Robotics as a Tool for Value-Oriented Education in Primary Schools: A Case Study in Kazakhstan

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***Abstract*—The present study evaluates the pedagogical potential of educational robotics as a tool for fostering value orientations among primary school students in Kazakhstan. Using a quasi-experimental mixed-methods design, 122 fourth-grade students from two urban schools were assigned to either an experimental group, which completed an 8-week "Robotics + Values" module, or a comparison group that followed a standard robotics curriculum. The intervention combined robotics activities with explicit tasks promoting collaboration, respect for shared resources, cultural identity, and public presentation. Findings revealed significant gains in cooperation, respect, and civic engagement for the experimental group compared to the control. Observational data confirmed more frequent peer assistance, respectful listening, and references to cultural themes, while reflective responses and teacher interviews indicated that these norms transferred beyond robotics classes. Based on the field data, a process model was proposed to illustrate how technical activities can progressively acquire social and cultural meaning, linking collaborative construction and programming with narrative localization and public recognition. The results suggest that educational robotics, when designed with intentional value integration, can serve a dual role in primary education: building Science, Technology, Engineering, and Mathematics (STEM) competencies and cultivating prosocial values. These findings contribute to global discussions on the integration of character education into STEM and provide practical guidance for curriculum innovation in contexts of digital transformation.**

***Keywords*—educational robotics, value-based education, primary school, collaboration, respect, patriotism, Science, Technology, Engineering, and Mathematics (STEM), positive technological development**

I. INTRODUCTION

The modern digital environment presents new challenges for the value-based education of younger generations. On one hand, there is a growing need to instill core moral principles in children as they become increasingly immersed in virtual communication. Specific issues such as ensuring digital safety, addressing cyberbullying, and maintaining ethical standards in online interactions are becoming more prominent [1]. On the other hand, recent experiences—particularly the period of enforced social isolation during the pandemic—have highlighted the importance of intentionally fostering human values and social interaction skills in children from an early age [2]. Such preparation is essential for equipping them with the capacity for responsible behavior in an increasingly dynamic digital society.

Simultaneously, there is a global surge of interest in Science, Technology, Engineering, and Mathematics (STEM) education and its integration into school curricula. This trend raises the question of how to merge technical instruction with humanistic goals—namely, how to enrich STEM education with value-oriented content. In recent years, an increasing number of scholars have emphasized the importance of combining technical knowledge with the development of socio-humanitarian competencies. There is a discernible trend toward incorporating humanities disciplines into STEM frameworks to introduce a philosophical and ethical dimension to technological education [3]. It is argued that STEM approaches can and should be implemented on a moral-ethical foundation, with frameworks designed to integrate the acquisition of technical skills with the cultivation of virtues and values [4]. For example, the pedagogical model "Coding as Another Language" is aimed not only at developing algorithmic thinking but also at intentionally fostering children's positive character traits through playful programming activities [5]. In this regard, the integration of STEM and value-based education is increasingly recognized as a promising path for modern education—one that aligns technological advancement with humanistic ideals.

Against this backdrop, the educational potential of robotics as a tool for value formation among primary school students becomes a particularly relevant subject of investigation. The aim of this study is to explore how robotics activities can contribute to the development of foundational value orientations in students. To achieve this goal, it is necessary to: identify the value-relevant aspects of robotics education (e.g., the social skills and character traits cultivated through collaborative robot-building tasks); describe pedagogical strategies for implementing robotics instruction with an emphasis on moral development (e.g., integrating discussions of ethical dilemmas and cooperative practices into technical projects); and analyze changes in students' value orientations and attitudes as influenced by robotics learning (using questionnaires, observations, and pre/post comparisons).

It is hypothesized that participation in educational robotics will support the formation of key social and personal values among primary schoolchildren—particularly the values of collaboration (teamwork, mutual assistance), respect (toward peers, ideas, and rules), and patriotism (pride in the achievements of one's team, school, or community). This hypothesis is supported by findings indicating that group-based robotics activities naturally foster cooperation and collaborative problem-solving skills [6], and that joint creative construction and programming tasks encourage children to be mindful of each other and the outcomes of shared work [7]. Furthermore, it is expected that through project-based activities (e.g., designing robots to serve helpful functions in their school or local environment), children will develop a deeper sense of civic engagement and belonging.

II. Literature Review

Value-based (or moral) education in primary school refers to a purposeful pedagogical process aimed at fostering children's basic moral understanding, value orientations, and socially acceptable behaviors. According to UNESCO, value-based education encompasses all deliberate pedagogical efforts to nurture children's awareness of positive values and to raise them in ways that are aligned with their individual potential [8]. In the context of primary education, this process is implemented through both specialized lessons (e.g., ethics classes, extracurricular activities) and the incorporation of moral and civic content into everyday instruction. The overarching goals of value-based education at this stage include the holistic development of the child's personality and the internalization of norms related to morality, communication culture, and civic identity.

In many countries, it is enshrined in educational policy that schools are responsible not only for imparting knowledge but also for cultivating responsible members of society. For example, national educational standards explicitly state that schools must foster the development of morally upright and responsible citizens who respect the law and others [9]. Primary school teachers, therefore, act as key agents of socialization, transmitting values through both the content of their lessons and their personal example, as well as through the broader school culture [10, 11]. The theoretical foundations of value-based education draw upon a variety of frameworks—ranging from the development of emotional intelligence and empathy to the reinforcement of traditional virtues such as honesty, diligence, and kindness. Overall, primary education lays the foundation for children's value orientations, which substantially shape their future development.

In recent years, educational robotics has emerged as an innovative tool capable of supporting not only technical skill acquisition but also the development of a wide range of cognitive and personal competencies among students. The cognitive effects of robotics education include increased interest in science and technology, as well as the enhancement of analytical and algorithmic thinking. Empirical studies demonstrate that working with robots helps children understand scientific and mathematical concepts more effectively and apply knowledge of physics and engineering in practical tasks [12–14]. When solving real-world challenges (e.g., building and programming a robot to perform specific actions), students develop skills in systems analysis, problem definition and solving, and creative technical thinking.

Beyond subject-specific learning, robotics also promotes so-called 21st-century skills, including learning-to-learn, critical thinking, communication, and creativity. Group projects involving the design and programming of robots foster initiative, independence, and teamwork [15]. Collaborative activities in robotics clubs provide a space to train social communication and cooperation skills, such as assigning roles, discussing ideas, and overcoming difficulties together. There is also evidence that participation in educational robotics has a positive impact on students' self-esteem and enhances their motivation to learn [16, 17]. In general, practice shows that robotics—by virtue of its engaging, hands-on nature—offers a favorable environment for the development of important personal traits such as perseverance, self-confidence, creative imagination, and collaboration. These qualities are directly connected to the value sphere of personality: for instance, collaboration is rooted in mutual respect and trust, while creative problem-solving nurtures openness to new ideas.

In addition to cognitive and personal outcomes, educational robotics holds significant potential for interdisciplinary learning. Robotics projects inherently integrate knowledge from various domains: to build a functioning robot, a student must apply elements of mathematics (calculations, measurements), computer science (algorithm programming), engineering (mechanical construction), and often art (model design, creative aesthetics), as well as social sciences when addressing real-world social issues. Thus, robotics naturally aligns with the principles of STEAM education, enriching the traditional STEM framework with creative and humanistic dimensions. Researchers have noted that robotics activities increase children's overall interest in science and technology, particularly because of their engaging and playful format [18]. Moreover, learners observe tangible results from their actions (e.g., a robot that functions), which lends meaning and real-world relevance to the learning process.

