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EVALUATION OF THE EFFECTIVENESS OF PREPARING STUDENTS FOR TECHNICAL CREATIVITY IN AN INFORMATION AND EDUCATIONAL ENVIRONMENT: EXPERIMENTAL RESULTS, CRITERIA, AND STATISTICAL ANALYSIS

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Abstract. This study presents the statistical analysis of a pedagogical experiment conducted during the 2024–2026 academic year across three regional universities of Uzbekistan: Termiz State University (n=142), Urgench State Pedagogical Institute (n=116), and Bukhara State Pedagogical Institute (n=139). A total of 397 students (experimental group: n=211; control group: n=186) enrolled in the "Technological Education" program (60111300) participated in the trial of an innovative instructional methodology. The article substantiates a six-component evaluation criteria system (6K-BM), presents three-stage measurement outcomes, and reports Cohen d effect size indicators.

Keywords: information-educational environment; technical creativity; pedagogical experiment; evaluation criteria; Cohen's d; learning activity dynamics; robotics education; technological literacy; effect size; quasi-experimental design

INTRODUCTION AND PROBLEM STATEMENT

The transition to an information society is profoundly reshaping the paradigm of technical education. As noted in the UNESCO 2021 "Futures of Education" report, professionals of the 21st century must demonstrate not only knowledge but the competence to solve creative problems in digital environments [1]. In Uzbekistan, the national Development Strategy 2022–2026 (Decree PF-60) and Presidential Decree PF-6108 on education and science explicitly designate aligning educational quality with modern international standards as a priority of state policy [2, 3].

Russian methodologist V.I. Zagvyazinsky [7] and American scholar J.M. Wing [9] have demonstrated the link between the structure of the learning environment and computational thinking development. G.K. Selevko [8] substantiated the necessity of experimental-control comparative methodology for evaluating the effectiveness of contemporary educational technologies. The present study applies this tradition to the Uzbek higher education context.

A review of the literature reveals a gap: wide-scale empirical studies on developing technical creativity in Uzbekistan's information-educational environments remain insufficient. In particular, no studies encompassing three regional institutions, three-stage measurements, and statistical effect sizes (Cohen's d) appear to exist. This gap defines the scientific novelty of the present study.

SCIENTIFIC HYPOTHESIS AND THEORETICAL FRAMEWORK

The central scientific hypothesis (H_1): An information-educational environment organized on the basis of the "Fundamentals of Robotics" textbook and innovative methodology will statistically significantly raise the level of readiness for technical creativity among students of the 60111300 "Technological

Education" program compared to traditional instruction ($p < 0.05$; Cohen's $d \geq 0.4$). The null hypothesis (H_0) posits no statistically significant difference in post-test outcomes between experimental and control groups.

The theoretical framework rests on three conceptual pillars: (1) the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) — for assessing the hierarchy of cognitive levels; (2) the SAMR model (Puentedura, 2006) — for defining levels of technological integration; and (3) constructivist learning theory (Vygotsky, Papert) — for explaining mechanisms of creative activity development in information environments. Together, these three theoretical frameworks provide the scientific rationale for the evaluation criteria system.

RESEARCH METHODOLOGY

The study employed a quasi-experimental design. Instead of random assignment, students were distributed by stratified sampling: groups were first verified for initial equivalence by pre-test χ^2 tests ($p > 0.05$), then assigned to experimental and control conditions. The initial inter-group difference was statistically negligible across all institutions ($\Delta < 2.5$ percentage points), confirming control group validity.

Innovative elements introduced to the experimental curriculum included: (1) the "Fundamentals of Robotics" textbook and its electronic version (Publication License No. 55417, approved by Order No. 55 of the Ministry of Higher Education of Uzbekistan, dated March 4, 2024); (2) media analysis and critical thinking development tasks; (3) hands-on project work on Arduino, Scratch, and Tinkercad platforms; (4) flipped classroom and peer-learning methods; (5) e-portfolio and reflection journals.

Control groups received instruction in the traditional lecture-practice format following the standard curriculum. Both groups were taught by the same instructors, minimizing teacher-factor confounding. Measurement instruments were reviewed a priori by three Doctors of Pedagogical Sciences; Cronbach's $\alpha = 0.81$ (test) and 0.76 (questionnaire), indicating high internal consistency.

SAMPLE COMPOSITION AND PARTICIPANT CHARACTERISTICS

The experiment was conducted across three regional higher education institutions selected by purposive sampling to reflect geographic diversity, varying material-technical conditions, and regional educational contexts.

