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Cross-Age Peer Tutoring in Educational Robotics to Support Technological Literacy in Young Learners' STEAM Education

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Abstract

Technological literacy is essential in a society where even the youngest children interact with devices and technologies. This study explores cross-age peer tutoring as an approach to support technological literacy in educational robotics (ER). The study focuses on the mediation practices employed by cross-age peer tutors (aged 11–12) when guiding younger tutees (aged 7–8). To examine these practices Science, Technology, Engineering, Arts, and Mathematics (STEAM) education, a multiple case study was conducted with six cross-age teams. These teams conducted ER task with Sphero Indi robot while tutors guided the actions. Video recordings of the actions were analyzed through micro-level analysis. The results highlight three mediation practices: tutor-directed, tutee-directed, and collaborative practices. These practices identify six distinct types of mediators among the tutors labelled: gentle mediators, persistent facilitator, strict mediators, linear instructors, humour-based mediators, and hesitating mediators. The results suggest that cross-age peer tutoring as a pedagogical practice can support technological literacy through joint verbal and non-verbal mediation and collaborative mediation practices. Recommendations for organizing tutoring to support technological literacy are provided.

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Introduction

In today's technology-driven world, digital devices and new technologies are constantly present in children's lives. Thus, technological literacy is essential in the modern world, and its development from an early age is crucial. Technological literacy is defined as humans' capability and competence to use, manage, critically assess, and, most importantly, comprehend technological content (Garmire & Pearson, 2006; International Technology and Engineering Educators Association [ITEEA], 2020). It is considered as, the ultimate aim of teaching and learning technology (Frederik, 2011).

In Science, Technology, Engineering, Arts, and Mathematics (STEAM) education for research, technological literacy is implemented in scarce fashion (Marín-Marín et al., 2021; Toh et al., 2016; Sung et al., 2023). Instead, the research has focused concept and skills related to technological literacy, such as digital literacy, computational thinking, and problem-solving (Alonso-García et al., 2024; Bers et al., 2019; Chaldi & Mantzanidou, 2021; Marín-Marín et al., 2021; Zviel-Girshin et al., 2020). Educational robotics (ER) are frequently integrated into STEAM education, that has been strongly influenced by Seymour Papert's constructionism (Abanoz & Kalelioğlu, 2024; Bers, 2008; Beynon, 2017). Papert (1980) argued that thinking is embedded within culture and that environmental objects can act as 'objects-to-think-with', enabling individuals to 'use [their] body to think' (p. 11). This connection between doing and thinking with technology is recognized as an essential aspect when developing technological literacy (ITEEA, p. 5).

Research has indicated that teachers lack competences to integrate technological and digital content into young learners' educational settings (Casillas Martín et al., 2020; Kara & Cagiltay, 2017). Also, previous research has highlighted the role of peer collaboration and cross-age peer tutoring in advancing STEAM education (Davies et al., 2024; Greca Dufranc et al., 2020; Tenhovirta et al., 2022). Tenhovirta et al. (2022) argued that tutors can offer expanded resources for the pedagogical integration of digital technologies in the teaching and learning of technology. According to Wells (1999), peer tutoring foundations lie in Vygotsky's theory of the zone of proximal development (ZPD), where learners can achieve levels beyond their actual developmental stage with the support of a more capable individual mediating the process. Research on cross-age peer tutoring in ER with the explicit aim of supporting young learners' technological literacy is also limited.

The current study investigates ER as a mean of engaging with technology through cross-age peer tutoring where older pupils (*tutors*; fifth and sixth-graders aged 11–12) guide young learners (*tutees;* first and second-graders aged 7–8). The focus is on tutors' mediation practices to provide guidance for tutees. The study's settings and ER task the participants conducted followed the principles of technological literacy (Garmire & Pearson, 2006; ITEEA, 2020) and constructionism (Papert, 1980), while incorporating a cross-age peer tutoring to facilitate sociocultural learning and the implementation of tutors' mediation practices (Vygotsky, 1978; Wertsch, 2007). The study aims to support young learners' technological literacy and inform the pedagogical practice of cross-age peer tutoring in STEAM education, addressing the following research questions:

1. What mediation practices do cross-age peer tutors employ in ER activities with young learners?
2. How young learners' technological literacy can be supported in cross-age peer tutoring settings?

Theoretical Background

Technological Literacy in STEAM and ER

Previous research has not reached consensus on a universally accepted definition of technological literacy for application in educational settings (Avsec & Jamšek, 2016). Nevertheless, technological literacy is regarded as either a universal objective or a targeted goal within the learning and teaching technology (Dakers, 2018). According to ITEEA (2020, p. 22–23), young learners begin to understand that technology and engineering design are employed to modify the natural environment to meet human needs. Korhonen et al. (2023) argue that technology design aims to convey, that technological solutions are human-made and intentionally created (see also Garmire & Pearson, 2006, p. 30; ITEEA, 2020, p. 24).

This encompasses awareness of the human-made world, technology as a facilitator of everyday life, its relationship to sustainable development, and the concept of technological self-efficacy (Turja et al., 2009). Temiz and Çevik (2024) argue that early science education should foster understanding about the natural world, with STEAM serving as a strong foundation for this purpose. Tangible ER provides opportunities to develop this understanding of the underlying logic of technology (Çetin & Demircan, 2020). Niiranen (2021) indicates that in hands-on activities learners actively construct knowledge through experience (see also Tsagaris et al., 2019).

According to Dakers (2018) technological literacy is not a fixed state but an ongoing process, that reflects the continuous evolution of technology. Consequently, becoming technologically literate cannot be fully predetermined. This makes measuring and assessing technological literacy challenging and unreliable (Avsec & Jamšek, 2016; Garmire & Pearson 2006, p. 21). Thus, earlier research has failed to indicate standardized measure for technological literacy. There have been investigations attempting to measure technological literacy in research (cf. Avsec & Jamšek, 2016; Hohlfeld et al., 2010: Luckay & Collier-Reed, 2014) but not targeted in the context of young learners STEAM education.