The interdisciplinary nature of robotics also accommodates students with diverse abilities: some may excel in programming, others in mechanical construction, and others in artistic expression—within a team, all talents find a role [19]. This environment fosters collaboration, encouraging students to value each member's contribution and to respect a diversity of skills. Such an approach aligns with current educational trends that aim to prepare students for complex, real-world problems, which rarely fall within single-subject boundaries.

Globally, there is growing experience with educational programs that combine technological learning with the cultivation of social and moral qualities. A number of international and domestic studies illustrate this integrative approach. For instance, the "Beyond STEM" project (USA–Argentina) implemented a robotics curriculum in experimental kindergarten classrooms that simultaneously focused on technical skills and core virtues. Children worked with simple KIBO robots, inventing stories and tasks that reflected their school's values—such as kindness, cooperation, and mutual respect [20, 21]. According to teachers' observations, during the sessions, young learners exhibited creative imagination, curiosity, and generosity, while also practicing listening and collaborative problem-solving. The curriculum was based on Bers' [22] framework of Positive Technological Development, which emphasizes intentional character education through programming activities. In this way, children not only learned basic robotics concepts but also internalized ethical behavior (e.g., negotiating and forgiving after a peer conflict involving the robots) [22]. This experiment demonstrated the effectiveness of integration: children advanced both in early STEM skills and in socio-emotional development.

In Kazakhstan and other post-Soviet countries, robotics courses in middle schools are increasingly being used for educational and developmental purposes. For example, a study conducted in Kazakhstan from 2019 to 2021 assessed the impact of robotics training on students' competencies in online learning [23]. In addition to gains in technical skills (e.g., algorithmic thinking), the researchers observed significant improvements in teamwork, self-confidence, and learning motivation. They concluded that educational robotics, even when delivered remotely, creates a synergistic learning environment that fosters both cognitive engagement and social cooperation skills. Another notable aspect is student participation in robotics competitions. Russian educators have emphasized that preparing for robotics tournaments acts as a strong motivator for academic achievement and group cohesion [24]. When students represent their school or region in such competitions, they experience pride and responsibility, which can be seen as a form of local patriotism. Thus, even within the regional context, robotics contributes not only to technological literacy but also to students' personal growth and identity formation.

In sum, the literature review highlights the promising pedagogical potential of integrating STEM education with value-based learning. While moral and social education in primary school lays the groundwork for students' ethical and interpersonal development, robotics provides a modern, hands-on platform to put these values into practice. At the same time, scholars caution that an overemphasis on technical efficiency and competition in robotics projects may undermine reflective and value-oriented goals, highlighting a tension that needs careful curricular design [4, 24]. Addressing these tensions requires deliberate integration of tasks that encourage collaboration, respect, and civic responsibility alongside coding and engineering. Both international and local studies confirm that such integration can greatly enrich the educational process. This synergy not only responds to the challenges of the digital age but also prepares well-rounded, technically competent, and value-driven citizens of the future.

In addition to these insights, the present study contributes novelty by extending the Positive Technological Development framework to a multilingual Central Asian context, which remains underrepresented in existing research. Unlike prior studies that largely focus on preschool or Western classrooms [20, 23], this research examines value-oriented robotics in primary schools in Kazakhstan, explicitly embedding cultural localization (e.g., maps, national heroes, community issues) into robotics tasks. By combining technical skill development with locally meaningful value education, the study advances the international discourse on how STEM curricula can simultaneously promote cognitive, social, and civic outcomes in diverse educational environments.

III. Materials and Methods

A. Research Design

The study employed a quasi-experimental, multicenter, mixed-methods design, combining quantitative and qualitative data to provide a comprehensive assessment of the impact of an integrated robotics curriculum on the value orientations of primary school students. This design is recommended for educational innovation studies where cognitive, socio-emotional, and contextual outcomes are evaluated simultaneously.

Design Components. The quantitative component included pre- and post-test assessment of value orientations using the Primary Values Inventory-12 items (PVI-12) questionnaire, behavioral observations via the VIA Class rubric, and performance indicators for team-based robotics tasks. The qualitative component involved semi-structured interviews with teachers, focus groups with students, reflective written responses from children, and artifact analysis (project materials from LEGO® MINDSTORMS® EV3 activities).

Group Comparison. Cluster-distributed classroom groups were used. School No. 17 implemented the value-integrated program and served as the Experimental Group (EG), while School No. 11 followed a standard robotics curriculum without explicit value-based modules, constituting the Comparison Group (CG). This type of non-equivalent control group design is typical in school-based research where random assignment is constrained by administrative limitations.

B. Context and Research Sites

The study was conducted in two public urban primary schools in Shymkent, Republic of Kazakhstan: School No. 17 named after M. Yu. Lermontov is a Russian-language/bilingual institution with a well-developed robotics club and prior experience in city-level STEM events; School No. 11 named after Alisher Navoi operates in a multilingual environment (Kazakh, Russian, and Uzbek) and offers robotics as an elective course, with comparatively less experience in thematic competitions.

Both schools were equipped with LEGO MINDSTORMS Education EV3 kits and agreed to participate in the research. The selection of these sites ensured variability in linguistic and cultural contexts, which is critical when investigating the value-based impact of STEM interventions.

C. Participants

The study involved 128 fourth-grade students (age: M = 9.8 years, SD = 0.4; range: 9–10 years). The gender distribution was 62 boys (48.4%) and 66 girls (51.6%). After excluding participants with incomplete data sets (>20% missing values; n = 6), the final analytical sample comprised 122 students (EG = 60; CG = 62) (Table 1).

Linguistic and cultural background (based on parental questionnaires): Kazakh was the dominant home language for 41% of participants, Russian for 38%, Uzbek for 14%, and other/mixed languages for 7%. This multilingual composition enabled an additional analysis of how different language groups perceived the patriotic and cultural elements of the program.

Inclusion/exclusion criteria. Inclusion: regular attendance of the robotics course, signed informed consent from parents, oral assent from the child, and no medical restrictions on participation in regular school activities. Exclusion: refusal to participate, absence in more than 30% of sessions, or placement on an individualized educational path requiring an adapted robotics curriculum.

Table 1. Group allocation

Group	School	Classes	*n* enrolled	*n* analyzed	Program type
EG	No. 17 Lermontov	4A, 4B	63	60	Robotics + Values
CG	No. 11 Navoi	4Ә, 4B	65	62	Standard robotics

D. Learning and Technical Resources: LEGO® MINDSTORMS® Education EV3

All classes utilized LEGO MINDSTORMS Education EV3 kits (Education Core Set; partially with Expansion Set). The standard configuration included the EV3 Intelligent Brick, large and medium servo motors, ultrasonic, color, gyroscopic, and touch sensors. Programming was carried out using the EV3 Classroom environment (a Scratch-like block-based interface with support for collaborative work via projection onto an interactive whiteboard).

Additional materials included printed thematic mats (e.g., map of Kazakhstan, school-based routes), scenario cards with value dilemmas, and sets of colored markers to indicate team roles.

The choice of platform was motivated by its wide usage in early STEM education research, its accessibility for primary-aged learners, and its suitability for integrating artistic and socio-cultural components.

E. Description of the Intervention: "Robotics + Values" Module

The intervention in the experimental group lasted 8 academic weeks (February–April 2025) and included 16 lessons of 45 minutes each (8 thematic blocks, 2 lessons per block). The curriculum was designed based on the principles of Positive Technological Development (PTD) and the integration of Social-Emotional Learning (SEL) into STEM.