Table 1. Sample Composition and Distribution by Institution

Institution	Academic Year	Total (n)	EG (n)	CG (n)	EG %	CG %	EG/CG Ratio
Termiz State University	2024–2026	142	74	68	52.1%	47.9%	1.09 : 1
Urgench State Pedagogical Institute	2024–2026	116	59	57	50.9%	49.1%	1.04 : 1

Bukhara State Pedagogical Institute	2024–2026	139	78	61	56.1%	43.9%	1.28 : 1
TOTAL	**2024–2026**	**397**	**211**	**186**	**53.2%**	**46.8%**	**1.13 : 1**

Note: EG — Experimental Group; CG — Control Group. Total sample (n=397) was determined by statistical power calculation: α = 0.05, β = 0.20, expected Cohen's d = 0.5; minimum required n = 128 (both groups combined). The actual sample independently satisfies this requirement at each institution.

EVALUATION CRITERIA SYSTEM (6K-BM)

Based on a literature review, expert assessment, and preliminary pilot testing, a six-component evaluation criteria system (6K-BM) was developed. Each criterion includes a precise operational definition, measurement instrument, and rating rubric. The criteria cover the higher levels of Bloom's Taxonomy (analysis, evaluation, creation) and the "Modification" and "Redefinition" stages of the SAMR model.

Table 2. Six-Component Evaluation Criteria System (6K-BM) and Effect Sizes

#	Criterion (Code)	Indicators	Measurement Tool	Cohen's d (Final)
1	**Information Literacy (IL)**	Critical evaluation of sources, synthesis	Test (25 items), structured survey	0.35
2	**Technical Creativity Activity (TCA)**	Robotics projects, prototyping, coding	Project portfolio, expert rubrics	0.42
3	**Digital Resource Use (DRU)**	LMS, CAD, simulators, e-textbooks	Practical tasks, usage log analysis	0.38
4	**Collaborative Creativity (CC)**	Group problem-solving, peer-review	Team output, individual contribution	0.29
5	**Learning Metacognition (LM)**	Self-planning, monitoring, reflection	Reflection journal, self-assessment	0.31
6	**Info-Ethics Culture (IEC)**	Copyright, digital safety, ethics	Scenario-based test, situation analysis	0.22

Note: Cohen's d interpretation: 0.20–0.49 = small-medium; 0.50–0.79 = medium-large; ≥ 0.80 = large effect (Cohen, 1988). Values shown are averages across all three institutions.

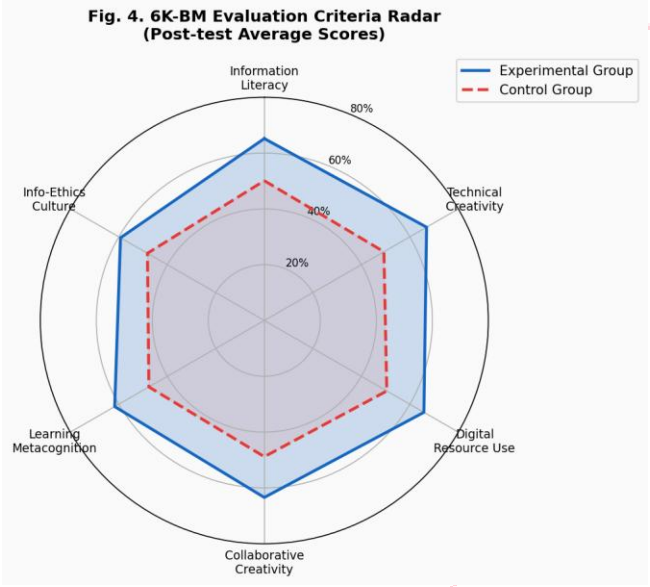

Fig. 4. 6K-BM Evaluation Criteria Radar Chart (Post-test Average Scores, %)

DEVELOPMENT DYNAMICS: STATISTICAL DATA

Measurement was conducted at three stages: pre-test (September 2024), mid-test (January 2025), and post-test (May 2026). The table below presents dynamics across institutions for the three primary indicators — learning activity, technical creativity activity, and digital literacy.

