakhstani universities. A quasi-experimental pre-test/post-test design was employed, with control (*N* = 95) and experimental (*N* = 94) groups across three teacher-training institutions. Baseline equivalence in motivation, cognitive knowledge, and practical skills was confirmed through pre-test assessment. During one semester, the experimental group used the locally developed kurastyrgysh.kz platform, which integrates Arduino/Robot Operating System (ROS)-based simulations and interactive virtual laboratory modules. The findings demonstrate substantially greater improvements in student motivation, practical competence, and cognitive understanding in the experimental group compared to traditional instruction. Students reported increased engagement, confidence, and willingness to perform independent tasks, while quantitative results indicated consistent gains across all components. These outcomes support the growing international evidence that virtual and hybrid laboratory environments strengthen learning in engineering and Science, Technology, Engineering, and Mathematics (STEM) education, particularly in resource-constrained settings.**

***Keywords*—educational robotics, Science, Technology, Engineering, and Mathematics (STEM), practical skills development, Arduino/Robot Operating System (ROS) simulations, student motivation, virtual laboratories, electronic stands**

I. Introduction

Robotics has become one of the central domains of technological progress over recent decades, finding wide application in industry, medicine, education, and other fields. The growing demand for specialists capable of designing, programming, and managing robotic systems has highlighted the need for modernized approaches to engineering and Science, Technology, Engineering, and Mathematics (STEM) education. Numerous international studies confirm that educational robotics plays a significant role in developing critical thinking, problem-solving, and interdisciplinary skills among learners [1, 2].

One of the key problems in introducing robotics is the lack of laboratory facilities. Even when physical equipment is available, its operation is associated with risks, such as electric shock or mechanical injury. This issue is especially relevant for students in teacher education and information technology programs who lack background knowledge in electrical engineering and mechatronics [3, 4]. Similar challenges are observed in universities worldwide, where limited resources restrict the development of full-fledged laboratory environments [5]. The use of electronic and virtual stands has therefore become an increasingly viable solution, allowing universities to ensure safety, interactivity, and accessibility in teaching robotics [6].

Despite a steadily growing body of international research on virtual laboratories, remote experimentation systems, and simulation-based robotics instruction, several limitations remain in the existing literature. Meta-analyses and systematic reviews demonstrate the overall effectiveness of robotics and virtual labs in enhancing cognitive and practical learning [1, 7]. However, most studies have been conducted in well-equipped engineering programs, often in technologically advanced contexts.

There is a notable gap in research on how virtual and electronic stands perform in low-resource environments, particularly in teacher-training programs, where students often lack prior engineering experience. The Kazakhstani context—characterized by equipment shortages, heterogeneous student preparedness, and the need for safe practical training—remains underrepresented in international literature. As a result, it is not yet clear whether findings from engineering-focused institutions can be generalized to pedagogical universities that train future computer science teachers.

This study addresses this gap by evaluating the impact of electronic stands within the specific constraints of Kazakhstan's higher education system and by providing empirical evidence from a multi-site quasi-experiment across three universities.

The pedagogical foundation of this study is grounded in constructivist and experiential learning theories. According to constructivism, learners build new knowledge through active engagement, manipulation of objects, and reflection on their actions. Electronic stands support these principles by enabling iterative experimentation, immediate feedback, and hands-on problem solving.

Kolb's Experiential Learning Theory [8] further emphasizes the cyclical development of understanding through four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Electronic robotics stands aligns naturally with this model, as students first engage in simulated practical tasks, analyze outcomes, adjust their solutions, and reapply knowledge in new configurations. Thus, the use of electronic stands is theoretically expected to enhance both cognitive and practical competencies by integrating perception, action, and reflection into a unified learning environment.

In Kazakhstan, many universities face limitations related

to insufficient laboratory equipment and a lack of resources for creating safe and practice-oriented environments for teaching robotics. Research by Kazakhstani authors confirms that virtual simulators and electronic stands can effectively compensate for the lack of hardware and increase students' interest in practical training

The purpose of the study is to determine the pedagogical impact of electronic stands on students' motivation, cognitive understanding of robotics, and practical skills in programming and circuit design. The study employs a pre-test/post-test quasi-experimental design conducted across three Kazakhstani universities.

The research objectives of this study include:

1) To analyze the pedagogical potential of electronic stands for robotics education;
2) To compare the effectiveness of traditional instruction and electronic-stand-supported instruction in terms of motivation, cognitive learning, and practical skills;
3) To examine the internal relationships between motivational, cognitive, and practical learning outcomes.

II. Literature Review

Robotics as an academic discipline has undergone significant changes in recent years. These changes require the implementation of new, adaptive teaching methods. One such means, which simultaneously addresses the problem of the lack of specialized laboratories and ensures the safe development of students' practical skills, is electronic stands [9, 10]. According to the research by Ching and Hsu [10], the use of educational robots contributes to the development of computational thinking and increases interest in academic activities [11]. At the same time, many foreign studies focus on the integration of virtual and remote laboratories, which provide safe and interactive acquisition of practical skills [2, 3].