Mantzanidou (2020) suggests that ER serves as a means to foster technological literacy of young learners through construction and functional use. There is also evidence that ER can enhance learners' technological literacy in out-of-school contexts (Jäggle et al., 2020). In Jäggle et al.'s (2020) investigation of technological literacy in ER. the focus was on understanding of what is the robot and how it works. Also, Garmire and Pearson (2020, p. 32) assert that, at its most fundamental level, technological literacy represents a general understanding of technology (see also de Vries, 2016). However, Toh et al. (2016) observed that technological literacy has not been the main focus in ER research with young learners. Instead, ER research has been focused on supporting various other skills in STEAM and STEM education, such as digital literacy and computational thinking (Alonso-García et al., 2024; Bers et al., 2019; Fridberg & Redfors, 2021), and collaboration and social competences (Mosley et al., 2016; Pugnali et al., 2017; Taylor & Baek, 2018).

Govender's (2025) systematic review investigated the relation between digital literacy and STEM skills. The results indicated that digital literacy can advance STEM skills, such as critical thinking, design, and collaboration. Hsu et al. (2023) note that within STEAM education, computational thinking is an aspect of learning that enables achieving technological literacy through problem-solving. Computational thinking has been investigated widely in learning and teaching ER, using different measures such as *Bebras Tasks* or *TechCheck* (Chiazzese et al., 2018; Sung et al., 2023; Relkin et al., 2020; 2023). Still, the research has not recognized such tests to measure technological literacy of young learners. According to Martínez-Bravo et al. (2022), digital literacy, computational thinking, critical thinking, design and collaboration are all abilities constituting 21st century skills that are essential for the development of technological literacy (Garmire & Pearson, 2006; ITEEA, 2020).

Garmire and Pearson (2006, p. 21) divides technological literacy into three interconnected components: (1) knowledge, (2) capacity, and (3) critical thinking and decision-making, in their *Assessment Matrix of Technological Literacy* (AMTL). Also, ITEAA (2020, p. 5) emphasizes that knowing, thinking, and doing constitute interconnected and equally significant dimensions of technological literacy. In this study, these dimensions are considered as a framework for supporting technological literacy with ER. The AMTL categorizes technological literacy into four areas: technology and society, design, products and systems, and core concepts and connections (Garmire & Pearson, 2006). This study's ER task focused on the areas design and characteristics, core concepts, and connections to explore the nature of technology and its fundamental principles (Collier-Reed, 2006; Garmire & Pearson, 2006).

Cross-age Peer Tutoring and Mediation

According to Papert's constructionism (1980, p. 54), technology acts as a learning tool that empowers students to create projects, they find personally meaningful. Constructionism emphasises hands-on learning that enables learners to engage in creative processes alongside instructors' guidance (Tenhovirta et al., 2022). Papert (1980, p. 115) referred to this as 'a real intellectual collaboration' in which the child and teacher share a computational problem during programming and attempt to understand it together. Similarly, Nemiro (2021) highlighted the importance of the teacher acting as a co-problem-solver in ER activities. Furthermore, Cervera et al. (2020) identified lack of time and human resources as a principal barrier to implement ER activities in schools. Against this backdrop, the present study examines cross-age peer tutoring as a pedagogical approach for supporting young learners' technological literacy through hands-on ER activities.

Cross-age peer tutoring in STEAM is defined as a process in which older and more technologically skilled learners engage in collaboration by assisting and supporting younger peers (Tenhovirta et al., 2022). In ER, asymmetrical settings involving a more competent peer have been shown to support young learners' attention, critical thinking, and collaboration skills (Cervera et al., 2020). However, Mercer (1996) cautioned that working with a more competent peer is not always conducive to learning, as asymmetry may in some cases hinder progress. Cervera et al. (2020) investigated tutoring in ER from the perspectives of motivation and computational thinking, while Rönkkö et al. (2021) applied peer tutoring within young learners' STEAM projects. However, investigations of cross-age peer tutoring involving age difference presented in this study, remain scarce.

It has been argued that embedding constructionist principles within STEAM education and ER can enhance collaboration between learners (Beynon, 2017; Demetroulis et al., 2023; Pugnali et al., 2017). Papert's emphasis on collaborative activities are connected to Vygotsky's (1978) sociocultural learning and ZPD. Vygotsky (1978, p. 85) noted that, in the learning process, there are many tasks a learner 'barely misses' when attempting to solve a problem independently. He argued that what learners can accomplish with assistance is developmentally and diagnostically more significant, defining this capacity as ZPD. He further emphasised that 'collaboration with more capable peers' (Vygotsky, 1978, p. 86) is one a means by which learners operate within ZPD.

The relation between ZPD and collaboration skills has been recognised in ER research (Demetroulis et al., 2023). ER offers a platform to not only explore how technology works but also to foster collaboration, problem-solving, and experiential learning (Greca Dufranc et al., 2020; Sisman et al., 2022; Tsagaris et al., 2019). In STEAM practices, collaboration typically involves joint participation in tasks where individual contributions to the final product are difficult to distinguish (Greca Dufranc et al., 2020). Moreover, the absence of direct adult instruction in the learning process may foster more authentic collaborative learning environments (Çetin & Demircan, 2020).

Mediation has been a central concept in much of Vygotsky's work, referring to the developmental processes that occur through tools, signs, and social interactions (Wertsch, 2007). As Yliverronen et al. (2018) noted, when young learners collaborate, they require various cognitive skills, including the ability to share and express ideas through both verbal and non-verbal communication. According to Vygotsky (1978), language encompasses talking, seeing, acting, thinking, and representing ideas and experiences. Verbal communication and questioning are important aspects of effective peer collaboration (Belland, 2014; Tartas & Perret-Clermont, 2008). However, in peer tutoring, questioning has been found to occur less frequently than the provision of direct answers (Berghmans et al., 2013).

Visible bodily actions and gestures, such as hand and head movements, are considered important for communication, interaction, and problem-solving (Alibali & Nathan, 2012; Kita et al., 2017). Non-verbal interactions, including facial expressions, body gestures, and tone of voice, are emphasised as mediators of meaning, where the mediator provides a stimulus through expression (Tzuriel, 2021). In young learners' STEAM activities, such gestures are particularly relevant (Yliverronen et al., 2018). Non-verbal knowledge is also considered important for offering learners opportunities to engage with experiences directly (Svensson & Johansen, 2019). Tzuriel (2021) further highlighted mediation using concrete instrumental tools, such as machines, to support learner's internalisation of these tools, enabling their independent use. Young learners start distinguishing the natural and human-made worlds and learn to safely use basic tools, materials, and processes at the same time exploring how STEAM contents shape their surroundings (ITEEA, 2020, p. 22). ER provide learners with tangible feedback through their own actions, as noted in prior research (Brainin et al., 2021; Di Lieto et al., 2017; Taylor & Baek, 2018).