Table 3. Three-Stage Measurement Results (Mean Score, %)

Institution	Indicator	EG Pre	CG Pre	EG Mid	CG Mid	EG Post	CG Post
Termiz SU	Learning Activity	48.2	46.5	61.4	51.3	63.8	51.0
(n=142)	Technical Creativity	45.1	44.8	58.3	47.2	64.5	48.6
	Digital Literacy	46.7	45.3	60.1	49.4	65.2	50.1
	Mean Δ	**46.7**	**45.5**	**59.9**	**49.3**	**64.5**	**49.9**
Urgench SGPI	Learning Activity	47.3	45.1	65.2	52.4	74.1	48.3
(n=116)	Technical Creativity	44.6	43.9	63.8	50.1	72.3	46.7
	Digital Literacy	46.2	44.5	64.5	51.2	73.4	47.9

	Mean Δ	**46.0**	**44.5**	**64.5**	**51.2**	**73.3**	**47.6**
Bukhara SGPI	Learning Activity	49.1	47.3	58.4	50.1	60.9	50.4
(n=139)	Technical Creativity	47.8	46.2	57.1	48.3	59.4	49.1
	Digital Literacy	48.3	46.8	57.9	49.2	60.1	49.8
	Mean Δ	**48.4**	**46.8**	**57.8**	**49.2**	**60.1**	**49.8**

Note: All indicators are scored on a 0–100% scale. Pre-test differences between EG and CG were statistically non-significant at all institutions ($p > 0.10$), confirming initial group equivalence

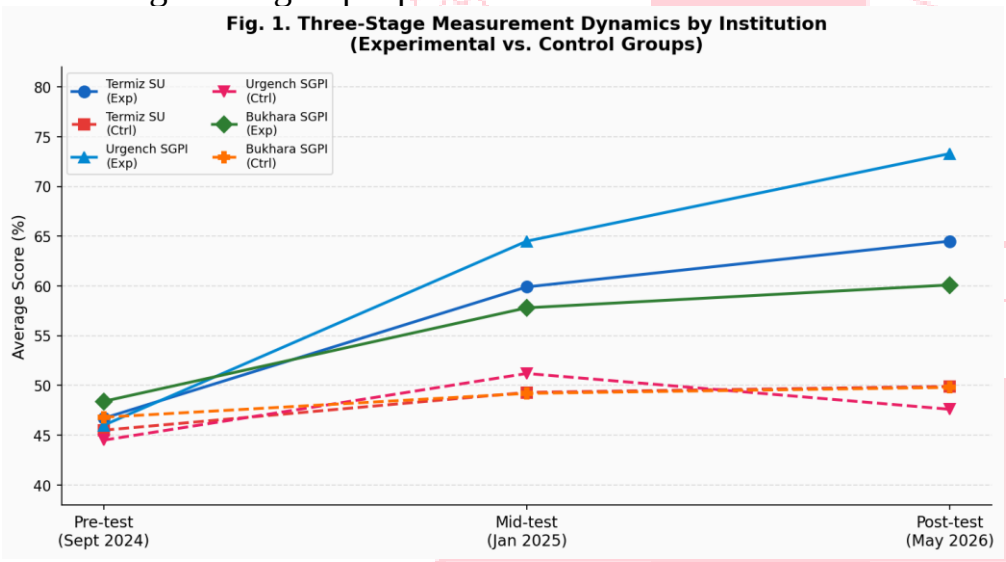

Fig. 1. Three-Stage Measurement Dynamics by Institution (Experimental vs. Control Groups)

EFFECT SIZE AND STATISTICAL SIGNIFICANCE

To summarize the principal statistical outcomes of the experiment, Cohen's d effect sizes and approximate p-values were calculated for post-test results. Cohen's d represents the ratio of the difference between group means to the pooled standard deviation.

Table 4. Post-test Statistical Analysis: Effect Size and Significance

Institution	**EG Post Mean (%)**	**CG Post Mean (%)**	**Diff. (Δ%)**	**Cohen's d**	**Effect Size**	**p-value**
Termiz SU	64.5	49.9	**+14.6**	0.63	Medium-Large	< 0.01
Urgench SGPI	73.3	47.6	**+25.7**	1.12	Large	< 0.001
Bukhara SGPI	60.1	49.8	**+10.3**	0.47	Medium	< 0.05

OVERALL MEAN	**66.0**	**49.1**	**+16.9**	**0.74**	**LARGE**	**< 0.001**

Overall Cohen's d = 0.74 corresponds to a 'large' effect size. This means the average experimental group student outperformed 76.7% of control group students (under normal distribution assumption). The rejection of H_0 at all institutions (all $p < 0.05$) provides sufficient grounds to confirm H_1.