Beyond empirical findings, the pedagogical potential of electronic and virtual stands aligns with established learning theories. From a constructivist perspective, students develop new knowledge through active manipulation of digital or physical objects, reflection on outcomes, and iterative problem-solving. Kolb [8] further supports the relevance of electronic stands by emphasizing concrete experience, reflective observation, abstract conceptualization, and active experimentation—stages that naturally occur during robotics programming and simulation. These theoretical foundations help explain why electronic stands often enhance motivation and cognitive engagement in robotics education.

Additional international research supports this theoretical perspective. Alimisis [12] emphasizes that the effectiveness of robotics in education depends primarily on teacher preparation and instructional design rather than on the technology itself. Likewise, Bers [13, 14] shows that developmentally appropriate robotics environments and structured learning cycles enhance computational thinking and creative problem-solving. Sullivan and Bers [15] additionally demonstrate that scaffolded robotics activities aligned with students' prior knowledge help establish stable positive learning trajectories and sustained motivation. Together, these studies reinforce the view that robotics technologies are most effective when implemented within a coherent pedagogical framework.

In several recent works, educational robotics is recognized as a crucial component in integrating Science, Technology, Engineering, and Mathematics (STEM) and Science, Technology, Engineering, Arts, and Mathematics (STEAM) approaches. For example, Sapounidis, Tselegkaridis and Stamovlasis [7] conducted a meta-analysis showing that the use of robots promotes the development of cognitive activity, critical thinking, and interest in science among students of various levels of preparation. Wang *et al.* [1] emphasize that robotics classes strengthen interdisciplinary connections and improve the academic performance of engineering students. However, most of these studies focus primarily on technical efficiency and learning outcomes, while offering limited discussion of contextual factors such as teacher preparation, curriculum alignment, or institutional constraints. This creates a gap regarding how robotics tools function in environments with restricted resources, such as teacher training programs in Central Asia.

A study by Sapriati *et al.* [16] notes that virtual laboratories have a significant impact on the development of self-regulation and research skills in students. The importance of practice-oriented educational technologies in improving the effectiveness of the educational process is emphasized in [17]. These results confirm the effectiveness of combining physical and digital formats of laboratory classes in training future engineers.

According to the results of a comparative analysis, virtual laboratories and electronic stands allow students to reproduce experiments multiple times and analyze the results. As a result, this allows them to master algorithms for controlling robotic systems without risk to their health [3, 6, 18]. Ouyang and Xu [2] confirm that educational robots, in combination with digital platforms, statistically significantly improve student performance and engagement. Similar results are demonstrated in the work of Li and Liang [6], where the effectiveness of virtual laboratories was evaluated through a meta-analysis of engineering education. However, the practice of implementing such technologies abroad differs from the Kazakhstani context.

Zhabayev and Revshenova [19] show that the use of virtual simulators and educational stands in robotics training courses compensates for the lack of equipment, increasing students' interest in practical classes. The authors emphasize that the successful implementation of such technologies requires the training of teachers and methodological materials adapted to local conditions.

In Kazakhstan, many universities face limitations in terms of material and technical resources, a lack of specialized equipment, and limited opportunities for conducting safe practical classes. Koshanova *et al*. [20] notes that the introduction of virtual laboratories in Kazakhstani universities requires the adaptation of teaching methods and additional training for teachers. At the same time, international experience demonstrates the wider use of remote and hybrid laboratories, which allows innovative technologies to be integrated into the educational process in almost all disciplines [3, 18, 21]. Particular attention is paid to the pedagogical aspects of using educational robots and virtual stands. For example, project-based learning using robots increases the level of problem-oriented skills and research activity of students [22, 23]. At the same time,

studies show that the effectiveness of such approaches directly depends on the structure of courses, the qualifications of teachers, and the level of technical support [20, 24, 25]. In the Kazakhstani context, there is a certain discrepancy: although the methodologies are similar, limited resources and low availability of equipment reduce the potential effectiveness [26].

Compared with international practice, where virtual and hybrid laboratories are widely institutionalized, Kazakhstani universities are still in the early stages of adopting such technologies. The pace of adoption is constrained by limited laboratory infrastructure, insufficient technical support, and the need for localized methodological resources. This distinction is important because it suggests that approaches validated in well-equipped contexts cannot be transferred directly without adaptation.

Some studies focus on the development of "soft skills" in robotics education. Silva *et al.* [27] show that student participation in project activities with educational robots promotes the development of communication, leadership, and responsibility. Similar conclusions were made in a study by Nannim *et al.* [28], where project-based learning with Arduino robots enhances students' resilience and independence.

A synthesis of foreign and Kazakhstani experience has yielded the following key conclusions. First, virtual and hybrid laboratories have proven their value in international practice, allowing students to develop practical skills safely and interactively [2, 3, 6, 24]. Second, the direct transfer of these approaches to the Kazakhstani education system is impossible without taking into account local conditions and adapting methodologies [26]. Third, electronic training stands are the most promising solution, capable of combining the advantages of international experience and the realities of Kazakhstani universities, ensuring interactivity, repeatability of experiments, and the safe formation of practical skills [6, 18, 26]. Despite the substantial international evidence, there is still a lack of empirical multi-site studies examining electronic stands specifically within teacher-training programs and under resource-constrained conditions such as those found in Kazakhstan, which forms the research gap addressed in the present study.