Method

Research Design

To examine cross-age mediation practices and possibilities to support technological literacy, a multiple case study methodology was employed (Yin, 2018). The tutors and tutees worked in six teams, which served as the individual cases for detailed investigation. The study was conducted in an elementary school in a rural area of Finland within the DIGIKUMMI development project (DIGIKUMMI, n.d.). The project implemented '*digitutoring*' procedure, training learners to support peers and staff with digital and technological issues within the daily life of the schools. Building on this procedure, older learners guided younger ones in cross-age teams working with ER task. The tutors participated a four-week ER intervention designed to teach the basics of programming and provide experience with various educational robots. Prior to the ER intervention, programming and robots were unfamiliar for the tutors.

In Finnish educational context there is no separate STEAM subject. Instead, In Finnish primary education, STEAM contents are integrated in multidisciplinary hands-on subject of craft, design and technology (CDT) (Finnish National Board of Education [FNBE], 2014). Thus, the ER intervention was organized within Finnish CDT education lessons (90-min lessons per week). During the first three weeks of the intervention, the tutors explored different robots within their own class, collaborating with peers under the guidance of the teacher-researcher. The learning focused explicitly on the basics of programming and how to use ER. In the fourth week, the tutors guided ER task to young learners.

Participants

A total of 24 learners, organised into six cross-age teams, participated in the study (see Table 1). Among the tutors, seven were girls and five were boys, while among the young learners, eight were girls and four were boys. Participants' names were anonymised, and their genders were neutralised in reporting. The study adhered to the guidelines of the Finnish National Board on Research Integrity (2019). Participation to this study was voluntary, and learners were allowed to withdraw at any stage. Informed consent was obtained from all learners and their legal guardians prior to participation.

Table 1. Cross-age Teams in Collaborative ER Activities

Team *	Tutors (n = 12)	Young learners (n = 12)
Team 1	Finley, Harper	Kendall, Poppy
Team 2	Pierce	Kurt, Musa
Team 3	Silas, Koa	Purity, Rafael
Team 4	Farrah, Murphy	Hendrix, Ruben
Team 5	Victoria, Pleasant, Raegan	Adele, Kai
Team 6	Addison, Taylor	Valentin, Peter

** Teams 1–3 were 5th and 1st graders and teams 4–6 were 6th and 2nd graders*

In Finland, older learners are often named to act as '*school siblings*' for younger learners starting elementary school. This tutoring practice promotes participation, democratic values, and collaboration skills essential for working life (FNBE, 2014). Teams were organized to pair these '*school siblings'* and were formed in consultation with learners' own class teachers to ensure effective group dynamics. The first author, acting as the teacher-researcher, was involved throughout the research process, including the planning of the ER intervention, teaching the tutors during the intervention, and collecting data from the cross-age ER activities. Similar teacher-researcher positioning has been reported in previous ER research settings (cf. Demetroulis et al., 2023; Taylor & Baek, 2018).

ER Task and Data

This study utilized the Sphero Indi robot, which is not widely investigated in ER research (see Figure 1). Love et al. (2022) examined Sphero Indi but their focus was on teachers' professional development in integrating computational thinking into educational settings. The Sphero Indi robot employs unplugged, hands-on programming using rubber colour tiles, each of which represents a specific function. For example, green starts and accelerates the robot, orange turns it diagonally to the right, and purple indicates the goal. The Indi robot kit includes challenge cards and aim is to create different sequences to achieve goal according to challenges. All cards are available on the Sphero Indi website (Sphero Central, n.d.).

