ROBOTICS EDUCATION THROUGH CROSS-AGE PEER TUTORING: EVALUATING THE LEARNING OUTCOMES FOR TUTORS AND TUTEES

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ABSTRACT

This study examines the impact of educational robotics and cross-age peer tutoring in primary education and focuses explicitly on the outcomes for tutors and tutees. Forty students from a public school in a European country participated, with fifth graders as tutors and fourth graders as tutees. Using the LEGO Education SPIKE Prime Set, both groups showed significant improvement in computational thinking after nine hours of learning with educational robotics activities. A quasi-experiment research procedure was followed to collect quantitative and qualitative data. The results indicate that peer tutoring was effectively used as a learning strategy to promote computational thinking through educational robotics activities. Implications for future research are provided.

KEYWORDS

Educational Robotics, Cross-Age Peer Tutoring, Computational Thinking Primary Education

1. INTRODUCTION

Educational robotics (ER) activities in classrooms are on the rise, aimed at developing 21st-century skills (Chevalier, 2020). ER promotes learning through engaging pedagogical activities that include active robot participation (Angel-Fernandez & Vincze, 2018) and holds significant promise for enhancing Computational Thinking (CT) in primary school children (Ching & Hsu, 2023).

Peer tutoring (PT) is a structured learning strategy in which one student tutors another, aiming at mutual benefits (Topping, 2000). Due to their recent experiences and relatable communication styles, students often mediate learning more effectively than adults (Alegre et al., 2019). PT has shown academic and non-academic advantages across various educational levels (Ain et al., 2023). It has been applied in subjects like Language (Thurston et al., 2021; Xu et al., 2008), Mathematics (Thurston et al., 2020; Alegre et al., 2019), Music (Fernández-Barros et al., 2023), Sciences (Zeneli & Tymms, 2015), and education for minority students (Barahona et al., 2023). The benefits of PT include improved academic performance, self-esteem, social skills, and positive student relationships (Alegre et al., 2019; Ain et al., 2023; Barahona et al., 2023; Thurston et al., 2021). While positive impacts on both tutees' and tutors' academic performance have been observed (Alegre et al., 2019), there is no unanimous agreement. Research by Thurston et al. (2021) suggests more significant benefits for tutors, indicating a need for further study. The literature review reveals further gaps in the research. Alegre et al. (2019) note that most PT studies focus on same-age groups and academic performance, with less emphasis on other forms. Additionally, there is a lack of research on using PT to develop CT using ER, thus presenting an opportunity for future research.

This study aims to evaluate the effectiveness of peer tutoring in the context of robotics education in primary education and examines the outcomes for both tutors and tutees. The research questions are:

1. Does student performance in computational thinking tests differ according to their role (tutors or tutees) in educational robotics activities using peer tutoring?
2. What benefits do tutors and tutees perceive they gain from participating in educational robotics activities with peer tutoring?

The lack of research on using PT in ER to develop CT highlights the importance and necessity of this study. Practically, the study offers guidelines and advice for cost-effective implementation of ER in elementary schools using PT. Theoretically, it investigates the effects of PT in ER courses, providing data to address current research gaps related to the teaching and development of CT.

2. LITERATURE

2.1 Educational Robotics and Computational Thinking

ER activities are connected to Papert's constructionist theory and the concept of learning by making (Papert & Harel, 1991). Robots are cognitive tools that facilitate practical, interactive learning, allowing students to test hypotheses, receive immediate feedback, and better understand abstract concepts and problem solving (Chevalier et al., 2020).

It is reported that ER is increasingly utilized in primary classrooms to cultivate CT (Chevalier et al., 2021). Wing (2006) defines CT as solving problems, designing systems, and understanding human behavior through computer science principles. Wing (2006) emphasizes that CT is an essential skill for everyone and should be included in primary education. CT encompasses abstraction, generalization, decomposition, algorithmic thinking, and debugging (Angeli, 2022). Abstraction focuses on identifying the essential features of an object, generalization involves creating solutions applicable to various problems, decomposition breaks down problems into smaller parts, algorithmic thinking involves writing step-by-step instructions, and debugging entails identifying and correcting errors (Piedade & Dorotea, 2023). Additionally, critical elements of CT include the algorithmic concepts of sequencing (writing an algorithm) and flow of control (Angeli, 2022).