Although numerous international studies confirm the effectiveness of virtual and electronic laboratories, most of them focus on technologically advanced environments, which limits their transferability to resource-constrained teacher-training programs. This highlights the need for a contextualized approach rather than direct replication of foreign methodologies. The present study is explicitly grounded in constructivism and Kolb's Experiential Learning Theory [8], which together explain the mechanisms through which electronic stands influence learning: active manipulation, iterative experimentation, reflective analysis, and abstraction. Integrating these theories provides a coherent pedagogical framework that links the design of the electronic stands with the expected motivational, cognitive, and practical outcomes. Thus, the review not only synthesizes previous research but also critically evaluates its limitations and positions the current work within a defined theoretical foundation.

III. Materials and Methods

The methodological basis was formed in line with current trends in pedagogical research in engineering and STEM education, where quasi-experimental design is a key tool. The study was structured according to a pre-test/post-test design with control and experimental groups, which enabled the tracking of students' cognitive, practical, and motivational characteristics before and after the introduction of electronic stands. This scheme is widely used in international research on educational robotics, as it provides an opportunity for an objective comparison of the initial and final levels of material assimilation and minimizes distortions associated with individual differences among students [2, 6, 23]. In addition, the methodological rationale followed established learning theories, including Kolb's experiential learning cycle and the Technological Pedagogical Content Knowledge (TPACK) framework [8], which together justify the pedagogical integration of electronic stands into robotics education.

The experiment involved 189 students from Kazakhstani universities studying to become computer science teachers. All participants were divided into two groups: a control group (95 people) that was taught using traditional methods, and an experimental group (94 people) that used electronic teaching stands. Because random assignment was not feasible, intact academic groups were allocated to conditions. To reduce selection bias, groups were matched by year of study, GPA, and prior programming experience. Baseline equivalence was statistically confirmed ($p > 0.05$ for all pre-test components). This ensured methodological comparability before the intervention. This selection of participants reflects the current task of Kazakhstan education—to improve the quality of training for future teachers in conditions of limited material and technical resources, and the need for safe, yet practice-oriented forms of training [20, 22]. International practice shows that it is in the context of training teachers and engineering specialists that the use of virtual and electronic laboratories is most in demand, as it allows for standardized training regardless of the level of equipment in educational institutions [5, 7, 18, 19].

The electronic stands developed and tested in this study included simulation modules based on Arduino and ROS, as well as virtual environments for studying basic and advanced elements of robotics. Additionally, these stands featured interactive interfaces for performing laboratory tasks and mini-projects. The software solutions provided the ability to repeat experiments multiple times, correct errors, and analyze the results obtained. This is consistent with the findings of Li and Liang [6], who showed that virtual laboratories in engineering education improve the level of mastery of complex technical disciplines, as well as the conclusions of Jara *et al.* [4], who confirmed that interactive interfaces significantly increase student engagement.

To improve instrument transparency, the motivational questionnaire (9 items, 5-point Likert scale) was developed by the authors based on established constructs of student motivation and adapted to the Robotics course context. Internal consistency was high (Cronbach's $\alpha = 0.855$). Content validity was confirmed through expert review by three robotics instructors. Cognitive assessment consisted of 20 items, including 15 multiple-choice questions scored dichotomously (0/1) and 5 open-ended analytical problems

scored using a structured rubric. Reliability of the MCQ component, calculated using the KR-20 coefficient for dichotomous items, was acceptable (KR-20 = 0.78). The open-ended tasks were evaluated using a rubric aligned with course learning outcomes; their scoring reliability was ensured through inter-rater agreement (Cohen's $\kappa = 0.82$ for practical/performance-based scoring). Each rubric dimension corresponded to defined learning outcomes of the Robotics course, ensuring alignment between assessment and instructional content.

A fragment of the pedagogical experiment is shown in Fig. 1. The photo captures the moment when students are performing practical tasks in an interactive digital environment using the developed electronic stands. The students assembled and programmed microcontroller devices while observing the visualization of the processes through the system interface. This format of classes allowed them not only to master theoretical knowledge but also to immediately apply it in practice, which increased the level of cognitive and motivational engagement of the participants.

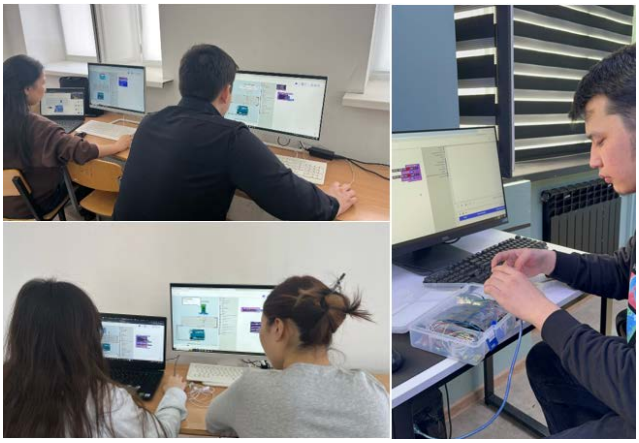

Fig. 1. The course of the pedagogical experiment: students working with digital stands.