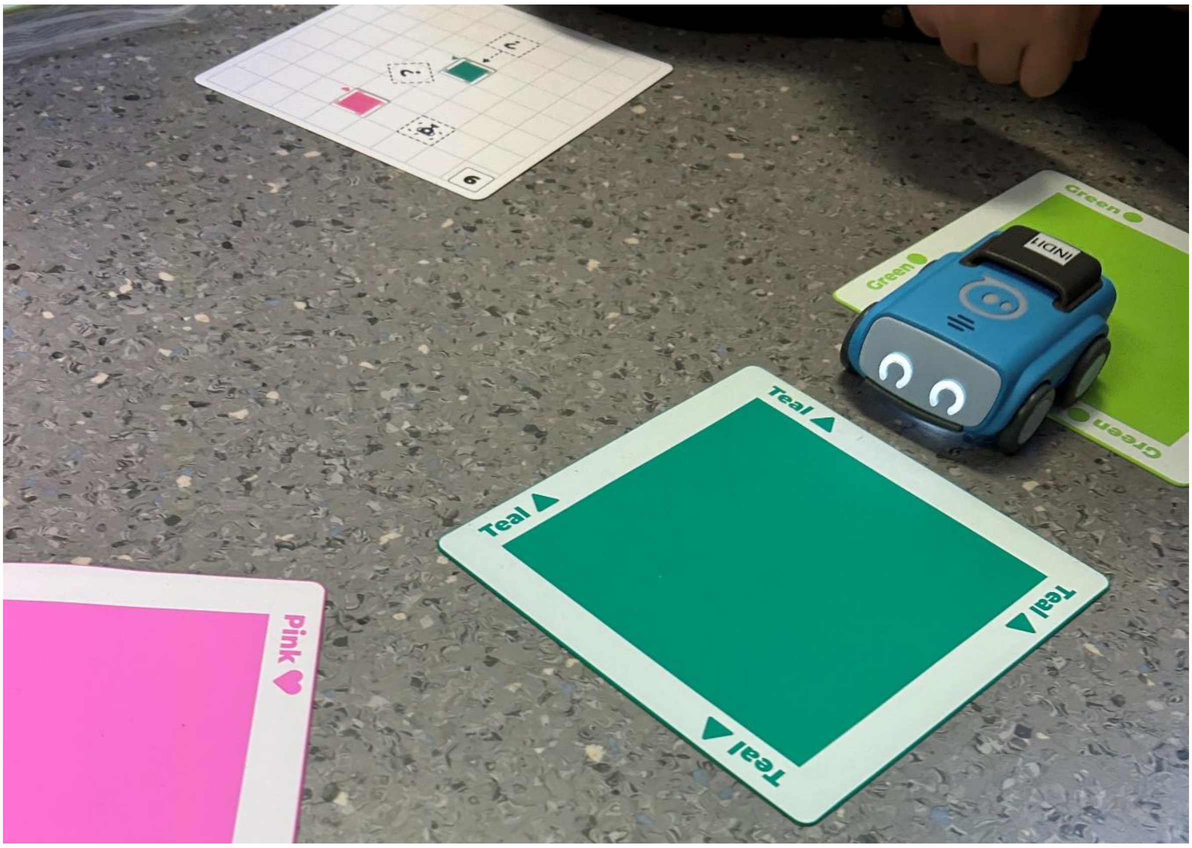


Figure 1. The Sphero Indi Robot and Colour Tiles

The Sphero Indi task used in this study was designed in line with the principles of technological literacy and constructionism (Garmire & Pearson, 2006; Papert, 1980) to promote collaboration, technological understanding, problem-solving, and hands-on engagement with technological tools. Hands-on programming with tangible tools like Sphero Indi's colour tiles exemplifies a core concept in ER. When combined with cross-age collaboration, this approach demonstrates how Garmire & Pearson's (2006) AMTL framework – covering the content area of characteristics, core concepts, and connections – can be applied in young learners' educational settings. A full task sheet for the assignment is provided in Appendix A.

Four of the challenge cards were used in the present study: cards one and two (*instructions cards*) and cards seven and ten (*challenge cards*). The selected challenge cards represented two levels of difficulty, consistent with previous ER research (Taylor & Baek, 2018). Before attempting the challenge cards, teams were instructed to explore how different colour tiles function. Tutors were also given a cheat sheet containing the correct solutions for the challenge cards, with instructions not to show it to the young learners.

The ER activities of the teams performing the Sphero Indi task were video-recorded. As Derry et al. (2010) noted, videos are valuable tools for meaning-making and support the construction of scientific knowledge. In the context of investigating tutors' mediation practices while guiding young learners through an unfamiliar and novel ER task, video recordings enabled a precise analysis of the actions. Ninety-four minutes of video data were transcribed, capturing what was said (speech), what was done (actions), and what the Indi robot did (the Indi movement). An example of the transcribed material from Team 1's activities is presented in Table 2.

Table 2. Example of Team 1's Transcribed Material

Row	Speech	Actions	The Indi movement
90	Poppy: Why is the purple one there? [the colour tile]	Points the goal [the purple tile] on the floor.	The Indi starts moving
91	Harper: We will see in a moment.	Everyone is watching the Indi robot.	

Data Analysis

The transcriptions were analysed at the micro-level in three phases (Ash, 2007). According to Ash (2007), micro-level analysis foundation is based on Vygotsky's ZPD, which aligns with the theoretical framework and methodological design of this study. The workflow of the analysis is illustrated in (see Figure 2).

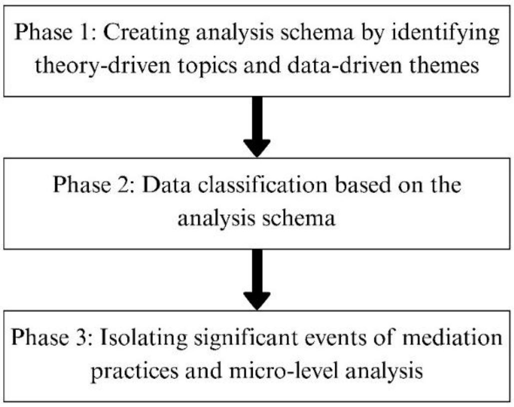


Figure 2. Workflow to Analyse Cross-age Peer Tutors Mediation Practices

In the first phase, the transcribed material was read multiple times to develop an analysis schema (see Table 3). The topics of verbal and non-verbal mediation were derived from relevant research on verbal mediating actions (Tzuriel, 2021; Wertsch, 2007; Yliverronen et al., 2018). Drifting off task is recognized as an aspect to consider in ER (Taylor & Baek, 2018). Thus, the off-task activities were identified as an individual topic. According to

Creswell and Poth (2018, p. 186), themes are broad units of information consisting of multiple codes to aggregate common ideas. Themes were formed by identifying recurring elements within the data. Following Creswell and Poth (2018, p. 184), this 'lean coding' approach involves dividing the material into labels after repeated review. In addition, prior research has informed the formation of themes, including aspects such as questioning and bodily gestures (Alibali & Nathan, 2012; Berghmans et al., 2013; Kita et al., 2017).

Table 3. The Analysis Schema

Topic	Theme	Description
Verbal mediation	Linear instructions	Telling young learners straight what to do, explaining what is happening or guiding towards the answer (e.g., 'Blue turns the Indi right')
	Questioning	Asking young learners open-ended or dichotomic questions (e.g., 'What tile could fit the question mark?', 'Is it green or yellow?')
	Experimentation	Cheering young learners to try out. Discussions related to experimenting (e.g., 'You can try it')
	Individual attention	Encountering young learners individually. Following young learners' lead (e.g., talking straight to young learners and catching their thoughts)
	Humour	Joking and situational humour. Using humour to enliven the mediation.
	Confirmation or denial	Short expressions (e.g., yes, no, good)
Non-verbal mediation	With the Indi robot	Showing what to do with the Indi robot (e.g., putting the Indi to route, turning the Indi on top of the colour tiles)
	The colour tiles	Using the colour tiles for guidance
	The Indi instruction cards	Using Indi cards 1 or 2 for guidance.
	The Indi challenge cards	Using Indi cards 7 or 10 for guidance.
	The task sheet or cheat sheet	Using the task sheet or cheat sheet for guidance
	Gestures	Small gestures (e.g., smiling, acting thoughtful), hand and head gestures (e.g., pointing, nodding, shaking head). Leaving space for young learners' actions or ignoring them.
Off-task activities	Distraction	Verbal and non-verbal distraction (e.g., talking about topics not related to the task)
	Frustration	Anxious behaviour (e.g., failing in the task)
	Teacher interference	Asking help from the teacher or teacher's intervention in the actions.
	Tutors' collaboration	Verbal and non-verbal interactions between the tutors (e.g., discussion of what to do, exchanging glances).

