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Observing Agency and Collaboration in Educational Robotics Activities: Preliminary Findings from Four Primary School Classes

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Abstract: Agentic engagement, understood as students' constructive contribution to learning activities, has recently been recognized as a key dimension of engagement in collaborative STEM settings. Educational robotics (ER) may provide opportunities for the development of agency and collaborative skills; however, such outcomes depend on instructional design rather than on technology itself. This study reports preliminary findings from an action-research project involving Italian primary and lower-secondary schools and focuses on the pilot implementation of an observation tool designed to assess collaboration in ordinary classroom contexts. The analysis included 70 primary school students observed before and after cooperative activities, including educational robotics tasks. The observation grid assessed three dimensions: participation, perspective taking, and social regulation. Pre-post comparisons using Wilcoxon signed-rank tests showed a significant increase in the overall collaboration index, driven mainly by improvements in participation and, to a lesser extent, social regulation. Responsibility initiative emerged as the indicator showing the strongest growth, while changes in perspective taking were more limited. Contextual differences between classes highlighted the influence of task design, teacher scaffolding, and observation procedures on observed outcomes. The findings support the usefulness of the observation tool while suggesting that educational robotics may provide contexts in which opportunities for participation and agency become more visible when embedded within carefully structured collaborative learning environments.

Keywords: Educational Robotics; agentic engagement; collaborative skills; instructional design; educational assessment

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1. Introduction

According to the constructionist approach, children and young people should be able to invent technologies, and not merely use them: learning consists in the active construction of knowledge through the act of creating something that can be shared (Martinez & Stager, 2021). Seymour Papert (1980) therefore encouraged us to consider the computer as an object-to-think-with, that is, a tool through which children could develop powerful ideas and actively participate in knowledge-building processes. Constructionist environments are characterized by a collaborative culture that seeks to ensure "an explosion of possibilities", with the aim of democratizing access to technologies and fostering the development of a wide variety of projects (Resnick, 2017).

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Within this framework, Educational Robotics (ER) can contribute to creating educational contexts that encourage everyone's active participation and promote epistemic agency, understood as the process through which learners take responsibility for their own learning, comparing their knowledge with that of the community and contributing to the generation of new knowledge (Vasconcelos et al., 2024). From the perspective of the Embodied Cognition paradigm (Varela et al., 1991), robots' ability to give bodily form to action makes them active interlocutors in mixed social ecologies, where their participation in a shared space generates a tangible and embodied encounter (Dumouchel & Damiano, 2019). Unlike technologies that constrain users to screens, such as tablets or phones, robots elicit embodied behaviors related, for example, to the communication of scientific knowledge, as well as to social and emotional messages, which are expressed more spontaneously than in conventional settings (Kim & Tscholl, 2021).

Interventions involving ER have increased alongside advances in technoscientific development, particularly in STEM disciplines. The literature reports benefits in areas such as critical thinking, problem-solving, engagement, interest in scientific subjects, and self-efficacy (Mosley et al., 2016), as well as, at the relational level, in social skills such as participation, communication, and the ability to connect different concepts (Tsiomi & Nanou, 2020). ER programs have proven effective in fostering the development of 21st-century skills, particularly when combined with cooperative and collaborative learning approaches (Avcı, 2024).

However, it should be emphasized that, in the absence of careful pedagogical mediation, technologies may risk promoting disengagement (Bond et al., 2020): the mere introduction of an artefact into the educational setting is not sufficient to guarantee improved learning outcomes. From a systemic perspective, technologies should not be regarded as neutral objects, but rather considered in light of the relationships established with them (Rivoltella & Rossi, 2019). Engagement – which is not a characteristic of the student, but rather a multidimensional construct encompassing cognitive, emotional, and behavioral aspects (Fredricks et al., 2004) – is in fact dynamic and influenced by the life context (Pivetti & Dusi, 2025). In particular, agentic engagement (Reeve & Tseng, 2011), understood as students' constructive contribution to the learning activity, involves active participation in collaborative dynamics, such as proposing initiatives, negotiating meanings and decisions, adopting others' perspectives, and regulating joint work. Within this framework, in ER programs, educators' support and presence, a duration extending beyond brief periods, and the adoption of a group-based, project-based or game-based arrangement oriented towards collaboration foster more beneficial effects than traditional lessons, individual activities, and instructor-directed approaches (Ouyang & Xu, 2024).