Data collection was conducted comprehensively, reflecting the principles of mixed methods research. At the quantitative level, standardized tests and practical tasks were used to assess cognitive and practical components. For the cognitive component, multiple-choice tests and open-ended questions on the basics of robotics and Arduino programming were used; the practical component included assembling electronic circuits, programming simple robots, and completing mini-projects. Example of a cognitive item: "Which Arduino mechanism enables non-blocking execution when controlling multiple actuators? (A) delay(); (B) millis(); (C) analogWrite(); (D) attachInterrupt()." Example of a practical task: "Assemble a circuit with an HC-SR04 ultrasonic sensor and a servo motor; program the servo to rotate proportionally to measured distance."

The motivational component was assessed using questionnaires based on a 5-point Likert scale, which measured interest in the discipline, readiness for independent activity, and emotional involvement. Qualitative data were gathered through interviews and questionnaires with students and teachers, allowing for the identification of subjective perceptions of electronic stands, as well as the barriers and opportunities for their implementation in the educational process. The qualitative analysis followed thematic coding by Braun and Clarke [29]. Two researchers independently coded transcripts; inter-coder agreement $\kappa = 0.79$.

Statistical data processing included the use of nonparametric methods. For independent samples, the Mann–Whitney U test was used to identify differences between the control and experimental groups, and for related samples, the Wilcoxon test was used to record the dynamics of changes within each group. Effect sizes were reported for all comparisons ($r = \frac{Z}{\sqrt{N}}$ for Mann–Whitney and Wilcoxon; Cliff's δ for pre/post differences). Holm-Bonferroni correction was applied to control for multiple comparisons across three components and two timepoints. Key results remained significant after correction.

This approach is consistent with the practice of international pedagogical research, where it is often necessary to work with heterogeneous samples and data that deviate from normal distribution [2, 6]. The interpretation of statistical results was carried out taking into account the size of the effect and pedagogical significance, which made it possible to correlate quantitative data with qualitative observations. Given the non-normal distribution of the data (Shapiro–Wilk test, $p < 0.05$), Spearman's rank correlation coefficient was used. The analysis showed consistently strong positive associations between cognitive and practical indicators, as well as moderate-to-strong links with motivation. These coefficients reflect the internal consistency of learning outcomes, where students who performed better on practical tasks also demonstrated higher cognitive achievement. All correlation values are provided numerically in the corresponding tables and figures.

All participants provided informed consent, and data were anonymized before analysis. Ethical approval for the study was obtained from the institutional ethics committee, ensuring compliance with research ethics standards.

An important element of the study was the comparison of the results obtained with international experience. The world literature notes that the use of electronic and remote laboratories can significantly improve students' practical skills and their motivation for research activities. Teng *et al.* [24] showed that collaborative work by students in remote laboratories enhances the cognitive and social effects of learning. Serik *et al.* [23] confirmed that the integration of robotics with modern digital technologies (including neural network models) contributes to the growth of students' creativity and research skills. Indirect confirmation of the high effectiveness of electronic stands can also be found in meta-analyses on the introduction of virtual reality and simulation platforms in engineering education, which show not only an increase in academic performance but also a sustained increase in student engagement [22, 24].

The methodological approach of this study combines elements of international practice with adaptation to local conditions. On one hand, the study design adhered to the standards of pedagogical experiments in engineering education widely used in Europe, the USA, and China. On the other hand, the use of electronic stands in Kazakh universities allowed taking into account the specifics of the national education system, where limited material and technical resources necessitate the search for safe and cost-effective

solutions. A generalized overview of the experiment structure is provided in Table 1 [1, 5, 9].

Table 1. Study design

Stage	Actions	Tools	Participants
Pre-test	Assessment of knowledge and skills prior to the introduction of electronic stands	Testing, surveying	All groups
Intervention	The use of electronic stands in the educational process	Lectures, practical classes, laboratory classes	Experimental groups
Post-test	Repeated measurement of knowledge and skills	Testing, surveying	All groups
Qualitative analysis	Interview and observation	Zoom, Microsoft Teams	Subsample of students and teachers

IV. Result and Discussion

The pedagogical experiment provided convincing evidence of the effectiveness of using electronic stands to increase student motivation, cognitive knowledge, and practical skills. The analysis of the data obtained was carried out using the results of pre-test and post-test measurements, which included questionnaires and standardized practical tasks. For statistical processing, the Mann–Whitney U test for independent samples and the Wilcoxon test for related samples were used, with effect sizes (r and Cliff's δ) additionally calculated to assess the practical significance of the differences between the control and experimental groups. Holm–Bonferroni correction was applied to control the family-wise error rate across three components and two timepoints, as recommended in the methodological section. This methodological approach made it possible to identify allowed identifying both general growth trends in the experimental group and confirm the reliability of differences in three key components: motivational, cognitive, and practical. The results are presented in a structured form: first, the initial indicators at the pre-test stage are described, then the changes after the introduction of electronic stands and a comparison of the identified effects with international experience and relevant learning theories [8].

A. Characteristics of the Sample and Pre-Test Baseline

The experimental work was carried out over one semester at three Kazakhstan universities: K. Zhubanov Aktobe Regional University, Y. Altynsarin Arkalyk Pedagogical University, and Academician E. A. Buketov Karaganda University. These particular sites were chosen because of their strategic role in the teacher training system and their well-established educational programs in the field of computer science. In recent years, these universities have shown increased interest in the introduction of digital technologies into the educational process, which makes them a suitable base for testing innovative methods. In addition, the material and technical base of the universities is comparable, which ensures the representativeness of the sample. Thus, the study was aimed not only at assessing the pedagogical effectiveness of the introduction of electronic stands, but also at determining their potential for scaling and their applicability in conditions of limited access to physical laboratory equipment, as highlighted in the methodological section.