In the second phase of the analysis, the transcribed material was classified into three main topics and sixteen themes based on the analysis schema (see Table 3). A total of 1,233 units of analysis were manually coded in

NVivo 14 by two authors working simultaneously in collaboration, discussing each unit to reach consensus. Units ranged from one to seven rows of transcription, although in some cases, such as when tutors allowed space for young learners' individual actions, units exceeded seven rows. All units analysed in this phase are presented in Appendix B. In the third phase, one to two significant events from each team's activities were isolated (Ash, 2007). These significant events were segments that exemplified each team's characteristic mediation practices investigated on micro-level. Micro-level analysis of the events, as Ash (2007) noted, allowed detailed examination of social interactions, including dialogue, actions, gazing, gesturing, and listening.

Results

Mediation Practices

Based on the significant events and the classified units in Appendix B, three different mediation practices were identified: tutor-directed (Teams 3–5), tutee-directed (Team 6), and collaborative mediation practices (Teams 1 and 2). Each of the six teams were labelled to characterize mediation practices they implemented. Figure 3 illustrates teams' verbal mediation, non-verbal mediation, and off-task activities. A qualitative description of each team's mediation practices is presented in this section.

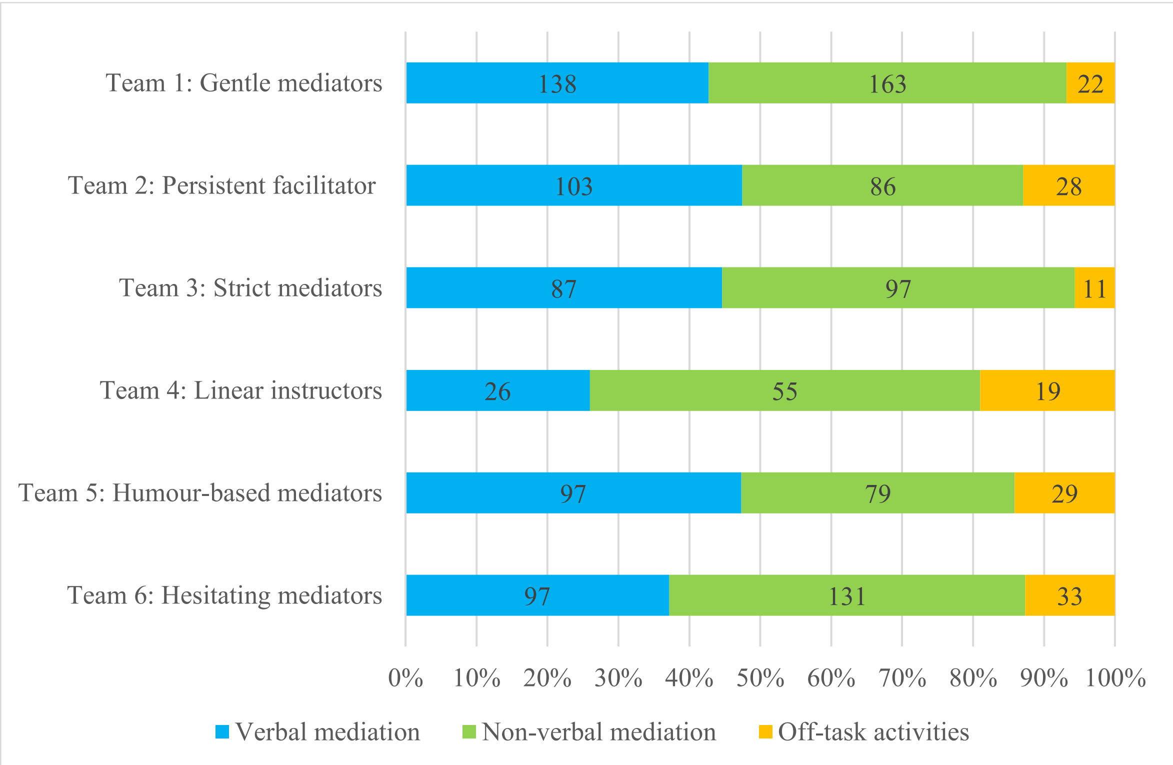


Figure 3. Cross-age Peer Tutors' Mediation Practices

Tutor-directed Mediation

In Team 3, identified as *strict mediators*, the process was guided by tutors Silas and Koa. Koa led the activities with a direct and structured approach, while Silas assumed a more passive, observational role. The tutees, Rafael and Purity, participated actively, with Rafael displaying higher engagement and Purity adopting a more reserved stance. Two significant events exemplified the tutors' mediation practices: guiding the tutees on the functions of the colour tiles and working with challenge card 7. The practices encompassed both verbal (87 units, 45%) and non-verbal (97 units, 50%) mediation, with off-task activities recorded in 11 analysis units (6%) (Figure 3).

A defining feature of these practices were the tutor-directed explanation and demonstration, focused on advancing task progression. The tutors combined linear instructions with both open-ended and dichotomous questions, often employing brief, strict expressions to affirm or correct the tutees' actions. Individual attention and encouragement for experimentation were observed only occasionally. Despite this rigid style, the practices ensured comprehensive mediation of the ER activities and aimed to confirm the tutees' understanding, particularly evident in the first significant event involving the colour tile functions (see Figure 4).

Koa [behind Silas on the right]: Oh, the orange one?	Rafael takes the orange and puts it in front of the green tile. Rafael nods.	
Koa: Hey, first I ask how it would turn left?	Rafael shakes head [to indicate ignorance] and takes the red tile.	
Koa: Okay.	Rafael shows the red tile to Koa and takes the orange off the route.	
Rafael [top left]: Should we take another green?	Takes also green tile, smiles, and looks Koa questioningly.	
Koa: No.	Rafael giggles.	
Rafael: Okay.	Puts the red in front of the green.	
	Koa puts the Indi on green tile.	Indi makes countdown.
	Rafael looks at Koa sneaky and smiles.	Starts moving and stops on the red.
	Rafael removes the red tile from the route. Meanwhile, Silas grabs the Indi and moves it on top of each color tiles. Young learners watch Silas actions.	The Indi's color changes according to tiles colour.
Koa: That's a stop sign, that red on. So what could, um, turn it left?	Silas leaves the Indi on the orange tile. Koa moves Indi on the floor next to pile of tiles.	Orange light and then the light turns off.