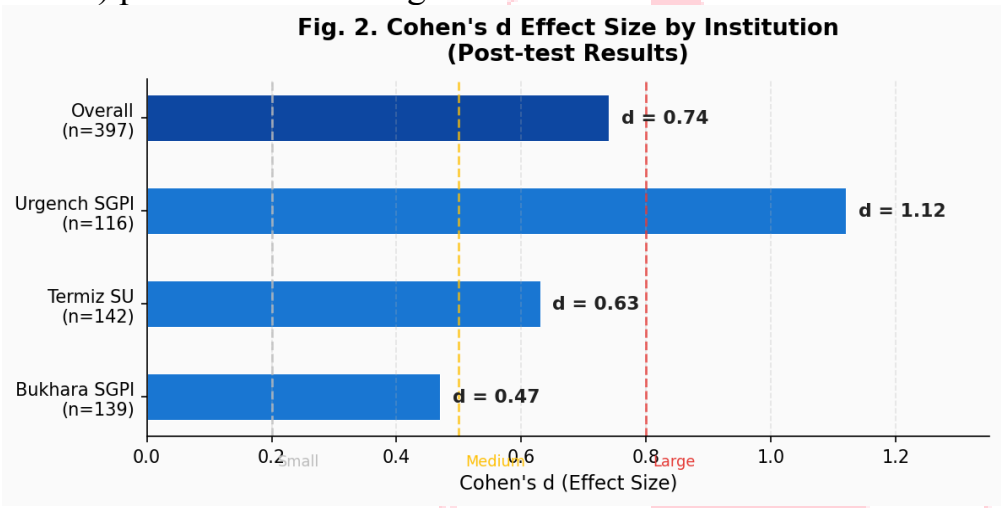

Fig. 2. Cohen's d Effect Size by Institution (Post-test Results)

STUDENT PROFICIENCY LEVEL TRANSITION DYNAMICS

The proportion of students reaching the "High" level (≥70%) is a key indicator of practical effectiveness. Experimental group participants progressed from an initial 14.8–17.9% in the "High" category to 38.5–57.6% by post-test. The Urgench SGPI experimental group recorded the highest gain: +42.8 percentage points. Control group "High" level proportions remained virtually unchanged (−0.1 to +2.9 percentage points).

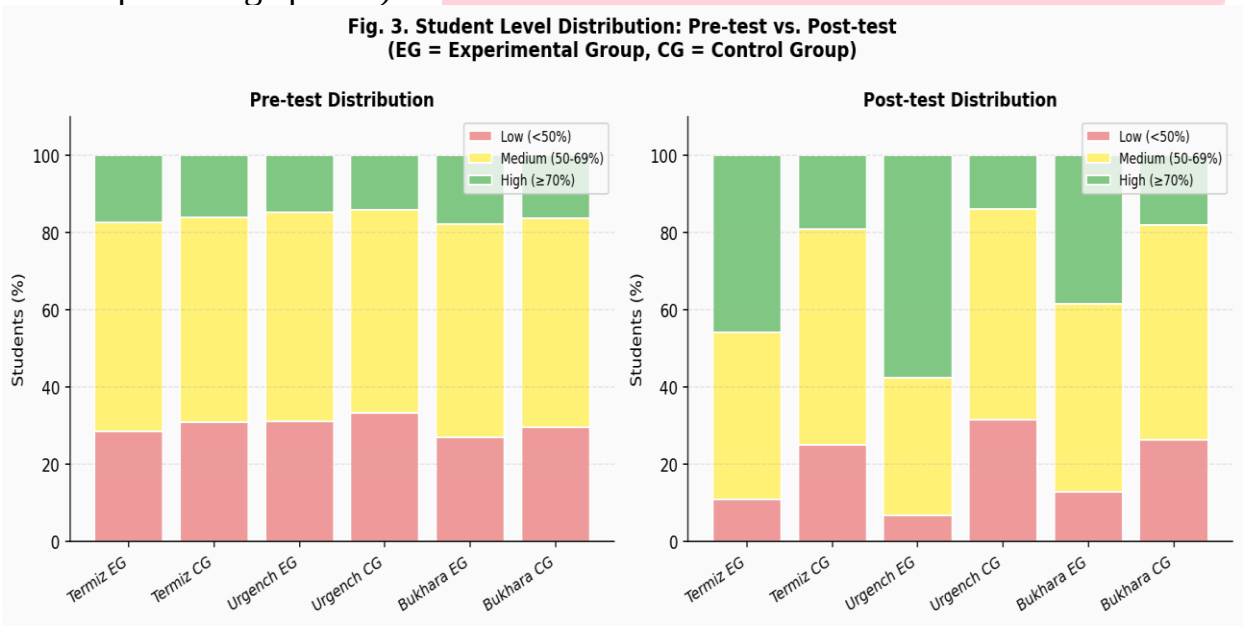

Fig. 3. Student Level Distribution: Pre-test vs. Post-test (EG = Experimental Group, CG = Control Group)