A total of 189 students from the "Training of Computer Science Teachers" educational program participated in the experiment. They were divided into two groups: a control group (95 students) that continued their education under the traditional program, and an experimental group (94 students) where the "Robotics" course was supplemented with the use of electronic stands. The distribution of students was based on existing academic streams, which made it possible to maintain the natural conditions of the educational process and exclude the effect of subjective selection. Since full randomization was not feasible, intact groups were used; however, matching by GPA, prior programming experience, and year of study (as described in Section III) helped reduce selection bias and ensured baseline comparability.

At the first stage of the experiment, a pre-test was conducted, which included three components: motivational, cognitive, and practical. Each component was assessed using a combination of questionnaires, tests, and practical tasks. that were described in detail in the Materials and Methods section, including reliability indicators (Cronbach's $\alpha = 0.855$ for the motivational scale; KR-20 = 0.78 for the cognitive MCQ items; inter-rater agreement $\kappa = 0.82$ for practical tasks).

The motivational component was assessed using questionnaires on a 5-point Likert scale and included parameters such as interest in studying robotics, readiness to perform independent tasks, and level of emotional involvement. The average score in the experimental group was 22.2 points, and in the control group, 22.7 points (SD = 4.22 and 4.36, respectively). The difference was statistically insignificant ($p = 0.401$), indicating a comparable level of academic motivation among students in both groups. Effect size analysis confirmed the absence of meaningful differences at baseline ($r = 0.05$), which is consistent with the reliability of the scale (Cronbach's $\alpha = 0.855$), ensuring that motivational growth observed later cannot be attributed to pre-existing disparities.

The cognitive component reflected the level of mastery of theoretical knowledge on the basics of robotics and programming on the Arduino platform. The average results were 61.6 points for the experimental group and 61.7 points for the control group (SD = 9.55 and 8.74, respectively; $p = 0.984$). This means that the initial level of theoretical training was equal. The cognitive test consisted of multiple-choice items and short-answer tasks (KR-20 = 0.78), ensuring internal consistency of the instrument described in the Methods section. The negligible effect size ($r = 0.002$) further confirms the equivalence of baseline cognitive preparation, which is essential for valid comparison of post-test changes.

The practical component was assessed based on the results of tasks involving the assembly and programming of simple circuits (LED, servo drive, sound alarm). The average scores were 54.9 points for the experimental group and 53.3 points for the control group (SD = 9.37 and 9.32, respectively;

p = 0.183), which also confirms the absence of statistically significant differences between the groups at the initial stage. The assessment rubric (three subcriteria: correctness of circuit assembly, program logic, and debugging accuracy) demonstrated high inter-rater reliability (Cohen's κ = 0.82), as specified in the Methods section. The effect size was small (r = 0.10), supporting the equivalence of practical readiness before the intervention and ensuring methodological validity for comparing post-test improvements.

Table 2. Pre-test results of both groups

Component	Experimental group (N = 94)	Control group (N = 95)	p-value (Mann–Whitney U)
Motivation (points)	22.2 (SD = 4.22)	22.7 (SD = 4.36)	0.401
Cognitive level	54.9 (SD = 9.37)	53.3 (SD = 9.32	0.183
Practical skills	61.6 (SD = 9.55)	61.7 (SD = 8.74)	0.984

As can be seen from Table 2, the differences in all three criteria were statistically insignificant, confirming the correctness of the chosen quasi-experimental design. Both groups demonstrated comparable levels of motivation, theoretical knowledge, and practical skills at the baseline stage. This aligns with the methodological description provided earlier, where group matching and baseline equivalence checks ensured comparability before the intervention.

B. Changes in Motivation

At the post-test stage, the experimental group demonstrated a statistically significant increase in motivation, confirming the positive influence of electronic stands on students' engagement.

As presented in Table 3, the average motivation score rose from 22.2 (SD = 4.22) to 26.2 (SD = 4.22) in the experimental group, showing a distinct growth of +4.0 points. In contrast, the control group showed minimal growth (+0.9 points), moving from 22.7 (SD = 4.36) to 23.6 (SD = 4.44).

According to the Wilcoxon test, the motivational growth in the experimental group was significant (W = 132.5, $p < 0.05$), whereas changes in the control group were statistically insignificant. Intergroup comparison using the Mann–Whitney U test further confirmed significant differences at the post-test stage (U = 3032, $p < 0.05$).

These results support the hypothesis that interactive, practice-oriented environments strengthen internal motivation. By facilitating repeated experimentation and error correction, electronic stands visibly increased students' confidence and emotional involvement.