Figure 4. Team 3's Significant Event of Investigating How the Colour Tiles Function

The tutors employed non-verbal mediation primarily using the colour tiles. Although the overall mediation was tutor-directed, the testing of the colour tiles demonstrated tutee-directed practices. This detailed engagement contributed to the prominence of the colour tiles theme in the classification (see Appendix B). As shown in Figure 4, tutors integrated verbal and non-verbal mediation during guidance. This approach was also evident in the second significant event, during which the team completed challenge card 7. Tutors used both the robot and colour tiles to support verbal mediation by demonstrating the robot's movements—turning it and using additional tiles to represent empty squares indicated on the challenge card. The use of the instruction and challenge cards themselves was minimal.

In Team 4, identified as *linear instructors*, tutors Murphy and Farrah employed a straightforward, tutor-directed mediation practices. Using a cheat sheet, they provided direct instructions for task completion. Murphy led the process with concrete demonstrations, while Farrah offered more detailed guidance. This approach was particularly evident during the significant event involving challenge card 10. Non-verbal mediation was predominant (55 units, 55%), whereas verbal mediation was less frequent (26 units, 24%). Off-task activities were recorded in 19 units (19%) (see Figure 3). Tutees Hendrix and Ruben were primarily passive observers but participated by constructing routes under tutor guidance. Their engagement was largely self-initiated, as the tutors did not actively encourage experimentation or questioning. Mediation remained tutor-directed, with minimal attention directed towards the tutees. During the completion of challenge card 10, the tutors maintained full control over the process. Prior to the example shown in Figure 5, the Indi robot exhibited unusual behaviour, prompting the tutors to seek assistance from the teacher-researcher.

Farrah [on the left]: So, think about traffic lights. Green goes forward, yellow slows down little bit and red stops.	Points different colors while speaking.
Murphy [on the right front]: Yep.	Prepares the route for challenge card 10. Moves green in the beginning of the route and collects blue ones off.
Murphy: Okay, first two greens.	Ruben takes the green one and gives it to Murphy who places it next first green.
Farrah: And if there are two greens in a row, it goes faster.	Points the greens on the route.
Murphy: Then there was that one. This dark grey. No, wait is that dark blue?	Points the teal in the cheating sheet.
Farrah: It's dark green	Takes the teal one.
Murphy: Um… And it turns kind of diagonally over there. And then the yellow one [incorrect].	Points diagonally along the route and places the teal in position. Places the yellow in the spot where orange should be.
Murphy: Then blue. Do you want to put it on? [speaks to Hendrix]	Gives the blue to Hendrix.
Hendrix [in the middle]: Yes	Looks at the cheat sheet for reference.
Murphy: Then, it's there. And then it has to be this again. You can put it too.	Points the spot and Hendrix puts the blue tile there. Gives the teal tile to Hendrix who places it correctly.
Murphy: Ours turns a bit oddly [speaks to teacher who arrives in the situation]	Shows Indi to the teacher.

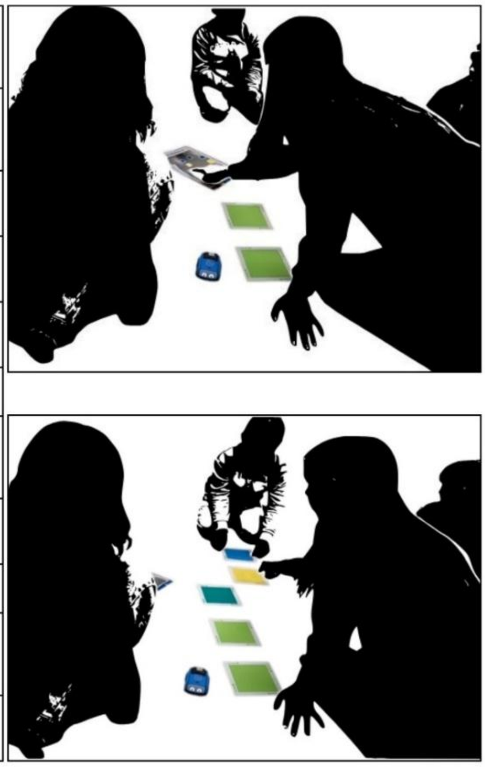
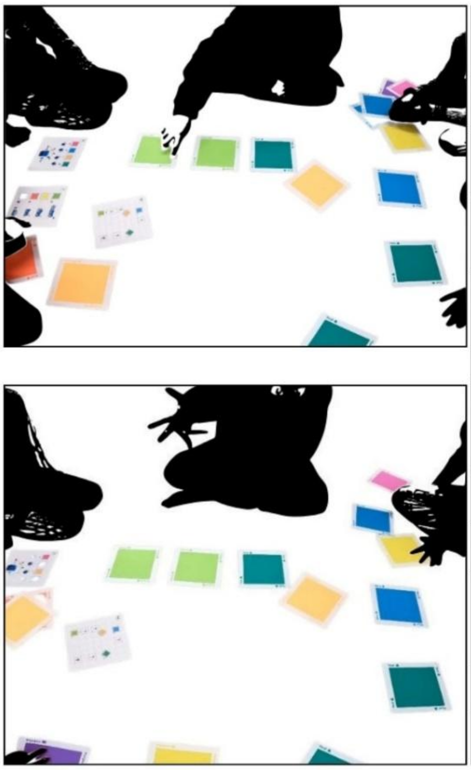


Figure 5. Team 4's Significant Event of Conducting Challenge Card 10 with Tutor-directed Mediation Practices

Following the event illustrated in Figure 5, the Indi robot again turned unexpectedly, prompting the teacher to replace it. This malfunction exposed the tutors' limited resilience, resulting in off-task activities as they sought assistance. These events also reflected frustration and collaboration between the tutors in response to the Indi's unexpected actions. Despite these challenges, the significant event demonstrated the tutors' clear verbal mediation, as they 'verbally walked through the process' during task completion. Non-verbal mediation remained tutor-directed, with the tutors constructing the route independently. Although the tutees were allowed to place the colour tiles, the tutors dictated their exact placement through combined verbal and non-verbal cues (see Figure 5). The tutors relied primarily on the cheat sheet for guidance rather than using the instruction or challenge cards, reinforcing the directive nature of their mediation.