Thematic-Value Sequence of Lessons:

1) Team and Rules – assembling a basic mobile robot, discussion of norms for teamwork (value: cooperation).
2) Respect Others' Work: exchanging subassemblies between teams, testing and improving peers' constructions (values: respect, responsibility).
3) Robot Assistant at School: programming useful functions (e.g., delivering notebooks, cleanliness reminders), promoting social responsibility.
4) Cultural Route: navigating a printed map of Kazakhstan, actively naming cities and cultural symbols (values: patriotism, cultural identity).
5) Heroes and Stories: the robot "tells" a mini-story about a national hero using movement, sound, and lights (value modeling).
6) Fair Play: Mini-Tournament: competitive challenges, discussion of fairness, opponent respect, and accepting defeat (values: character, respect).
7) Project for the Community: teams design prototypes to address local problems (e.g., waste disposal, safe crosswalks, flowerbed irrigation).
8) Presentation and Reflection: public defense of projects, group reflection on values expressed, and self-assessment of contributions.

The comparison group followed an 8-week standard EV3 robotics curriculum without targeted value discussions; any value-related behavior was recorded by observers retrospectively.

F. Measurement Instruments for Assessing Value Orientations

Given the target age group and the lack of standardized Russian- or Kazakh-language value scales for primary school children, a set of instruments was developed and adapted based on frameworks of moral-value STEM education and Positive Technological Development (PTD) [25–28].

The Primary Values Inventory (PVI-12) consisted of 12 items (5-point Likert scale) across three subscales: Cooperation, Respect, and Civic Affiliation. Items were originally written in English, translated into Russian and Kazakh using forward–backward translation, and pilot tested with 20 students. While the subscale on civic affiliation included references to national symbols, pilot data indicated that younger children often interpreted these items through local frames (e.g., pride in school or city). Accordingly, the measure should be interpreted as assessing a blended sense of local and national identity. Internal consistency was acceptable ($\alpha = 0.72$–0.83).

The VIA Class Observation Rubric captured students' value-related behaviors during robotics lessons, including cooperation, respectful listening, responsibility, and cultural referencing. Trained observers coded behaviors at 5-minute intervals using a 4-point scale, with inter-rater agreement exceeding $\kappa = 0.75$.

Additional sources included student reflective cards, semi-structured teacher interviews, student focus groups, and analysis of project artifacts (photos, videos, EV3 scripts). These provided triangulation and enriched the understanding of how values were expressed and discussed in classroom practice.

G. Procedure

Step 0. Preparation (January 2025) Teachers in the Experimental Group (EG) participated in two 2-hour training seminars on value integration methodology; Comparative Group (CG) teachers reviewed the standard EV3 curriculum. Observers were calibrated, and instruments were pilot-tested.

Step 1. Baseline Assessment T0 (Week 1 of February) All students completed the PVI 12 questionnaire in a classroom setting. Parental background questionnaires were collected. One standard robotics lesson in each school was video-recorded to establish baseline behavioral profiles.

Step 2. Intervention Phase (February–April, 8 weeks) EG received the "Robotics + Values" intervention; CG followed the standard LEGO® MINDSTORMS® EV3 curriculum. VIA Class observations were conducted during lessons in thematic blocks 1, 4, and 7 in both groups. Students' reflection cards and team task logs were also collected.

Step 3. Post-Test Assessment T1 (Final week of April) A second administration of the PVI 12 questionnaire was conducted. Final observations were carried out during the public presentation (Block 8). Team presentations were video-recorded. Focus group interviews with students and individual teacher interviews were held.

Step 4. Delayed Post-Test T2 (June, ~8 weeks later, optional) An abbreviated version of the PVI (PVI 6) was administered online. Teachers completed a short rating questionnaire on the sustainability of observed effects.

The variables and corresponding instruments used in the study are summarized in Table 2.

Table 2. Variables and measures

Variable	Data Type	Instrument / Source	Time Points	Supporting References
Cooperation (self-report)	Continuous (Likert)	PVI 12–Cooperation	T0, T1, T2	[25, 28]
Respect (self-report)	Continuous	PVI 12–Respect	T0, T1, T2	[4, 25]
Patriotism / Civic Affiliation	Continuous	PVI 12–Patriotism	T0, T1, T2	[26, 27]
Behavioral Value Indicators	Coded (0–3)	VIA Class Rubric (Codes A–D)	L1, L4, L7, L8	[29, 30]
Team Task Performance	Time / Success / Score	EV3 Challenge Logs	L3, L7	[31]
Teacher Ratings of SEL/Values	Ordinal (1–5)	Teacher Global Rating	T0, T1	[25]
Linguistic-Cultural Covariates	Categorical	Parent Questionnaires	T0	[1]

H. Statistical Data Processing

All analyses were carried out in R (version 4.4.0) and JASP (version 0.18.2). Given the quasi-experimental school-based design with nested data (students within classes), we used analytical approaches that account for clustering and variation across teachers. Specifically, class-level random effects were included to control for possible teacher-specific influences, while gender and baseline scores were entered as covariates to adjust for potential differences between groups at the start of the study.

To evaluate changes in value orientations measured by the PVI-12, we applied Linear Mixed-effects Models (LMM). These models allowed us to track growth over time while accounting for class-level clustering. For the behavioral observations recorded with the VIA Class rubric, data were analyzed using Generalized Mixed-effects Models (GLMM), which are suited for categorical and count outcomes. Effect sizes (Hedges' g and partial η^2) were reported alongside significance tests to facilitate interpretation.

The reliability and validity of the instruments were also assessed. The PVI-12 demonstrated satisfactory internal consistency (α and $\omega \geq 0.70$). Factor analyses supported a three-factor structure, and convergent validity was indicated by positive correlations with teacher ratings of social-emotional learning. Inter-rater agreement for the behavioral rubric was high, with κ and ICC values within acceptable ranges.

In practical terms, the statistical results indicate that the integrated "Robotics + Values" module produced consistent improvements in cooperation, respect, and civic identity, above and beyond technical skill acquisition.

I. Design Limitations

Potential baseline differences between schools were addressed through the inclusion of covariates and random class effects. Nevertheless, the quasi-experimental design without randomization limits the strength of causal inferences, as unmeasured school- and culture-specific factors may have influenced the outcomes. For example, variations in school culture, teacher facilitation styles, and prior exposure to STEM-related activities could partially account for the stronger value-oriented gains observed in the experimental group. Moreover, the multilingual and multicultural context of Shymkent may have shaped how students interpreted and expressed constructs such as respect and patriotism, underscoring the need for caution when generalizing to other settings. Variability in instructional delivery by different teachers may have influenced the expression of value-related behaviors; therefore, teacher effects were modeled as random factors. To account for possible social desirability bias in students' self-assessment of values, triangulation was employed using behavioral observations and teacher ratings. Interpretations of patriotism may have differed across linguistic groups; thus, survey wording was culturally adapted and subgroup analyses were conducted.

Although the intervention demonstrated significant positive effects, its relatively short duration (eight weeks) may have amplified immediate gains while limiting insights into long-term stability. Effect sizes should therefore be interpreted with caution, as some outcomes may reflect short-term novelty effects rather than fully consolidated behavioral change. Future longitudinal studies with extended interventions are needed to assess the durability of these impacts.