Table 3. Comparison of motivation scores in the experimental and control groups (Pre-test vs. Post-test)

Group	Pre-test (M ± SD)	Post-test (M ± SD)	Δ (Increase)	p-value
Experimental group (N = 94)	22.2 ± 4.22	26.2 ± 4.22	+4.0	<0.05
Control group (N = 95)	22.7 ± 4.36	23.6 ± 4.44	+0.9	>0.05

The more pronounced increase in the experimental group aligns with international evidence on technology-enhanced learning. Studies such as Jara *et al.* [4] and Teng *et al.* [24] emphasize that interactive and feedback-rich digital environments significantly elevate students' motivational responses. The findings in this study are consistent with such conclusions and indicate that the integration of electronic stands may serve as an effective motivational driver in robotics education.

C. Improvement in Practical Skills

The practical component was a focus element of the experiment, as it reflects students' ability to translate theoretical knowledge into hands-on problem solving—an essential competency for future computer science teachers. Practical tasks included assembling and debugging Arduino-based circuits, connecting sensors and actuators, and developing simple control programs.

In the experimental group, practical training was carried out using the kurastyrgysh.kz electronic stand. This platform provides a real-time simulation environment that allows students to construct circuits, test program code, visualize output signals, and correct errors through iterative experimentation. While functionally comparable to foreign simulation laboratories, kurastyrgysh.kz is uniquely adapted to local requirements: it supports Kazakh and Russian interfaces, aligns with national curricula, and can be deployed in large-scale teacher-training programs with limited laboratory equipment.

The results demonstrate a substantial increase in practical competence among students who used the electronic stand. As shown in Table 4, the experimental group's scores increased from M = 54.9 (SD = 9.37) to M = 75.0 (SD = 9.06), yielding a gain of Δ = +20.1 points. The control group also improved, but less substantially (Δ = +9.1 points). Statistical analysis confirmed significant within-group progress in both groups (Wilcoxon test, $p < 0.001$; $\delta > 0.40$), but the magnitude of improvement in the experimental group was markedly higher. Intergroup differences at the post-test stage were significant (Mann–Whitney U = 1442, $p < 0.001$, $r > 0.50$), remaining robust after Holm–Bonferroni correction.

Table 4. Dynamics of practical skills (Pre-test → Post-test)

Group	Pre-test (M, SD)	Post-test (M, SD)	Δ (Increase)	p-value
Experimental group (N = 94)	54.9 ± 9.37	75.0 ± 9.06	+20.1	<0.05
Control group (N = 95)	53.3 ± 9.32	62.4 ± 8.37	+9.1	<0.05

These results are visually illustrated in Fig. 2, which highlights the stronger upward trajectory of practical skills among students who worked with the electronic stand.

The observed pattern aligns with the theoretical frameworks underpinning the study. According to Kolb's Experiential Learning Cycle [8], the electronic stand provides a continuous loop of:

- Concrete experience—configuring and testing virtual

circuits.

- Reflective observation—analyzing real-time feedback.
- Abstract conceptualization—understanding circuit logic and device interaction.
- Active experimentation—modifying programs and retesting.

From a constructivist perspective, the ability to repeat experiments without risk encourages hypothesis testing, mistake-driven learning, and refinement of mental models. Qualitative feedback supports this interpretation: more than 70% of students reported increased confidence in transitioning from virtual tasks to real hardware, emphasizing the importance of iterative testing.

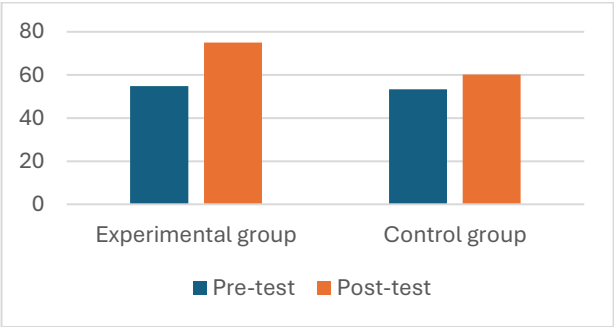

Fig. 2. Dynamics of practical skills of students in the control and experimental groups (Pre-test and Post-test).

A comparison of the data obtained with international studies confirms the universality of the identified effect. Thus, Li and Liang [6] show that the use of virtual laboratories in engineering education provides an average increase in practical skills of 15–20%. Martell-Chavez *et al.* [18] also point out that simulation stands can compensate for the lack of traditional equipment, ensuring a high level of training quality. The results obtained in our study demonstrate an increase of more than 36% relative to the baseline in the experimental group, which exceeds the indicators recorded in foreign analogues and emphasizes the effectiveness of the locally developed tool kurastyrgysh.kz.

D. Improvement in Cognitive Skills

The cognitive component was assessed based on multiple-choice tests and open-ended questions covering the basic concepts of robotics, the fundamentals of programming on the Arduino platform, and the principles of electronic circuitry. This approach made it possible to assess not only the level of mastery of factual material, but also the ability of students to apply theoretical knowledge in non-standard learning situations.

At the pre-test stage, the differences between the groups were statistically insignificant. The average score in the experimental group was $M = 61.6$ (SD = 9.55), and in the control group, $M = 61.7$ (SD = 8.74). A Mann–Whitney test ($U = 4457$, $p = 0.984$) confirmed the equality of the initial levels of cognitive preparation, which ensures the methodological correctness of subsequent comparisons.