In the context of primary education students, it is critical to avoid student frustration often caused from challenging hardware and software (Ching & Hsu, 2023). Thus, it is of utmost importance to use age-appropriate robotics kits in the context of systematic interventions to avoid trial-and-error attempts and allow the maximization of learning and CT development for all learners (Chevalier et al., 2020).

2.2 Peer Tutoring: from Theory to Practice

PT goes beyond traditional knowledge transfer, aligning with theoretical frameworks that emphasize social interaction, active learning, and the social construction of knowledge. Vygotsky's theory (1978), particularly the Zone of Proximal Development, underscores cognitive development through interactions with more knowledgeable peers (Akpan et al., 2020).

The Theory of Social Interdependence (Johnson & Johnson, 2013) focuses on structured group activities where learning and success hinge on collaborative efforts. By just grouping students, it does not guarantee effective collaboration; it requires more than just grouping such as setting common goals and cooperative actions. Johnson and Johnson (2013) identified five essential elements for successful cooperative learning: positive interdependence, where group members depend on each other to achieve their goals; individual and group accountability, ensuring personal and collective responsibility; promotive interaction, where members encourage and support each other; the appropriate use of social skills, including effective communication and teamwork; and group processing, which involves reflecting on group performance to enhance future outcomes.

PT can be implemented in various formats depending on the roles of the students. They can act as tutors or tutees with fixed or reciprocal roles. The implementation can vary based on the students' ages and abilities, including same-age groups, similar abilities, or cross-age tutoring where older students serve as tutors for younger students (Thurston et al., 2020; ul Ain et al., 2023). The latter was the focus of this study.

3. METHODOLOGY

3.1 Participants

The study included 40 students from a public elementary school in a European country. Twenty-two fifth graders, all 11 years old, acted as tutors, while eighteen fourth graders, aged 10, were the tutees. The fifth-grade students participated in learning activities guided by their classroom teacher. None of the participants had prior knowledge of educational robotics.

Tutor-tutee pairs were created based on academic performance in Mathematics and Language lessons, with students ranked from highest to lowest in each grade and paired with same ability students. Due to the difference in grade sizes, four groups consisted of one tutee and two tutors. Once formed, these groups remained consistent throughout the intervention to maximize interactions and benefits (Thurston et al., 2021).

3.2 Data Collection Methods

3.2.1 Computational Thinking Test

The same test was administered before and after the intervention to assess CT skills. The test includes a series of exercises designed to measure CT skills. Exercises 1A and 1B require students to number the steps for baking cookies or assembling a toy, thus measuring algorithmic skills (sequencing). Exercises 2A and 2B ask students to provide directional instructions for a taxi, assessing algorithmic thinking (flow of control) and decomposition. Exercises 3A and 3B involve selecting a dress or drawing based on specific attributes and evaluates pattern recognition, abstraction, and generalization skills. In Exercises 4A and 4B, students identify and repeat a dance pattern or guide a robot using repeated movements, measuring pattern recognition, decomposition, and generalization. Exercises 5A and 5B require students to confirm the sequence of steps for dressing as a pirate or to evaluate and correct taxi directions, thus testing algorithmic thinking, decomposition, and debugging skills. Finally, Exercises 6A and 6B involve completing or extending a pattern, assessing pattern recognition, abstraction, and generalization skills. Exercise 4B was excluded from the overall results due to student-expressed confusion.

The Intraclass Correlation Coefficient (ICC) and Cronbach's Alpha were calculated to assess interrater reliability. The ICC values for pretest and posttest scores were 0.985 and 0.995, respectively, indicating excellent agreement between raters. Additionally, the Cronbach's Alpha values for pretest and posttest scores were 0.995 and 0.997, respectively, demonstrating very high internal consistency of the ratings. These results confirm the reliability and consistency of the evaluations, supporting their use in assessing intervention outcomes.