IV. Results

Of the 128 students who completed the baseline assessment (T0), full T0–T1 data were obtained for 122 participants (EG = 60; CG = 62). Missing data analysis indicated no systematic differences between included and excluded participants in terms of gender, age, or baseline PVI scores (ps > 0.10). At T0, no statistically significant differences were found between groups on the PVI subscales of Cooperation, Respect, and Patriotism (t range = 0.31–0.74, ps > 0.40), supporting the assumption of baseline equivalence in value orientations within the quasi-experimental design. Similar attendance rates and prior robotics experience were confirmed via school records ($\chi^2 = 1.12$, $p = 0.29$). This comparability of initial conditions enhances the interpretability of intervention effects under a cluster-based design. The matching of baseline metrics across non-randomized school clusters aligns with best practices for field research in educational robotics under real-world school conditions [29-32].

Table 3 presents the psychometric properties of the PVI instrument.

These reliability coefficients meet the recommended thresholds for brief scales in younger populations and are consistent with prior research on social-emotional constructs in robotics/STEAM education settings [33–35].

Exploratory Factor Analysis (principal axis, oblimin) on the combined sample (N = 128) revealed a three-factor solution (eigenvalues > 1), corresponding to the theoretical subscales of Cooperation, Respect, and Patriotism, accounting for 63% of the total variance. Confirmatory Factor Analysis (WLSMV) showed acceptable model fit: CFI = 0.94, TLI = 0.92, RMSEA = 0.051 [90% CI 0.038–0.064]; factor loadings ranged from 0.54 to 0.81. Configural invariance across schools was supported (ΔCFI = 0.005), suggesting adequate construct validity for use in a multilingual primary school context.

Two coders independently evaluated 96 video segments (5-minute windows) from four core lessons. Mean Cohen's κ values for individual behavioral codes were: A = 0.78, B = 0.81, C = 0.75, D = 0.72. The overall inter-rater reliability for composite scores was ICC(2,k) = 0.88.

Tables 4 and 5 and Fig. 1 summarize the main quantitative outcomes (PVI-12).

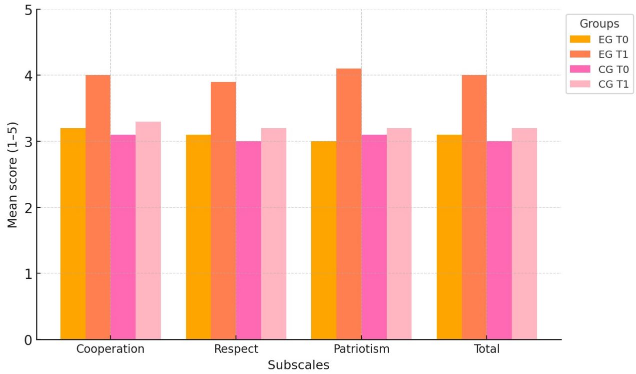


Fig. 1. Pre-post subscale means.

Table 3. Internal consistency (cronbach's α / McDonald's ω)

Scale	Items	α	ω	95% CI for α	Interpretation
PVI-12 Total	12	0.83	0.84	[0.78, 0.87]	Good
PVI-12 Cooperation	4	0.76	0.77	[0.68, 0.83]	Acceptable
PVI-12 Respect	4	0.79	0.80	[0.72, 0.85]	Good
PVI-12 Patriotism	4	0.72	0.73	[0.62, 0.80]	Acceptable

Table 4. Mean (SD) PVI Scores by Group and Time

Subscale	EG T0	EG T1	ΔEG	CG T0	CG T1	ΔCG	ΔΔ (EG–CG)
Cooperation	3.21 (0.62)	3.89 (0.58)	+0.68	3.18 (0.64)	3.38 (0.63)	+0.20	+0.48
Respect	3.34 (0.59)	3.93 (0.55)	+0.59	3.29 (0.61)	3.49 (0.60)	+0.20	+0.39
Patriotism	3.05 (0.70)	3.76 (0.66)	+0.71	3.07 (0.69)	3.28 (0.68)	+0.21	+0.50
PVI Total	3.20 (0.52)	3.86 (0.48)	+0.66	3.18 (0.53)	3.38 (0.52)	+0.20	+0.46

Table 5. Fixed effects estimates

Outcome	Parameter	β	SE	95% CI	p	Effect Size (d_pre-post diff)
Cooperation	Intercept (CG T0)	3.18	0.08	[3.02, 3.34]	<0.001	-
	Time (T1)	+0.20	0.06	[0.08, 0.32]	0.001	d_CG = 0.31
	Group (EG)	+0.03	0.11	[−0.19, 0.25]	0.78	-
	Group × Time	+0.48	0.09	[0.30, 0.66]	<0.001	d_diff = 0.82
Respect	Group × Time	+0.39	0.09	[0.21, 0.57]	<0.001	d_diff = 0.68
Patriotism	Group × Time	+0.50	0.10	[0.30, 0.70]	<0.001	d_diff = 0.80
PVI Total	Group × Time	+0.46	0.08	[0.30, 0.62]	<0.001	d_diff = 0.79

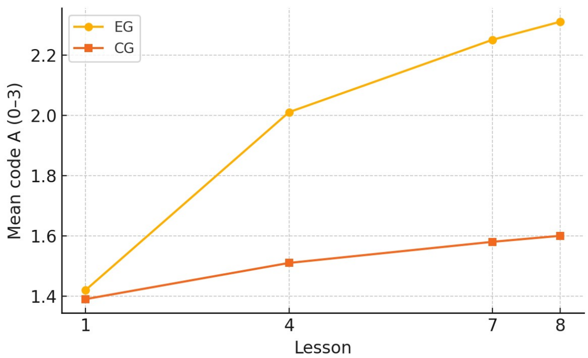
Note: Values presented: β, SE, 95% CI, p; reference group = CG at T0

The results reveal statistically significant Group × Time interactions across all subscales, indicating a greater increase in value orientations among students in the Experimental Group (EG) compared to the Comparison Group (CG). These findings support the argument that structured robotics activities, purposefully enriched with socially and culturally relevant tasks, can serve as a context for developing the virtues of cooperation, respect, and civic/cultural identity in children [36].

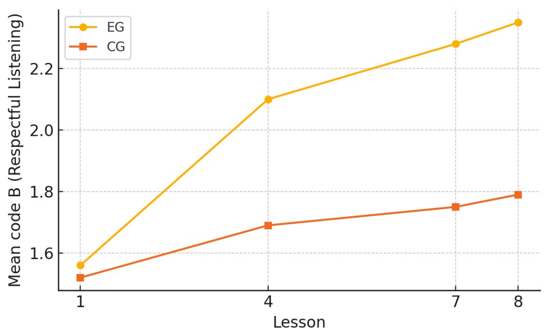
Tables 6 and 7, Figs. 2 and 3 summarize the behavioral indicators as measured by the VIA-Class Rubric.