2. The research context and general objectives

This study is part of a broader action-research project involving approximately 30 primary and lower-secondary school classes from Veneto and Lombardia, in Italy.

The project was carried out through an interdisciplinary collaboration involving researchers from the Department of Information Engineering at the University of Padova and researchers from the Department of Human and Social Sciences at the University of Bergamo: following a teacher training phase focused on educational

robotics, schools in the Veneto region were invited to voluntarily participate in a multi-method data collection initiative, involving classroom activities as well as the implementation of research and evaluation instruments; in contrast, the school in Brescia participated in the data collection within the framework of a multi-year research project characterized by a structured partnership with the University of Bergamo: this project specifically promoted sustained teacher-researcher co-design activities aimed at investigating and developing the pedagogical use of educational technologies.

The research included the administration of student questionnaires, teacher logbooks, observation grids, and the design and implementation of authentic learning tasks.

This contribution presents the pilot implementation of an observation grid designed to assess collaborative skills, along with preliminary findings from four primary-school classes, among the first to provide observation data as part of an ongoing research project. The study investigates the conditions under which educational robotics activities make observable forms of participation, perspective taking, co-regulation, and responsible initiative possible in ordinary classroom settings. It pursues two objectives: first, to explore changes between observations conducted before and after educational robotics activities; second, to examine the usability of the observation tool when applied by teachers without the direct presence of researchers.

3. Materials and Methods

3.1. Materials

Adapted from Demetroulis et al. (2023), the observation grid completed by teachers, which is the focus of the present analysis, includes nine indicators grouped into three dimensions: participation (action, interaction, perseverance), perspective taking (adaptive responsiveness, audience awareness), and social regulation (negotiation, self-evaluation, transactive memory, responsibility initiative). For each indicator, three ordinal performance levels - low, medium, and high - are described.

In addition to the observation grids, teachers completed a logbook designed to provide contextual information about the school and class characteristics, observation procedures, learning activities, group composition (random assignment, stratified random assignment, student preference-based grouping, teacher-selected groups, self-selected groups; see Johnson et al., 2015), and teacher interventions. The logbook also documented students' and teachers' prior experience with educational robotics, the methods used for data collection, and the organizational features of the cooperative learning activities in which the observations were conducted.

3.2. Methods

3.2.1. Study design and participants

The analytical sample comprised 70 pupils: 14 were fifth-grade students attending a primary school in the province of Padua, whereas 56 attended three third-grade classes in a primary school in Brescia.

The Brescia subsample included 18 pupils from class 3A, 18 from class 3B, and 20 from class 3C. The school register for class 3B included 19 pupils; however, one

pupil did not participate in the activities on which the observations were based. The scores initially entered for this pupil were therefore not considered valid observations of performance and were excluded from the paired analyses. Across the final analytical sample, 38 pupils were boys and 32 were girls; 16 had either an Individualized Education Plan (*Piano Educativo Individualizzato*, PEI) or an Individualized Learning Plan (*Piano Didattico Personalizzato*, PDP).

The Padua class had previous experience with educational robotics at an intermediate level, whereas both pupils and teachers in the Brescia classes reported basic previous experience.

Given the action-research framework, no random sampling or random allocation was performed, and no control group was included. The four classes therefore represent a convenience sample embedded in naturally occurring educational settings. The study was designed primarily to explore the applicability of the observation procedure and patterns of change across two observation occasions rather than to estimate a causal treatment effect.

3.2.2. Observation procedure and educational contexts

Data collection was conducted by the teachers in the participating schools during robotics-based activities focused on the development of computational thinking (Wing, 2006), without the direct presence of the university researchers. Teachers were asked to conduct at least two structured observations: one before or at the beginning of the educational robotics pathway and one after pupils had participated in the activities planned within the project. Within this common framework, schools retained responsibility for the design of the learning activities, group composition, and classroom management. This choice was consistent with the action-research approach but resulted in meaningful differences in tasks and observation conditions across the two educational settings.

In the Padua class, the PRE observation was conducted on 24 February 2026 during a paired creative-writing activity in which pupils collaboratively produced a fantasy story. The activity provided the narrative basis for the subsequent interdisciplinary pathway combining Italian language education and educational robotics. The POST observation, conducted on 24 March 2026, took place during one of the final sessions of the project, when the same pairs were completing the construction and programming of a robot puppet using LEGO® Education Spike Prime and Spike Essential kits. The robotic artefact was designed to present the main characteristics of the fantasy genre, reproduce the story created by each pair, and administer an interactive quiz. Pairs were selected by the teacher and remained stable throughout the pathway; no formal collaborative roles were assigned. The PRE observation was discussed and completed jointly by the classroom teacher and the support teacher, whereas the POST grid was completed by the classroom teacher alone.