3.2.2 Interviews

Eight pairs of tutors and tutees with varying academic performances were chosen for the interviews, making a total of 16 children. This maximum variation sampling was intended to encompass a wide range of cases for the study. Semi-structured interviews were conducted with the 16 children in the sample. Using a question guide with predefined questions, the interviews were adapted and guided by the children's responses, following suggestions from the literature (Gibson, 2012). The interviews included questions about each child's behavior, opinions, and feelings during the intervention. All interviews were conducted by the tutors' teacher, who, with her knowledge of child development and personal experience with the children, ensured the use of child-friendly language and created a trusting atmosphere. The interview protocols can be found in Appendix, Tables 3 and 4.

3.3 Digital Tools

The LEGO Education SPIKE Prime Set, suitable for ages ten and up, was used. The set includes Lego bricks, axles, a hub, motors, and various sensors. The children followed the building instructions in the Lego Spike app and used a drag-and-drop programming language based on Scratch to code the computer programs.

3.4 Research Procedures

A quasi-experimental design was used for the purposes of this study. Older students acted as tutors, and younger students as the tutees. As shown in Figure 1, the research procedure began with a 45-minute pretest to measure CT. The second phase included 14 forty-minute ER lessons for fifth graders over six days in three weeks, targeting different CT sub-skills with increasing difficulty and four worksheets for basic software commands. More details of each lesson are shown in Table 1. A forty-minute session explained the tutor's role. In the third phase, fifth graders tutored fourth graders using the same activities and worksheets over 14 forty-minute sessions. In the final phase, the interviews were conducted.

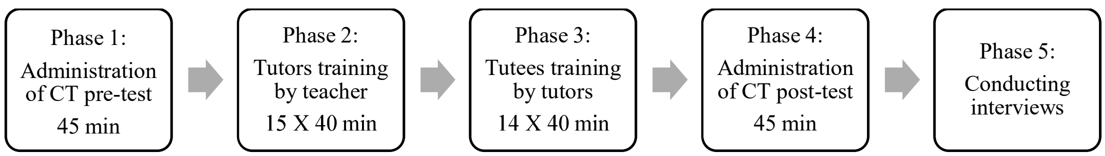

Figure 1. Research Procedure

Table 1. Robotics Course Content

	Course topic	Time	Programming	CT sub-skill
1	Introduction to educational robotics: What robots are and examples of robot use in our daily lives. Acquaintance with the Lego Spike educational robotics package and its software.	80’		algorithmic thinking
2	Assembling the Break Dancer robotic construction by following the build instructions in the software. Complete worksheet 1.	120’	Motors, light, events	algorithmic thinking debugging
3	Programming the Break Dancer robot. Complete worksheet 2.	80’	Use of color sensors When the color is, wait and repeat	abstract skill
4	Assembling the Robotic Construction Driving Base. Complete worksheet 3.	120’	The use of distance (when closure than) and pressure (when pressed) sensors, events – broadcast a message	generalization
5	Programming the Driving Base robot with color sensors. Complete worksheet 4.	80’	Use of color sensors When color is, events – Broadcast a message	decomposition
6	Robotic challenge: Children are asked to program a robot that moves around a city on a mat, avoiding obstacles, and responding accordingly when encountering traffic lights.	80’	All of the above	all

3.5 Data Analysis

To determine the improvement in students' computational thinking, statistical tests were conducted using SPSS. T-tests examined differences between tutors' and tutees' performances, and ANCOVA was conducted to examine the effect of role.

All interview data underwent qualitative content analysis to interpret students' participation during the intervention. After an initial reading, the researcher performed open coding, followed by axial coding to organize the codes into categories. Finally, selective coding was used to identify the most significant and frequent categories. The analysis employed an abductive approach, expanding conceptual schemas from the theoretical framework of Johnson and Johnson (2013), which identifies five essential elements for successful cooperative learning: positive interdependence, individual and group accountability, promotive interaction, appropriate use of social skills, and group processing. The interrater reliability was found to be .91.