Table 6. Mean Behavioral Scores by Code A–D (Scores range from 0 to 3, averaged across segments)

Code	Construct	EG L1	EG L4	EG L7	EG L8	CG L1	CG L4	CG L7	CG L8	Group Effect (GEE χ^2)
A	Proactive Cooperation	1.42	2.01	2.25	2.31	1.39	1.51	1.58	1.60	$\chi^2 = 18.7, p < 0.001$
B	Respectful Listening	1.56	2.10	2.28	2.35	1.52	1.69	1.75	1.79	$\chi^2 = 14.2, p < 0.001$
C	Shared Responsibility	1.60	2.05	2.22	2.30	1.55	1.67	1.74	1.77	$\chi^2 = 12.9, p < 0.001$
D	Cultural/Social Referencing	0.48	1.25	1.82	1.96	0.46	0.60	0.71	0.74	$\chi^2 = 41.5, p < 0.001$



(a)



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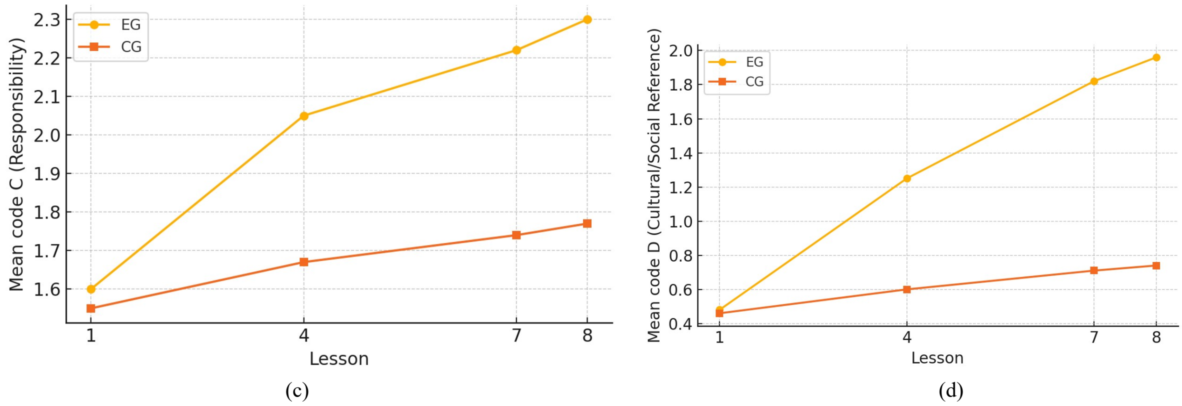


Fig. 2. Dynamics of value-related behaviors observed during robotics lessons: (a) Code A Dynamics; (b) Code B Dynamics; (c) Code C Dynamics; (d) Code D Dynamics.

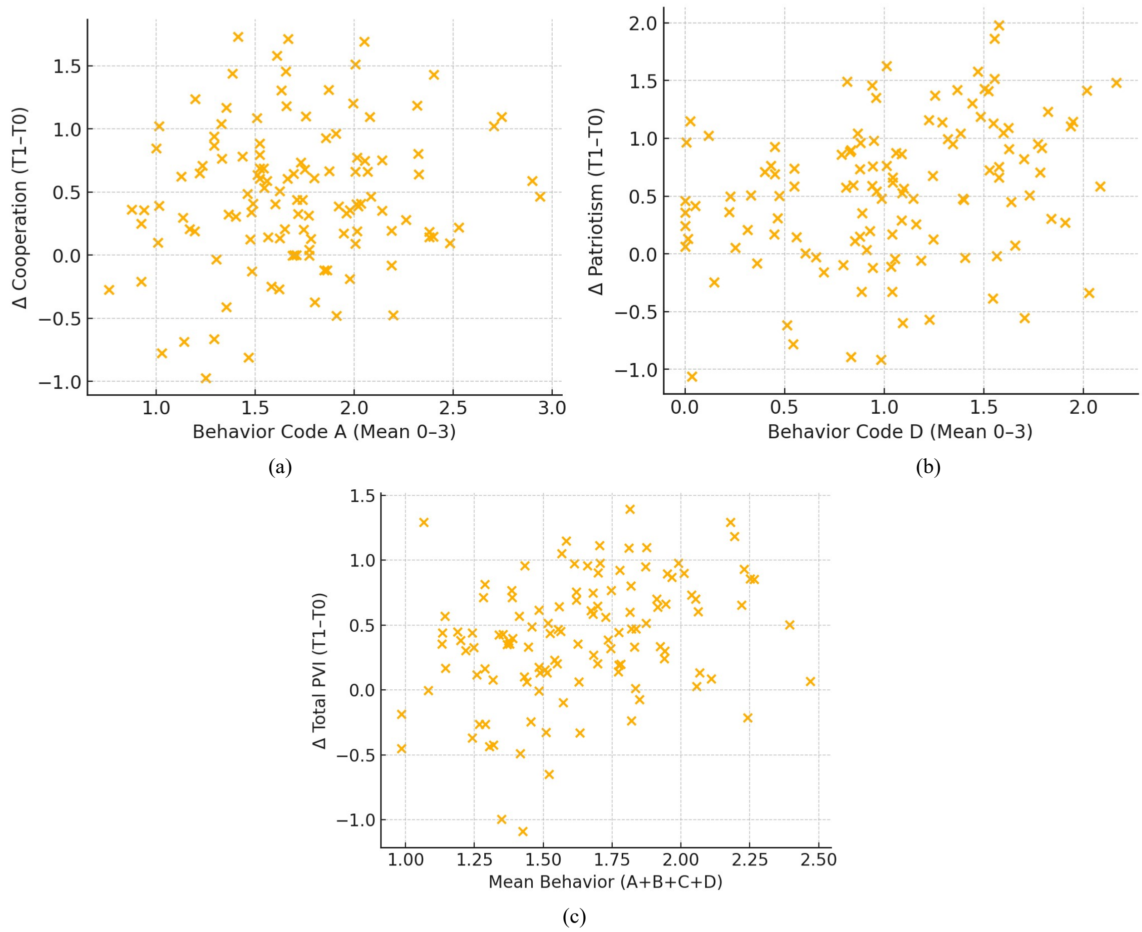


Fig. 3. The Scatterplot (a) Δ Cooperation vs. proactive cooperation (Code A); Δ Patriotism vs. cultural referencing (Code D); ΔTotal PVI vs. value-related behaviors (A+B+C+D).

Table 7. Correlations Between changes in self-reports and observed behaviors, Δ = (T1–T0) for PVI subscales; behavioral scores averaged across lessons L4–L8

Pair	ρ	p
ΔCooperation ~ Code A	0.41	<0.001
ΔRespect ~ Code B	0.38	<0.001
ΔPatriotism ~ Code D	0.44	<0.001
ΔTotal PVI ~ A+B+C+D (total)	0.46	<0.001

The most pronounced divergent effect was observed for Code D (Cultural/Social Referencing), which is expected given the thematically integrated tasks of the Experimental Group (EG). Field studies have demonstrated that contextualized robotics challenges enhance students' social interaction and collective meaningful engagement [37].

The scatterplots each represent individual students and illustrate positive trends between observed behaviors and self-reported value changes: in Fig. 3(a), higher levels of proactive cooperation were associated with greater gains in cooperation scores; in Fig. 3(b), increased cultural or social referencing behaviors correlated with larger growth in patriotism; and in Fig. 3(c), higher average frequencies of value-related behaviors (including cooperation, respect, responsibility, and cultural referencing) were linked to greater overall improvements in value orientations.

The alignment between improvements in self-reported values and observed behaviors supports the convergent validity of the measurement approach and reinforces the argument for using robotics as a meaningful context for practicing social virtues. This is consistent with the literature on Positive Technological Development (PTD), classroom social robotics, and group dynamics in Educational Robotics (ER) [38].