The Brescia classes followed a different sequence. The PRE observation was conducted during an interdisciplinary authentic task inspired by the travels of Ulysses, combining geography, Italian, art, mathematics and technology, depending on the class. The activity also included unplugged coding and collaborative problem-solving components. The POST observations were conducted during a treasure-hunt and orienteering activity carried out as part of the school's residential week. Although the latter was not an educational robotics activity in the strict sense, it required pupils to follow and interpret instructions, collaboratively solve problems,

negotiate strategies, and coordinate actions. It therefore provided an ecologically situated context in which collaborative behaviors potentially developed during the educational pathway could be observed outside the immediate robotics task. Groups generally consisted of four or five pupils and were selected and managed by teachers. Teachers could intervene during group work to coordinate the activities and support pupils in dealing with misunderstandings or interpersonal difficulties.

These differences are methodologically relevant. PRE and POST observations should not be interpreted as two administrations of an identical standardized task. Rather, they represent repeated observations of the same pupils in different but functionally comparable cooperative situations. Consequently, the study examines changes in observable collaborative behaviors across situated learning contexts. The PRE–POST comparisons should therefore be understood as exploratory within-context comparisons rather than as estimates of the effect of educational robotics, since task characteristics, teacher mediation, group organization, and observation procedures may all contribute to the scores obtained.

3.2.3. Data preparation and statistical analysis

Each of the nine indicators of the observation grid (see Section 3.1) was accompanied by behavioral descriptors corresponding to three ordered performance levels. For the present analyses, these levels were coded as 1 = low/basic, 2 = intermediate, and 3 = advanced. The descriptors were intended to support teacher judgement by anchoring ratings to observable behaviors rather than to global impressions of pupils' collaborative competence. Dimension scores were calculated as the mean of the indicators belonging to each dimension, and an overall collaboration index was calculated across the available indicators.

Importantly, a low/basic score was interpreted as an observed level of performance and not as a substitute for missing or non-observable behavior. This distinction became particularly relevant during the pilot phase and informed subsequent proposals for revising the instrument.

3.2.4. Observation measures

Analyses were based on paired observations, so only pupils with valid PRE and POST data were retained. For participation and perspective taking, complete paired data were available for all 70 pupils. One PRE rating for responsibility initiative was missing in the Padua class. Consequently, analyses involving social regulation and the overall collaboration index were conducted on 69 cases.

Because ratings were obtained on a three-category ordinal scale and observations were paired within pupils, PRE–POST differences were examined using the Wilcoxon signed-rank test. Arithmetic means were nevertheless retained as descriptive summaries of the dimensions and overall index to facilitate interpretation of the direction and magnitude of observed changes. For each score, individual trajectories were additionally classified as improved, stable, or decreased according to the sign of the POST minus PRE difference.

The primary analyses concerned the three-dimension scores and the overall collaboration index. Rank-biserial correlations were calculated as effect-size estimates for the paired comparisons. Indicator-level comparisons were subsequently conducted to identify which specific observable behaviors contributed most strongly to the overall patterns. Given the exploratory nature of this pilot

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study, these indicator-level tests were interpreted descriptively and no correction for multiple testing was applied.

Analyses were first performed on the entire analytical sample and were then repeated separately for the two schools and, for descriptive purposes, for each of the three Brescia classes. This contextual analysis was considered necessary because the classes differed in age, previous robotics experience, task design, group organisation, teacher scaffolding, and observation procedures. Accordingly, inferential statistics were used to characterize the observed data rather than to support causal claims regarding the effects of educational robotics.

4. Results

4.1. Overall changes in collaborative behaviors

Across the four classes, the overall collaboration index increased from 2.07 at PRE to 2.23 at POST. The difference was statistically significant, $n = 69$, $p < .001$, with a rank-biserial correlation of $r_{rb} = .66$. Individual trajectories were consistent with the aggregate result: 47 pupils showed an increase in their overall score, 15 remained unchanged, and 7 showed a decrease.