After the experiment, a marked increase in indicators was observed in both groups. In the experimental group, the average result increased to $M = 77.8$ (SD = 11.22), which corresponds to an increase of $\Delta = +16.2$ points. In the control group, an increase to $M = 70.3$ (SD = 9.40) was recorded ($\Delta = +8.6$ points). Intergroup differences at the post-test stage were statistically significant ($U = 2769$, $p < 0.05$), and intragroup analysis using the Wilcoxon criterion ($W = 0.0$, $p < 0.05$) confirmed a reliable increase in cognitive indicators in the experimental group. Effect sizes (r and Cliff's δ) also indicated meaningful practical significance, and the results remained robust after applying the Holm–Bonferroni correction.

The summary of cognitive dynamics is presented in Table 5, which clearly shows that the growth in the experimental group was almost twice as high as in the control group.

Table 5. Dynamics of cognitive knowledge (Pre-test → Post-test)

Group	Pre-test (M, SD)	Post-test (M, SD)	Δ (Increase)	p-value
Experimental group ($N = 94$)	61.6±9.55	77.8±11.22	+16.2	<0.05
Control group ($N = 95$)	61.7±8.74	70.3±9.40	+8.6	<0.05

This pattern can be explained by the pedagogical characteristics of the electronic stands. The integration of theoretical content with immediate simulation-based feedback supports key elements of experiential learning [8], allowing students to repeatedly test hypotheses and observe the consequences of their decisions in real time. This mechanism likely contributed to the deeper understanding of concepts such as signal processing, actuator control, and non-blocking programming logic, which students in the experimental group demonstrated more confidently in open-ended tasks.

These findings obtained are consistent with international studies. Ouyang and Xu [2] emphasize that interactive laboratories significantly increase the level of assimilation of theoretical knowledge through reinforcement in practical activities. Similarly, Teng *et al.* [24] show that the use of robotic simulators improves cognitive outcomes compared to traditional lecture-based instruction. In this study, the identified increase in cognitive indicators is consistent with the international trends and highlights the effectiveness of the kurastyrgysh.kz system under the conditions of pedagogical universities in Kazakhstan.

E. The Relationship between Motivational, Cognitive, and Practical Components (Correlation Analysis)

For a deeper understanding of the internal structure of the interrelationships between motivational, cognitive, and practical indicators in the experimental and control groups, a correlation analysis was conducted.

As preliminary diagnostics revealed a non-normal distribution for most variables (based on the Shapiro-Wilk test), the non-parametric Spearman's rank-order correlation coefficient (ρ) was used to calculate the intercorrelation coefficients.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (1)$$

where d_i is the difference between the ranks, and n is the sample size.

The correlation matrices are presented in Figs. 3 and 4. Analysis of the correlation matrices (Figs. 3 and 4) revealed a fundamental change in the internal structure of the interrelationships between motivational, cognitive, and practical indicators following the experimental intervention.

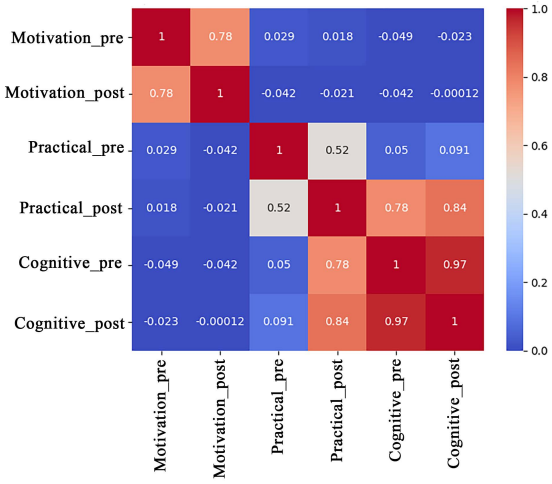

Fig. 3. Correlation matrix of the experimental group.

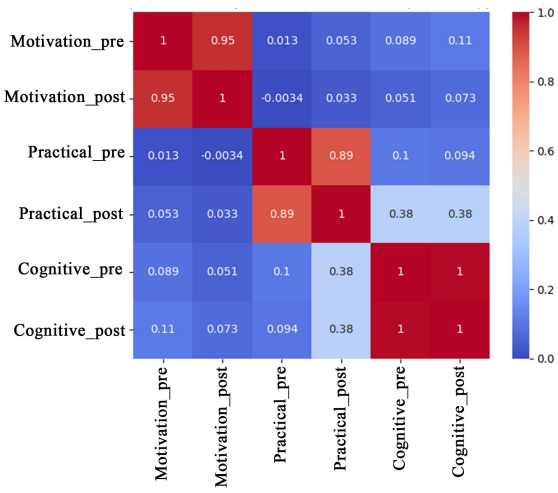

Fig. 4. Correlation matrix for the control group.

The Experimental Group demonstrates a unique integration of theoretical knowledge and practical skills. A strong positive correlation was recorded between post-training cognitive and practical indicators ($\rho = 0.84$), as well as between pre-training cognitive and post-training practical results ($\rho = 0.78$). This indicates that in the new learning format, the level of theoretical understanding directly determines the success of practical application. At the same time, the group shows varied stability across components. While cognitive stability remains extremely high ($\rho = 0.97$), the correlation between pre- and post-test practical skills is moderate ($\rho = 0.52$). Compared to the control group, this lower stability coefficient suggests that the experimental intervention significantly altered and restructured the students' practical skills, indicating a qualitative shift rather than a linear progression. Motivational indicators in this group remain independent, showing negligible or near-zero correlations with cognitive and practical results (ranging from $\rho = -0.04$ to $\rho = 0.02$), which points to the autonomous nature of motivational growth driven by the learning environment.