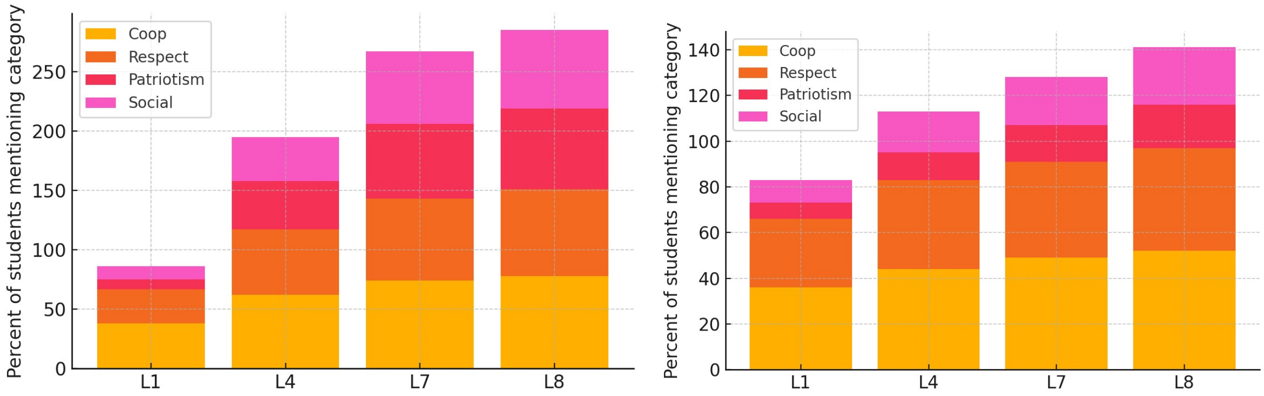
Table 8 and Fig. 4 present the results of the content analysis of student reflective responses. Coding categories were applied in a binary format (1 = mention/demonstration; 0 = no mention) to open-ended reflection cards collected at Lessons 1, 4, 7, and 8. The table shows the percentage of students who provided at least one mention of each category at each time point.

The increase in culturally patriotic and socially oriented references was particularly pronounced in the Experimental Group (EG) following the thematic modules 4 and 7. This supports the effectiveness of purposeful integration of local cultural content into robotics tasks, as recommended in the literature on STEAM, rights-based STEM education, and Positive Technological Development (PTD) programs [1, 37].

Table 8. Frequencies of Value Categories in Reflective Cards (%)

Category	EG L1	EG L4	EG L7	EG L8	CG L1	CG L4	CG L7	CG L8
Helped the team (Coop)	38	62	74	78	36	44	49	52
Listened to others' ideas	29	55	69	73	30	39	42	45
Pride in school/country	8	41	63	68	7	12	16	19
Social benefit of the project	11	37	61	66	10	18	21	25

Note: χ^2 comparisons between EG and CG at Lesson 8: all $p < 0.001$.



(a) (b)

Fig. 4. Reflective categories (a) by lesson (EG) (b) by lesson (CG).

Table 9 presents the results of teacher interviews (summary of qualitative data). Interview coding (n = 4 teachers: 2 EG, 2 CG) revealed seven recurring themes. Frequency counts are provided for reference.

Table 9. Themes from Teacher Interviews

Theme	EG Teachers (Segments)	CG Teachers	Example Statement (Paraphrased)
Explicit discussion of values enhances team discipline	14	3	"When we connect the task with how we function as a team, children argue less about details."
Cultural localization increases motivation	12	2	"The map of Kazakhstan made the lesson feel 'ours'—students named cities and made flags."
Transfer of skills to other lessons	8	2	"After the module, students in math more often ask each other instead of the teacher."
Time constraints / curriculum overload	5	7	"It's hard to fit value discussions into 45 minutes."
Need for professional development	9	6	"We need more examples of how to connect robots with patriotism."
Linguistic/cultural differences in interpreting patriotism	6	5	"In Uzbek-speaking families, students sometimes refer to 'our neighborhood' instead of 'our country'."
Material resources / equipment	4	4	"The kits are not always complete; parts get lost."

Teacher observations are consistent with international reports emphasizing that pedagogical scaffolding and contextualization of tasks are critical moderators for the successful integration of robotics with the development of social and value-based competencies.

A subgroup analysis by home language (Kazakh, Russian, Other) revealed that within EG, the increase in the Patriotism subscale was higher for students from Kazakh-dominant families (Δ = +0.82) compared to Russian-speaking (Δ = +0.61) and Other (Δ = +0.55) groups. However, the three-way interaction Language × Group × Time did not reach conventional significance (p = 0.07). Open responses indicated that students from the "Other" group more frequently referred to the local level ("our neighborhood," "our yard") than to the national level, which aligns with findings on cultural–regional variability in value interpretation within STEM and Education for Sustainable Development (ESD) contexts [32].

Field notes and qualitative data suggested recurring patterns in how students connected technical tasks with social and cultural meanings. These patterns informed the development of a conceptual model of influence, presented in the Discussion.

V. Discussion

The present study aimed to evaluate the pedagogical potential of educational robotics (LEGO® MINDSTORMS® Education EV3) as a tool for shaping value orientations—cooperation, respect, and patriotism/social affiliation—among 4th-grade students in urban schools in

Shymkent, Kazakhstan. The research was conducted amid the growing interest in STEM education and the parallel rise of challenges in values education in the digital era [1, 27, 32]. We implemented a quasi-experimental mixed-methods design with a non-equivalent comparison group, reflecting the realistic constraints of educational innovation in school environments.

Across all three target subscales of the PVI-12 self-report instrument (Cooperation, Respect, Patriotism), statistically significant Group × Time interactions were observed: value gains in the Experimental Group (EG), which completed the value-integrated robotics module, exceeded those in the Comparison Group (CG). Behavioral observations using the VIA-Class rubric revealed a similar pattern, with marked increases in Code A (proactive cooperation), Code B (respectful listening), Code C (responsibility), and especially Code D (cultural/social references) in EG compared to CG. Student reflective cards indicated growing frequency of references to team support and pride in school/country, particularly after thematic lessons involving the map of Kazakhstan and community-centered projects. Correlations between self-report changes and observed behaviors supported the convergent validity of the measurements. Teacher interviews confirmed that explicit value discussions and local content contextualization enhanced classroom discipline, student engagement, and respectful interactions.

Taken together, these multi-channel data suggest that educational robotics, when paired with appropriate pedagogical framing, can serve as an effective medium for promoting values education at the primary school level.

H1 (Cooperation) was supported: the Cooperation subscale and Code A increased significantly in EG. This is consistent with findings that small-group robotics tasks foster collaborative problem-solving and peer social engagement [25, 39]. H2 (Respect) was confirmed by substantial increases in the Respect subscale and Code B (respectful listening), aligning with Pearson's [40] "whole child STEM" perspective, which emphasizes the cultivation of social interaction norms alongside technical competencies.

H3 (Patriotism and Social Affiliation) was also supported. The greatest differential gain was observed for the Patriotism subscale and Code D, with EG students more frequently referencing cultural symbols and the social relevance of their projects. These findings align with the work of Teo and Choy [26] and Zakharova and Trenina [41], who advocate for the integration of social and sustainability values into STEM curricula, and with practice-oriented models of culturally relevant STEM education.

Fig. 5 presents a conceptual model of influence mechanisms, developed as an interpretive framework informed by the field data rather than as a direct empirical finding. The model outlines a hypothesized pathway from technical task to value meaning construction, suggesting how students' technical actions may gradually become imbued with social and cultural significance. This interpretation aligns with the logic of Positive Technological Development (PTD) proposed by Bers [28], which posits that technology-mediated activities can foster virtues—such as collaboration, responsibility, creativity, and community care—when intentionally guided by pedagogical practices. Practice-based descriptions of robotics implementation in early childhood and primary education [20] similarly indicate that even simple construction kits can support the development of generosity and civic agency, provided that tasks are connected to values meaningful to children and their families. International frameworks, including those by UNESCO [32], further emphasize the importance of such connections, underscoring the role of hands-on, project-based learning in cultivating sustainable development competencies and global citizenship. At the primary level, these competencies manifest through empathy, collective responsibility, and local identity.