The clearest change occurred in participation, whose mean score increased from 2.23 to 2.49, $\Delta = 0.26$, $n = 70$, $p < .001$, $r_{rb} = .75$. Thirty-three pupils improved, 32 remained stable, and 5 showed lower POST scores. Social regulation also increased, although more moderately, from 1.94 to 2.06, $\Delta = 0.12$, $n = 69$, $p = .007$, $r_{rb} = .54$. Twenty-four pupils improved, 37 remained stable, and 8 decreased.

In contrast, perspective taking displayed a smaller change. The mean increased from 2.09 to 2.19, $\Delta = 0.10$. Eighteen pupils improved, 46 remained unchanged, and 6 decreased. The paired comparison did not reach the conventional .05 threshold, $n = 70$, $p = .066$, despite a positive rank-biserial correlation ($r_{rb} = .41$).

Table 1. PRE–POST changes in the three dimensions and overall collaboration index.

Measure	n	PRE M	POST M	Δ	Improved	Stable	Decreased	p	rrb
Participation	70	2.23	2.49	+0.26	33	32	5	< .001	.75
Perspective taking	70	2.09	2.19	+0.10	18	46	6	.066	.41
Social regulation	69	1.94	2.06	+0.12	24	37	8	.007	.54
Overall index	69	2.07	2.23	+0.16	47	15	7	< .001	.66

[1] Scale range = 1–3. Social regulation and the overall index are based on 69 cases because one PRE rating for responsibility initiative was missing.

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4.2. Changes at indicator level

Indicator-level results clarify the pattern underlying the dimension scores. All three participation indicators showed higher mean values at POST. Action increased from 2.16 to 2.46 ($\Delta = 0.30$, $p < .001$), interaction from 2.31 to 2.60 ($\Delta = 0.29$, $p < .001$), and perseverance from 2.21 to 2.41 ($\Delta = 0.20$, $p = .004$). The proportion of pupils rated at the advanced level also increased substantially for these indicators: from 31.4% to 54.3% for action, from 45.7% to 67.1% for interaction, and from 30.0% to 55.7% for perseverance.

Within perspective taking, adaptive responsiveness increased from 2.14 to 2.31 ($\Delta = 0.17$, $p = .014$), whereas audience awareness remained largely unchanged, increasing only from 2.04 to 2.07 ($p = .593$). Thus, the relatively small overall change in perspective taking largely reflected stability in pupils' capacity to adapt their contribution explicitly to the understanding or needs of other group members.

The social-regulation indicators showed a more heterogeneous pattern. Responsibility initiative displayed the largest descriptive increase within this dimension, rising from 2.06 to 2.29 ($\Delta = 0.23$, $p = .002$). The proportion of pupils rated at the advanced level increased from 17.4% to 37.7%. Self-evaluation increased from 1.90 to 2.03, whereas changes in negotiation and transactive memory were smaller. In particular, transactive memory remained the lowest-scoring indicator at both observations, increasing from 1.79 to 1.87. Because these indicator-level analyses were exploratory and involved multiple comparisons, the associated p values should be read primarily as descriptive evidence of where changes were concentrated rather than as independent confirmatory tests.

Table 2. Indicator-level descriptive and exploratory PRE–POST comparisons.

Dimension	Indicator	PRE M	POST M	Δ	p
Participation	Action	2.16	2.46	+0.30	< .001
	Interaction	2.31	2.60	+0.29	< .001
	Perseverance	2.21	2.41	+0.20	.004
Perspective taking	Adaptive responsiveness	2.14	2.31	+0.17	.014
	Audience awareness	2.04	2.07	+0.03	.593
Social regulation	Negotiation	2.00	2.06	+0.06	.285
	Self-evaluation	1.90	2.03	+0.13	.050
	Transactive memory	1.79	1.87	+0.09	.109
	Responsibility initiative	2.06	2.29	+0.23	.002

[2] Indicator-level tests are exploratory and were not adjusted for multiple comparisons.

4.3. Differences between educational contexts

The aggregated results concealed marked differences between the two schools. In the three Brescia classes considered together, the overall collaboration index increased from 2.08 to 2.27, $\Delta = 0.19$, $n = 56$, $p < .001$. Forty-two pupils improved, 13 remained stable, and only one showed a decrease. Positive changes were observed in all three dimensions: participation increased from 2.25 to 2.52 (p

< .001), perspective taking from 2.09 to 2.19 (p < .001), and social regulation from 1.95 to 2.12 (p < .001).