In Team 5, identified as *humour-based mediators*, tutors Victoria, Pleasant, and Raegan employed a tutor-directed mediation practices incorporating humour. Pleasant led the process with consistent, task-focused guidance, while Victoria fostered a positive atmosphere through humour, occasionally diverging from the task and performing for the learners. Raegan played a minor role in the guidance. All tutors demonstrated a strong understanding of Indi's functions. The significant event involving challenge card 10 illustrated the team's mediation dynamics. Verbal mediation was dominant (97 units, 47%), with non-verbal mediation also present (79 units, 39%). Off-task activities (29 units, 14%) were mainly attributed to distraction and collaboration between the tutors (see Figure 3).

Tutees Adele and Kai participated in the task primarily through self-initiative, as the tutors did not actively encourage experimentation. Most of their engagement involved observing the tutors. Occasionally, the tutors provided individual attention, such as addressing the tutees by name or using gestures such as high-fives to acknowledge accomplishments. Engagement was predominantly facilitated through non-verbal mediation, allowing the tutees to place tiles or explore Indi's functions by initiating code. While the tutors clearly explained the learning content during task completion, the mediation remained largely directive. The use of humour and expressive bodily actions to maintain engagement occasionally led to off-task behaviour, particularly evident in Victoria's actions. Despite these diversions, task progression remained steady. The significant event illustrated in Figure 6 demonstrates how humour influenced the guidance process. Collaboration between the tutors also reflected this humour-based approach, although it did not directly enhance tutee engagement.



Adele [top left corner]: What does the green do?	Points green on tile on challenge card
Pleasant [bottom left corner]: Well it acclerates.	
Victoria [in the middle]: It acclerates and starts. Like this: din, din, dii! Swoosh!	Imitates Indi's countdown and throws hand from side to side
Pleasant: Well then… There is no more green ones. Let's use yellow one.	Seeks green tile from the pile
Victoria: No need for that because it's going to be too fast. And then all of these [the tiles] are going fly like swoosh swoosh. It's going to turn on a paper plane!	Waves hand dramatically in the air. Adele and Kai laugh.
Pleasant: Let's put the yellow one. And then… Toss me a purple one.	Places the yellow in the spot of the last question mark. Kai tosses the purple one to Pleasant.
Victoria: Purple	
Raegan [right front]: Purple	Repeats after Victoria.
Victoria: You should have tossed it like this. It would have hit the face really hard.	Makes a 'frisbee throwing' motion and grins to Kai who smiles back.
Adele: Now we try it!	Takes the Indi
Pleasant: Turn it on.	Adele turns on Indi.

Figure 6. Team 5's Significant Event of Conducting Challenge Card 10 with Humour-based Mediation

As shown in Figure 6, verbal mediation was closely integrated with non-verbal cues, including facial expressions and hand movements. The significant event also highlights the tutors' distinct roles in the mediation process: Victoria fostered a positive atmosphere and occasionally amused the tutees unnecessarily, Pleasant ensured steady task progression, and Raegan acted as a bridge, balancing humour with task-focused guidance. Notably, these practices did not emphasise the use of instruction or challenge cards. Instead, the tutors relied on Indi and the colour tiles for non-verbal mediation. No assistance from the teacher-researcher was required.

Tutee-directed Mediation

In Team 6, identified as *hesitating mediators*, tutors Addison and Taylor exhibited mediation practices characterised by hesitation, uncertainty, and minimal support. They did not actively encourage tutee participation, which led to more tutee-initiated engagement and experimentation. The mediation practices were dominated by non-verbal mediation (131 units, 68%), while verbal mediation was limited (29 units, 15%). The lack of guidance contributed to an increase in off-task activities (33 units, 17%) (see Figure 3).

Tutee Valentin completed tasks independently, while Peter remained passive, observing without engaging in the process. The tutors made no effort to involve Peter, instead allowing Valentin to experiment freely. This autonomy arose more from the tutors' inactivity than from an intentional mediation practices. Valentin's self-directed exploration of the colour tiles and Indi's functions exemplified non-verbal mediation in the analysis. The instruction cards were used in a focused manner, and the challenge cards served as the primary support; however, these were employed independently by Valentin rather than as active tools for mediation. Verbal mediation was minimal, limited to linear instructions and brief confirmations, such as indicating Indi's direction. The significant event involving challenge card 7, illustrated in Figure 7, demonstrates the tutors' insufficient support and the resulting excessive autonomy.

Valentin [on the right front]: No!!!	Addison catches the Indi.	Indi turns to wrong direction on teal color tile
Addison [on the right back]: It should turn that way.	Holds the Indi on top of the teal color towards the correct direction.	The code ends
Valentin: Yep, it should… This one is a tricky challenge now.	Takes the teal of the route and moves it back to pile of tiles.	
	Addison and Taylor [on the left front] exchange sneaky smiles.	
Valentin: Okay, maybe it is this red one? Okay then, please go to the correct direction now.	Puts the red tile on the route. Puts the Indi back on the first green tile.	Indi makes the countdown
Valentin: Go, go, go, go, go, go, go, go. That way! Turn!	Points the red tile.	Starts moving towards the red tile.
	Valentin looks first at Addison and then bows head dramatically. The tutors and Peter [in the middle] smiles to Valentin.	Stops on red tile.

Figure 7. Team 6's Significant Event of Young Learner Struggling in Conducting Challenge Card 7

Without reinforcement, hints, or guidance from the tutors, the tutee displayed signs of confusion and dissatisfaction (see Figure 7). The tutors remained passive, exchanging hesitant glances and subtle smiles. The tutee became frustrated by solitary efforts and the inability to complete the task. Inadequate mediation led to aimless interactions with Indi and the colour tiles, resulting in increased off-task behaviour, including frustration. Despite these challenges, Valentin remained focused, even when the task exceeded his developmental level. During an attempt at challenge card 10 without tutor support, the teacher-researcher intervened, which further contributed to off-task activity in the analysis.