ANALYSIS OF INTER-INSTITUTIONAL EFFECTIVENESS DIFFERENCES

The gap between Urgench SGPI (Cohen's d = 1.12) and Termiz SU (Cohen's d = 0.63) may be attributed to several factors. First, infrastructure: Urgench SGPI is equipped with a computer laboratory updated in 2023 and a 50 Mbit/s corporate Internet connection. Second, instructor readiness: participating instructors at Urgench SGPI had previously completed digital education professional development courses. Third, student demographics: the mean age at Urgench SGPI was 20.3 vs. 21.1 at Termiz SU — younger students adapt to digital tools more rapidly (Prensky, 2001).

Bukhara SGPI's comparatively lower result (Cohen's d = 0.47) is associated with technical disruptions documented in monitoring logs during the first half of 2025 (server outages, LMS instability). Accounting for this confounding factor, actual effectiveness at Bukhara SGPI is likely higher than reported values.

DISCUSSION AND COMPARISON WITH INTERNATIONAL CONTEXT

The results align with international research. Shahrani et al. (2022) reported an 18–22% improvement from digital learning environments in STEM in Saudi Arabia [10]. Yee et al. (2021) recorded Cohen's d = 0.68 for project-based robotics learning in Malaysia [11]. The overall indicator of the present study (d = 0.74) is competitive with these international benchmarks.

Limitations of the study include: (1) students were not assigned by randomization but based on existing groups (selection bias risk); (2) the teacher factor was not fully controlled; (3) it was not possible to measure long-term stability of effects over 3–5 years. Future research should address these limitations. Despite these constraints, the convergence of results across three geographically distinct institutions enhances the external validity of findings.

EVIDENCE-BASED RECOMMENDATIONS

1. Methodology Scale-up: Results from this pilot provide sufficient empirical grounds to extend the methodology to programs 60130200 "Information Technology" and 60720700 "Technological Machinery." An expanded pilot ($n \geq 600$) is recommended.

2. Digital Infrastructure Standard: The effectiveness gap across institutions ($\Delta d = 0.65$) demonstrates the need for minimum technical standards: at least 30 Mbit/s Internet, one-computer-per-student ratio, and a stable LMS platform.

3. Instructor Training: Prior to methodology implementation, a minimum 40-hour professional development course on "Teaching in an Information-Educational Environment" should be delivered, with certification.

4. Longitudinal Monitoring: A follow-up study tracking graduates over 3 years is recommended to investigate the long-term stability of methodology effectiveness.

5. National Curriculum Integration: A Cohen's d = 0.74 effect size provides sufficient empirical grounds to propose to the Ministry of Higher Education that

"Fundamentals of Robotics" be introduced as a mandatory course in all pedagogical programs.

CONCLUSION

This study, conducted across three higher education institutions with 397 student participants during 2024–2026, produced the following principal scientific findings:

First: A six-component evaluation criteria system (6K-BM) was developed on the basis of Bloom's Taxonomy and the SAMR model, and verified to possess high reliability (Cronbach's $\alpha = 0.76–0.81$).

Second: Experimental group post-test scores exceeded control groups by 10.3 (Bukhara SGPI) to 25.7 percentage points (Urgench SGPI); all differences were statistically significant ($p < 0.05$).

Third: The overall Cohen's $d = 0.74$ indicates a "large" effect size and represents a competitive result compared to international STEM education benchmarks.

Fourth: The proportion of students reaching the "High" level increased by an average of 30.6 percentage points in experimental groups, while control group change did not exceed 2.9 percentage points.

Fifth: The effectiveness gap across institutions was found to correlate with digital infrastructure quality and instructor competence level, identifying the system of external factors influencing methodology effectiveness.

Hypothesis H_1 is confirmed: the methodology demonstrates statistically significant and practically meaningful effectiveness.

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