The initial phase—collaborative construction—requires role distribution (e.g., who holds the sensor, who reads the instructions, who builds the base), which immediately renders cooperation a functional necessity rather than an abstract moral norm. Research by Ponticorvo *et al.* [29] on group-based educational robotics shows that working on a shared physical artifact within small teams enhances action interdependence and fosters the emergence of new social ties and mutual aid practices among students.

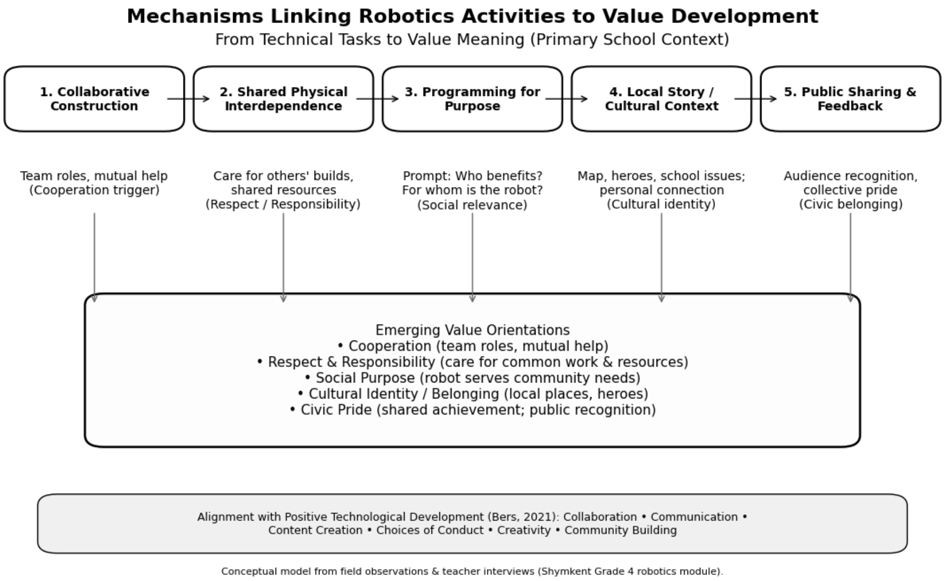


Fig. 5. Conceptual model from field observations & teacher interviews (Shymkent Grade 4 robotics module).

As subgroups create different modules of a robot and are later required to integrate them into a single working system, students develop behavioral incentives to treat each other's work with care and respect. This material interdependence promotes appreciation of shared resources and collective accountability—values that are difficult to cultivate solely through verbal instruction detached from activity. Reviews on educational robotics [42–44] highlight the significance of interdisciplinary, materially rich tasks in developing communicative and self-regulatory competencies among young learners. Scholarship on STEM-character education integration notes that shared ownership of equipment and the need to negotiate its use naturally generate situations of moral choice, reinforcing respect and responsibility. Similarly, observational studies by Labchuk [45] in robotics classrooms report that teacher-led discussions about how to handle components foster the formation of respectful and generous behavioral norms.

The next pedagogical mechanism arises when teams shift from building to programming and must decide what the robot will do and for whom. Teacher prompts such as "Who will your robot help?" redirect students' attention beyond purely technical tasks, anchoring them in the lived experiences of their class, school, or local community. Studies in justice- and equity-oriented STEM education demonstrate that explicit discussion of the social purpose of technological artifacts deepens student engagement and cultivates a sense of accountability toward real people, rather than abstract problem sets [46, 47]. According to Education for Sustainable Development (ESD) frameworks, tying school projects to tangible life issues is one of the most effective strategies for fostering children's social and environmental values. Finally, conversations about the social mission of STEM creations are viewed as central to integrating cognitive and affective learning goals in contemporary STEM-SEL models.

When robotics tasks are embedded within narratives familiar to children—such as regional maps, school heroes, or local environmental issues—an emotional resonance emerges, allowing students to relate technical actions to their own cultural and linguistic experiences. Literature on culturally relevant and justice-oriented STEM education highlights that acknowledging students' local stories enhances their "right to presence" in the learning process and fosters community-rooted identity development [46]. Reviews on educational robotics in early and primary education report increased communicative engagement and meaningful participation when narrative and artistic elements are incorporated [45]. Field reports further show that children are more likely to exhibit generosity and care for others when robotics projects are situated within culturally meaningful contexts [20].

The final stage—presenting the project to an audience (classmates, parents, school administration) and receiving feedback—transforms the technical product into a social event. Public presentation enhances the experience of collective achievement, encouraging pride in one's team, class, or school, and consolidates the values nurtured in earlier phases. Studies in educational robotics show that group presentations and discussions of team dynamics contribute to the strengthening of social bonds and a positive classroom climate [29]. Within the PTD framework, community building and external recognition are emphasized as key factors in anchoring the virtues developed through technological activity. Moreover, international ESD guidelines stress the importance of public sharing of children's projects as a mechanism for fostering civic responsibility and local identity in primary school.

Together, these five stages form an ascending trajectory of meaning-making: from purely technical interaction with a robotics kit, students move toward shared responsibility, then to socially oriented programming, cultural localization, and finally to public acknowledgment of collective contribution. This trajectory reflects the principle of a progressively expanding moral concern—from team to community—and demonstrates how STEM activities can serve educational and ethical purposes when supported by deliberate instructional design. Contemporary research on the integration of STEM, SEL, and character education emphasizes the value of such sequential pedagogical transitions, where each phase prepares the ground for the next, linking technical skills to human development goals.

Our findings support the claim that robotics can function as a platform for integrating STEM and SEL. In the intervention sessions, purposeful micro-reflections (e.g., "How did we help each other?", "How did we listen to ideas?") enhanced children's behavioral awareness; in quantitative terms, this was reflected in the increased scores of the corresponding subscales. Similar integrative approaches are described in contexts where technical learning is interwoven with social-emotional development, as in "whole child robotics" programs [25] and the PTD framework of the "palette of virtues". Reviews and practice-based reports emphasize that embedded pauses for team reflection significantly increase the effectiveness of robotics lessons as a context for SEL [20, 43].

The experimental curriculum included assignments linked to the map of Kazakhstan, local social challenges (e.g., clean schoolyard, safe crosswalks), and heroes relevant to children of diverse cultural backgrounds. This design aligns with recommendations from culturally relevant and socially engaged STEM education, where local context serves as a catalyst for personal meaning-making and value acquisition. The observed increase in Behavioral Code D and the rise in reflective statements about pride in school/country in the EG support the notion that cultural localization can amplify the value-based outcomes of robotics activities. Teachers also noted variations in the interpretation of patriotism across multilingual classrooms, reflecting findings in the literature on the variability of value constructs in intercultural education and the need for flexible instructional design [1, 27].

Several teacher comments indicated a transfer of respectful interaction norms, practiced during robotics lessons, to students' online communication (e.g., class messengers). This observation complements existing discussions in the literature suggesting that the development of digital citizenship and character requires materially grounded, collaborative practices through which children experience the consequences of joint actions. Given that many challenges of value education in the digital era are related to anonymity and social distancing, robotics practices that require physical cooperation may act as a compensatory environment, helping form more respectful behavioral patterns that are later transferred into online interactions.

Despite the technological foundation of the course, the key driver of value outcomes was pedagogical mediation. Teachers in the Experimental Group (EG) received targeted training on how to embed value-oriented questions, model respectful communication, and facilitate team-based discussions. The literature emphasizes that without intentional pedagogical support, robotics lessons risk being reduced to a purely technical exercise, without leading to sustainable changes in moral behavior [4, 25]. Studies in collaborative educational robotics also show that the quality of teacher facilitation is closely associated with the formation of positive social relationships in classrooms [29]. Our findings support this assertion: teachers in the Comparison Group (CG), who had not received values-based training, reported fewer spontaneous discussions about interaction norms.