4. RESULTS

4.1 Statistical Analyses

Descriptive statistics indicate an improvement in performance for both tutors and tutees after the intervention (Table 2). For tutors, the post-test score (M=83.5, SD=16.06) was higher than the pre-test (M = 77.95, SD = 11.60). The paired t-test confirmed that the difference was statistically significant (t = -2.49, df = 21, p < 0.02) suggesting that the intervention had a significant effect on the tutors' performance. Cohen's D was approximately 0.53, indicating a moderate effect size. For tutees, the post-test score (M=69.11, SD=16.3) was higher than the pre-test (M = 62.22, SD = 14.11). The paired t-test confirmed that the difference was statistically significant (t = -3.19, df = 17, p < 0.005) suggesting that the intervention had a significant effect on the tutees' performance. Cohen's D was approximately 0.75, indicating a moderate effect size.

Table 2. Tutors and Tutees Performance

	Test	M	SD	t	df	p
Tutors	Pre-test	77.95	11.60	-2.49	21	0.02
	Post-test	83.50	12.89			
Tutees	Pre-test	62.22	14.11	-3.19	17	0.005
	Post-test	69.11	16.30			

An ANCOVA was conducted to examine the effect of role (tutor vs. tutee) on posttest scores while controlling for pretest scores. Levene's test confirmed the assumption of equal variances (p = 0.672). The analysis showed no significant difference in posttest scores between tutors and tutees after adjusting for pretest scores (F(1, 37) = 0.088, p = 0.768). This suggests that the intervention had a similar effect on students regardless of their role as a tutor or tutee.

4.2 Qualitative Analyses

Both tutors and tutees stated that they benefited from the learning experience in various ways. Interviewees described it as a positive learning experience by using words like "nice," "creative," "perfect," and "fantastic." They appreciated the novel experience and the opportunity for collaborative learning. For example, tutee T4 stated, "I liked working with others. Collaboration is better when one person has one idea, and another has a different one."

All participants highlighted academic benefits, emphasizing the positive interdependence developed for achieving common goals. Tutees noted gaining new knowledge about robotics, while tutors mentioned reinforcing their existing knowledge, saying that teaching helped them learn it better.

The robotics activities encouraged tutors and tutees to engage in interactive learning activities and felt motivated and assisted each other in completing tasks and reaching group objectives. As stated in the interviews, all tutors asked questions to encourage tutees to think out loud. Tutees found tutors clear and compelling in their explanations and instructions, judging them as good teachers. For example, tutees said the tutors "explained everything like a game," "explained everything in detail," and "explained everything thoroughly and did not get tired of explaining." T4 tutee mentioned, "I understood everything as my tutor explained it." Many tutees revealed that they felt more comfortable asking questions to students rather than teachers, stating that a peer can explain things multiple times, making it easier to understand.

Tutors expressed pride and satisfaction from helping others and successfully teaching robotics activities, indicating individual accountability. Both tutors and tutees had responsibilities, reflecting on their own and their peer's performance at the end of each session. Tutors showed concern for the tutees' learning and asked questions to evaluate their understanding. Tutor TU2 mentioned, "I would ask if he understood certain things, and if he said OK, we would continue."

A significant finding was the creation of new acquaintances and friendships. Students noted that the robotics activities allowed them to meet new classmates and develop closer relationships, enhancing their social skills. Reflecting on the relationships between tutors and tutees, some children initially felt uncomfortable because they did not know their partner well. However, this changed over time. As the children got to know each other better, they reported that this familiarity helped the activities to proceed more smoothly and in a more enjoyable atmosphere. One tutor described the tutees as 'Teacher friends.'

Several students mentioned challenges they faced, indicating group processing. They discussed their actions when making mistakes and efforts to coordinate their work better, resulting in improved performance and outcomes. From the tutees' perspective, mistakes were not seen negatively by their peers and did not negatively impact their perception of their tutors. They believed that everyone learns from mistakes.

One issue highlighted in the interviews was the concern of some tutors during the teaching phase about providing more space for autonomy to the tutees. Tutor TU1 stated, 'Basically, it is difficult to know when to stop and when to leave him alone. That was a bit challenging for me.' Another tutor (TU8) mentioned that it was important for the tutees to do things on their own since 'That's how they'll learn. '

Another issue that emerged was almost all the tutees' preference for being taught by a peer rather than a teacher. They explained their preference by stating that it allowed for personalized instruction, more attention, and greater comfort in asking questions.