In the Control Group, the structure of connections is characterized by high stability but low integration. Extremely strong correlations were found within each component over time: Motivation ($\rho = 0.95$), Practical ($\rho = 0.89$), and Cognitive ($\rho = 1.00$). This implies a static learning process where students who started with certain scores tended to finish with similar relative scores, without significant structural shifts. Crucially, the link between theoretical knowledge and practical performance remains weak ($\rho = 0.38$). Unlike the experimental group, theoretical knowledge in the control group does not strongly predict practical performance, highlighting the persistent gap between theory and practice in the traditional training format.

The comparative analysis confirms that the introduction of electronic stands facilitates structural convergence. While the control group develops components in isolation—evidenced by the weak connection between theory and practice ($\rho = 0.38$)—the experimental group forms a unified system where theoretical knowledge and practical experience are strongly interconnected ($\rho = 0.84$).

V. Conclusion

This multi-site quasi-experimental study examined the pedagogical impact of electronic training stands on motivation, cognitive learning, and practical skills in the Robotics course across three Kazakhstani universities. The results demonstrate consistent and statistically significant advantages for the experimental group: motivation increased by 4.0 points (vs. 0.9 in the control group), practical skills by 20.1 points (vs. 9.1), and cognitive knowledge by 16.2 points (vs. 8.6). These findings indicate that simulation-based electronic stands provide a more effective learning environment than traditional instruction, particularly by enabling safe experimentation, repeated practice, and immediate feedback.

Pedagogically, the integration of electronic stands strengthened the alignment between theoretical concepts and hands-on problem solving, as reflected in the strong cognitive–practical correlations. Students in the experimental group demonstrated higher independence, improved analytical reasoning, and greater engagement with self-directed tasks. These outcomes correspond with principles of constructivism and experiential learning, where active manipulation, reflection, and iteration play central roles in the formation of durable understanding. For resource-constrained institutions, the results highlight that locally adapted simulation platforms can offer scalable and cost-effective alternatives to physical laboratories while maintaining educational rigor.

Nonetheless, several limitations should be acknowledged. The quasi-experimental design did not allow for full randomisation, and intact academic groups may contain unobserved differences. The motivational scale relied partly on self-reported perceptions, and the intervention lasted only one semester, limiting conclusions about long-term retention or transfer of skills. The study was conducted in teacher-training programs from three universities, which may restrict the generalisability of the results to engineering-focused contexts.

Future research should investigate longitudinal effects of electronic stands on students' professional development, classroom readiness, and creativity. Comparative studies involving engineering majors, alternative robotics platforms,

and hybrid laboratory models would further clarify the boundary conditions of effectiveness. Expanding the system with adaptive feedback, AI-supported assessment, and automated analytics could also enhance its pedagogical value.

In summary, the study provides empirical evidence that electronic stands substantially improve motivation, cognitive understanding, and practical competence in robotics education under resource limitations. These findings support the broader shift toward simulation-enhanced, practice-oriented learning environments and demonstrate that well-designed digital tools can meaningfully expand access to high-quality STEM education.

APPENDIX: PRACTICAL ASSESSMENT RUBRIC AND EXAMPLE TASKS

The practical component was assessed using a three-dimension rubric totaling 100 points.

Each dimension consisted of real laboratory tasks performed on the electronic stand and evaluated by two independent instructors (Cohen's $\kappa = 0.82$).

Criterion 1. Ability to operate the electronic stand (30 points)

Scoring range: 0–30 points (up to 10 points each for wiring accuracy, code correctness, and successful execution).

Example task:

Task 1. Connect a servo motor to pin 9 (VCC–5V, GND, signal–9) and write code using Servo.h (attach, write) to rotate it to 90°.

Criterion 2. Integration of theory and practice (40 points)

Scoring range: 0–40 points (up to 10 points each for theoretical explanation, practical implementation, and consistency between the two).

Example task:

Task 2. Explain the principle of ultrasonic distance measurement (echo method). Connect the sensor (Trig–2, Echo–3) and implement code that outputs the measured distance via Serial.print.

Criterion 3. Independence and problem-solving (30 points)

Scoring range: 0–30 points (up to 10 points each for initiative, correctness of solution, and reflection on performance).

Example task:

Task 3. Develop a reactive servo system: the ultrasonic sensor measures distance; the servo rotates to 0° if the object is farther than 30 cm and to 90° if the object is closer, using Servo.write and conditional logic.

Example of scoring

To illustrate the rubric's application, below is a condensed anonymized scoring instance (Task 2):

The student correctly explained the echo-based measurement principle (9/10).

The sensor was wired correctly and produced stable distance readings (10/10).

The explanation and output values were consistent (8/10).

Total for Criterion 2: 27/40.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The experiment and article writing were carried out by A.A.R. The literature review and scientific supervision were conducted by N.T.S. Observation and statistical analysis were performed by R.U.Z. and A.R.S. All authors had approved the final version.

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