The selection of LEGO® MINDSTORMS® EV3 proved appropriate for the 9–10-year-old age group: visual block-based programming lowered the entry barrier; the modularity of the kit enabled a quick shift from individual assembly to team-based integration, which is critical for value formation. Studies indicate that interface accessibility and the immediacy of feedback (the robot "failed" or "worked") enhance social dialogue and collective problem-solving [23]. Additionally, the kit's physical durability and reusability supported exercises involving part exchange, which we used as a pedagogical strategy to promote respect for others' work.

This study has several methodological strengths that enhance the trustworthiness of the findings despite the quasi-experimental design. Most notably, we employed a mixed-methods strategy combining quantitative (PVI-12 survey, VIA Class behavioral rubric, task journals) and qualitative (interviews, focus groups, mini-reflection surveys, artifact analysis) data sources. A key methodological advance was the use of Linear Mixed Models (LMMs) to account for data nesting (students within classes, classes within schools). This is especially critical in field-based school research, where full individual randomization is often unfeasible, and intra-cluster correlation can distort standard tests. The LMMs enabled us to control for covariates (gender, home language environment, prior robotics experience) and isolate the unique contribution of the intervention.

Another innovation was the development and adaptation of instruments suitable for primary school-aged children. The brief PVI-12 scale demonstrated acceptable internal consistency and a replicable three-factor structure; the VIA Class behavioral rubric achieved high interrater reliability in coding joint actions and cultural references. Such compact tools for value assessment are in high demand but remain scarce in elementary robotics research. Finally, we conducted a cultural and linguistic adaptation of the instruments (Kazakh and Russian versions) using forward-backward translation, aligning with best practices for localization of moral and value-oriented measurements in multilingual educational systems [1, 47].

Despite the advantages outlined above, several limitations should be considered when interpreting the results. First, the study employed a quasi-experimental design: classes were clustered within schools, and full randomization was not feasible. Although baseline measures of value orientations and key demographic variables did not differ significantly between groups, the influence of school-specific latent factors (such as instructional culture or administrative support) cannot be entirely ruled out—this is a common challenge in field-based educational research. Second, self-report measures among 9–10-year-old children are susceptible to social desirability bias and age-related limitations in interpreting scale items. While we mitigated this risk through the inclusion of behavioral observations and teacher ratings, complete elimination is not possible.

The third limitation concerns the duration of the intervention: although the eight-week module was sufficient to detect short-term shifts, it does not allow for conclusions about the long-term stability of value changes. Research on the sustained integration of social and ecological values in STEM education highlights the importance of extended pedagogical support [23]. Furthermore, the results are primarily generalizable to urban schools equipped with basic robotics infrastructure; in resource-constrained settings or rural schools, the effects may differ [20]. Finally, measuring patriotism and social belonging in multilingual classrooms remains conceptually challenging: references to "our district" or "our city" may not align with notions of national identity, a pattern observed in our own dataset.

The findings open up several directions for future research. A logical next step would be the implementation of randomized studies within schools, where parallel classes are randomly assigned to value-integrated or standard robotics conditions. Such a design would minimize inter-school variance and enhance the causal validity of findings. Equally important are longitudinal follow-ups: repeated assessments at six-month and one-year intervals could determine whether short-term value shifts evolve into stable dispositions and whether these changes manifest in other subjects or daily behavior.

The results also lead to several practical recommendations for teachers and school administrators, though these should be seen not as a checklist, but as a coherent pedagogical strategy. The key principle is that each robotics task should carry a value-based question: Whom are we helping? What are we learning as a team? How is our robot connected to school or community life? Embedded micro-reflections at the end of lessons ("How did we help?", "What respectful action did we take?") enhance awareness and consolidate behavioral norms, in line with the Positive Technological Development (PTD) and integrated SEL in STEM frameworks.

Practice showed that material interdependence fosters respect: when teams are required to exchange subassemblies or combine modules into a collective prototype, students become more attentive to each other's contributions and develop a sense of responsibility for the shared outcome. This approach may be particularly valuable in the early stages of cultivating a culture of cooperation, as suggested by Murphy [25]. Equally important is the localization of content—maps of the region, national symbols, and real-life schoolyard or neighborhood problems render robotics projects personally meaningful and open a pathway to developing social belonging. Role rotation within teams—engineer, programmer, tester, storyteller—helps prevent dominance by stronger students and supports inclusivity, as documented in group-based robotics studies.

Although the intervention was conducted in well-equipped urban schools, the findings have potential relevance for lower-resource or rural settings. Even with limited access to robotics kits, the core principles of value-oriented STEM learning—such as teamwork, respect, and community engagement—can be fostered through low-cost materials, unplugged robotics activities, or shared kits rotated among classes [16, 18]. Adapting the program in this way could broaden its accessibility and demonstrate that value-based outcomes are not dependent on high-end technologies but on intentional pedagogical design.

VI. Conclusion

This study assessed whether educational robotics, when supplemented with value-oriented tasks and culturally localized content, can contribute to the development of cooperation, respect, and civic engagement among primary school students. In a quasi-experimental design with 122 fourth-grade pupils, the experimental group participating in the "Robotics + Values" module demonstrated greater gains across all measures, supported by convergent quantitative, observational, and qualitative evidence.

Drawing on field observations, a conceptual trajectory was proposed that links joint construction, purpose-driven programming, cultural localization, and public presentation as stages through which technical tasks acquire social meaning. This model highlights how robotics can serve as a bridge between STEM skill acquisition and value-based education, aligning with frameworks such as Positive Technological Development (PTD) and justice-oriented STEM education.

Practically, four recommendations emerge for educators and curriculum designers:

1) Embed explicit value-oriented prompts into robotics tasks.
2) Incorporate local cultural narratives to strengthen civic and cultural identity.
3) Facilitate structured reflections and public presentations to reinforce value outcomes.
4) Provide teacher training in guiding value-centered dialogue.

The study is limited by its non-randomized design, the urban focus of the sample, and the short intervention period, which may limit long-term generalization. Future research should expand to rural and lower-resource contexts, test alternative robotics platforms, and employ longitudinal designs.

At the policy level, the findings demonstrate that robotics education can support not only STEM competencies but also civic and moral development. Embedding such integrative approaches into Kazakhstan's curriculum reforms and digital education programs would provide scalable pathways for nurturing technically skilled and value-driven citizens.

Ethical Considerations and Confidentiality

The study adhered to international guidelines on the protection of children's rights in educational research and to open science principles in the field of sustainable development [27, 32]. The research protocol was approved by the Scientific Ethics Committee of Zhanibekov University (Protocol No. 2025 01 EDU; dated 08.01.2025). Written permissions were obtained from the Department of Education of the city of Shymkent and from the administrations of both participating schools. Informational letters and consent forms were distributed to parents, and signed forms were collected prior to T0. Children received age-appropriate explanations of their participation, and verbal assent was recorded in the researcher's logbook.

Research procedures were embedded in regular robotics instruction, and additional risks were considered minimal. To reduce discomfort, children were given the option to skip any survey item without penalty.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, N.K. and A.I.; methodology, K.M.; software, Y.T.; validation, Y.T., S.B. and A.S.; formal analysis, S.B.; investigation, N.K.; resources, N.K.; data curation, A.I.; writing—original draft preparation, N.K.; writing—review and editing, A.I.; visualization, K.M.; supervision, A.I.; project administration, N.K.; funding acquisition, N.K. All authors have read and agreed to the published version of the manuscript.

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