The pattern was also visible within each Brescia class. The overall index increased from 2.04 to 2.22 in class 3A (n = 18, p < .001), from 2.00 to 2.27 in class 3B (n = 18, p < .001), and from 2.18 to 2.31 in class 3C (n = 20, p = .003). The dimensions contributing to these changes differed across classes: class 3A showed its clearest increase in participation, whereas perspective taking and social regulation changed relatively little; class 3B displayed the largest increase in social regulation, from 1.81 to 2.22, alongside increases in participation and perspective taking; in class 3C, participation and perspective taking increased, whereas social regulation was comparatively stable.

The Padua class showed a different profile: the overall index increased only slightly, from 2.01 to 2.08, and the paired comparison was not statistically significant, n = 13, p = .592. Five pupils improved, two remained stable, and six showed lower POST scores. Participation increased from 2.14 to 2.38, but with considerable variation among pupils (p = .331), while perspective taking increased from 2.11 to 2.21 (p = .642). Social regulation decreased descriptively from 1.90 to 1.83 (p = .535).

At indicator level, the Padua results were particularly heterogeneous: action, interaction, and adaptive responsiveness showed positive mean changes, whereas perseverance, negotiation, self-evaluation, and audience awareness decreased. For example, action increased from 2.14 to 2.57 and interaction from 2.07 to 2.57, whereas perseverance decreased from 2.21 to 2.00 and negotiation from 2.29 to 2.00. None of these indicator-level changes reached statistical significance in the small Padua subsample.

These contextual differences coincided with relevant differences in the observation conditions. The Padua POST task was technically and organisationally more complex than the PRE creative-writing task and involved the construction and programming of the robotic artefact. In addition, the PRE judgement was produced through comparison between two teachers, whereas only one teacher completed the POST observation. Conversely, the Brescia observations involved larger teacher-managed groups and different problem-solving tasks at PRE and POST.

The results therefore indicate substantial contextual heterogeneity and should not be interpreted as a direct comparison of the effectiveness of the two educational pathways.

4.4. Findings concerning the observation tool

The pilot implementation also yielded information about the usability of the observation grid itself. Teachers reported that the three-level response scale was not always sufficiently sensitive to small behavioral changes. This issue was considered particularly relevant when observing pupils whose progression could be meaningful without being large enough to justify movement from one performance level to another.

Some indicators were also considered more difficult to infer reliably from a single classroom observation. Self-evaluation and, especially, transactive memory required teachers to make judgements about processes that were not always directly manifested in observable behavior. Consistent with this feedback, transactive

memory showed limited variability in the quantitative data and remained concentrated around the lower two levels of the scale.

A further issue concerned the distinction between low performance and absence of an observable performance: the pilot data showed that assigning the basic level to a pupil who had not participated in the activity creates a conceptually different meaning from assigning the same level to a pupil who participated but displayed only minimal evidence of the behavior; the former represents missing or non-applicable evidence rather than low competence. The experience therefore supported the introduction of a separate "not observed/not applicable" category in subsequent versions of the grid.

5. Discussion and conclusions

The different patterns observed across the three classes suggest that collaborative competence is multidimensional and may develop differently depending on classroom and instructional conditions.

Overall, this preliminary stage of the research proved valuable for refining the study design and problematizing the relationship between robotics, engagement, and agency. Findings suggest that the activities considered may increase opportunities for action, interaction, and responsibility initiative, but they do not justify assuming that the more complex dimensions of perspective taking and social regulation are automatically activated. The next phase of the project will include revision of the observation grid through age-appropriate descriptors, a greater number of performance levels, and the addition of a "not observable" option; observer training and calibration; the use of double coding and video recordings whenever feasible; and integration with student questionnaires and teacher logbooks. Such triangulation will make it possible to distinguish more clearly between visible engagement and students' actual opportunities to guide processes, propose strategies, negotiate decisions, and assume shared responsibility. From this perspective, educational robotics should not be viewed as a technological cause of engagement, but rather as a designed learning environment in which individual and collective agency can be enabled, supported, or reduced by pedagogical choices.

The pilot study highlighted both the potential and the limitations of the observation grid. The instrument captured meaningful aspects of collaboration in educational robotics activities, but its refinement will require larger samples, repeated observations, and multiple sources of evidence.

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