5. DISCUSSION

This study demonstrated that PT effectively develops students' CT, confirming its value in educational settings including ER activities. PT improves understanding and skills and offers a cost-effective solution by utilizing existing student resources without needing additional materials or staff (Alegre et al., 2019; Ain et al., 2023).

Statistical analyses showed no significant difference in post-test scores between tutors and tutees when controlling for pretest scores. The analysis confirmed that cross-age PT benefited tutors and tutees and was an effective instructional approach to close the gap between tutors' and tutees' initial differences in CT, consistent with other studies (Alegre et al., 2019).

Qualitative analyses supported the Theory of Social Interdependence (Johnson & Johnson, 2013), highlighting the multifaceted benefits for both tutors and tutees. Students reported about a positive learning environment and engaging in enriching learning experiences. Beyond acquiring ER knowledge and skills, students developed social and interpersonal skills. The robotics activities also facilitated new friendships and social networks, further enhancing social skills and fostering a supportive learning community. Tutors also honed their mentoring skills, boosted their self-confidence, and experienced a deep sense of satisfaction from helping others. Similar findings were observed in related research on various subjects (Willis et al., 2012) and studies showing positive impacts on all participants, regardless of their role (Ain et al., 2023; Parker et al., 2023).

In conclusion, the study highlights the value of peer tutoring in educational robotics, showing significant improvements in computational thinking skills and promoting a collaborative learning environment in line with Social Interdependence Theory.

5.1 Future Suggestions and Limitations

Some tutors recognized the importance of learners actively confirming their understanding to regulate learning. They used targeted questions to encourage critical thinking and reflection, aiding self-regulation. These tutors displayed metacognitive skills essential for managing cognitive processes (Flavell, 1979). The link between

PT and metacognitive skill development needs more research, as Ain et al. (2023) noted, highlighting an area for future study.

Additionally, many tutees' preference for PT over adult educators reflects Bandura's social learning theory of learning through observation, imitation, and modeling (McLeod, 2011). Even when making mistakes, peer tutors serve as relatable role models, providing accessible examples. Positive feedback and rewards for successful tasks enhance learning, consistent with Bandura's theory that reinforcement and social rewards are crucial. Future research could explore the connection between social learning theory and peer tutoring.

This research is subject to limitations that should be acknowledged. The data collected do not support broad generalizations due to the small sample size. Further work is required to explore these patterns in more detail and determine whether they can be generalized to a larger sample of students. Future research should also explore long-term impacts and variations in PT to optimize educational outcomes further. Nevertheless, the current study provides baseline data for the effectiveness of PT in CT development through educational robotics activities.

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APPENDIX

Table 3. Interview Protocol for Tutors

	Questions and Probes
1	Today we did robotics with our class along with the 4th-grade students. How did you find the activity we did? What did you like? What didn't you like?
2	Did you previously know (name)with whom you collaborated in robotics activities? Describe the relationship you had until now.
3	You had the role of tutor, which means you had to teach a student at our school some robotics exercises. How did you find this role? What did you like? What didn't you like?
4	Did you encounter any difficulties teaching your tutee? What was the most challenging for you? What did you do to solve this problem?
5	How did you do in the end?
6	How important is your role in this collaboration?
7	What benefit did you gain?
8	Do you want to continue the robotics lessons?
9	What would you like to keep the same and what would you like to change?

Table 4. Interview Protocol for Tutees

	Questions and Probes
1	Today we did robotics with the 5th-grade students. How did you find the activity we did? What did you like? What didn't you like?
2	Did you previously know (name)with whom you collaborated in robotics activities? Describe the relationship you had until now.
3	Today you had a student at our school as your tutor. How did you find this role? What did you like? What didn't you like?
4	Did you encounter any difficulties having a student as your tutor? What was the most challenging for you? What did you do to solve this problem?
5	How clear were the instructions from your tutor?
6	How did you do in the end?
7	How important is your role in this collaboration?
8	If you had the choice to be taught by a teacher like me or a student of the school, what would you choose?
9	What benefit did you gain?
10	Do you want to continue the robotics lessons?
11	What would you like to keep the same and what would you like to change?