Collaborative Mediation

In Team 1, identified as *gentle mediators*, tutors Finley and Harper collaborated naturally, contributing equally to the mediation process. They frequently combined verbal and non-verbal mediation, with non-verbal mediation slightly more prominent (163 units, 50%) than verbal mediation (138 units, 43%). Off-task activities (22 units, 7%) primarily involved the tutors' side conversations or discussions unrelated to the task (see Figure 3). Among the tutees, Poppy was more dominant and impulsive, speaking frequently and interacting with the robot more than Kendall, who remained quieter but was still actively engaged in the process. Kendall used the instruction and challenge cards consistently and appeared to comprehend the task more thoroughly than Poppy.

The mediation practices emphasised empathy and inclusive engagement of the tutees. Finley actively encouraged Kendall, who tended to remain in the background. This empathetic approach fostered a positive atmosphere, supported by both verbal and non-verbal mediation. The tutors occasionally provided direct answers or posed dichotomous questions but primarily aimed to engage the tutees through open-ended questions and explanatory responses. These were often preceded or followed by linear instructions to reinforce understanding of the ongoing process. The mediation practices reflected a commitment to ensuring the tutees' comprehension through thorough explanation. This was particularly evident in the significant event illustrated in Figure 8, when Indi turned incorrectly and the tutors clarified the process.

As shown in Figure 8, the tutors frequently combined verbal and non-verbal mediation, including demonstrations with the Indi robot or colour tiles, as well as directional gestures such as pointing. While the mediation practices were primarily tutor-directed, it consistently incorporated tutee-directed practices and collaborative actions. The tutors allowed space for individual experimentation and provided explanations in response to the tutees' actions, particularly when the tutees explored the functions of the colour tiles with the robot. Overall, tutor- and tutee-directed practices were applied in a relatively balanced manner.

In Team 2, identified as *persistent facilitator*, tutor Pierce employed calm and consistent mediation practices, characterised by patience and perseverance. The approach aimed to engage the tutees by allowing space for individual experimentation. Despite challenges encountered during the task, the mediation practices remained largely consistent, although mediation occasionally shifted towards a more linear, tutor-directed style. These characteristics were evident in two significant events: the successful completion of challenge card 7 and the unsuccessful attempt at challenge card 10. Verbal mediation was prominent (103 units, 47%), with slightly less emphasis on non-verbal mediation (86 units, 40%). Off-task activities accounted for 28 units (13%) (see Figure 3).

Poppy [upper right]: There you go!		Indi turns left on the pink tile [wrong direction].
Finley [on the left]: But now it went to this way.	Catches the Indi. Acts thoughtful.	
Poppy: It doesn't matter.		The code stops.
Finley: But it should go there. So what [colour] should that be then?	Points right from the pink tile toward the goal. At the same time, Kendall [in the middle] moves to investigate instruction card 2.	
Harper [down right]: If the goal is there and it should turn this way? [interrogative]	Crouches closer to the route and points the purple tile.	
Poppy: Maybe only this should be turned.	Turns the pink tile 90 degrees right [the pink is wrong answer].	
Finley: But it can't really be, because it still turns in the same direction	Looks at Harper quickly. Turns Indi 90 degrees left on top of the pink tile.	
Poppy: Oh, okay then. Maybe teal. Let's try teal because we have not tried it yet [incorrect answer]	Takes the pink of the route.	
Harper: Okay	Takes the teal and replaces it with the pink.	
Finley: You can start this.	Hands the Indi to Kendall.	
Harper: That's good now [speaks to Kendall].	Monitors that Kendall puts Indi straight on the route.	Indi makes countdown

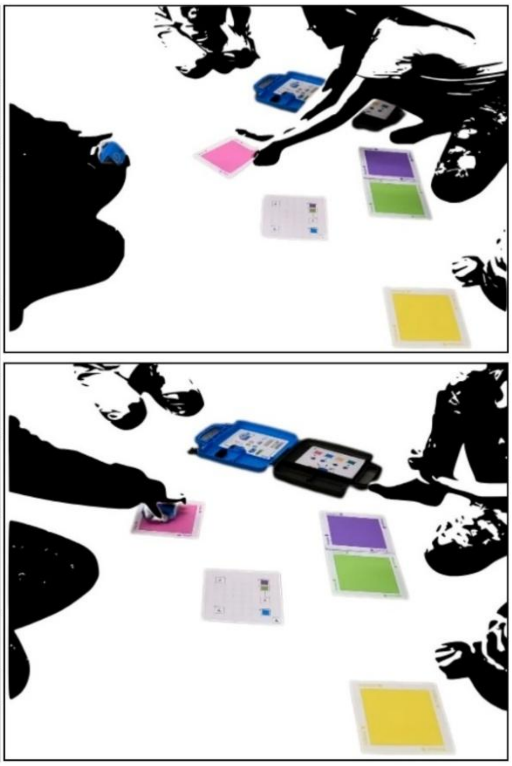


Figure 8. Team 1's Significant Event of Ensuring Understanding When Conducting Challenge Card 7

Tutees Kurt and Musa were active and talkative throughout the ER activities, collaborating both with each other and with the tutor. Musa acted more impulsively, experimenting with the colour tiles in an unstructured manner, while Kurt approached the task more thoughtfully, using the instruction and challenge cards to guide his actions. The first significant event highlighted the tutor's efforts to engage the tutees through questioning, encouragement, and reflective feedback. Verbal cues and directive gestures were minimal but purposeful – for example, using phrases such as 'yep' for confirmation or prompts like 'you have to now think what colour should be there'. Although the tutees worked largely independently, individual attention was limited. The tutor relied on recurring linear instructions and direct commands to guide them towards correct solutions.

In the second significant event, the team struggled with challenge card 10 due to incorrect task execution. Although unable to identify the error, the tutor persistently mediated the process without referring to the available cheat sheet. As difficulties increased, verbal mediation became more direct and commanding, and non-verbal mediation shifted towards a more tutor-directed approach. Despite these challenges, the situation strengthened the team's collaboration and encouraged tutee participation. At times, the roles of tutor and tutees appeared to reverse, with the tutees taking the initiative. Figure 9 illustrates this shift in roles, enhanced collaboration, and increased tutee involvement.

The failure to complete challenge card 10 led to moments of frustration for both the tutor and young learners, contributing to off-task behaviour, such as discussions that strayed from the task. The team frequently considered asking the teacher-researcher for assistance but ultimately did not do so. Finally, the teacher intervened to support the task completion after repeated errors.

Pierce [on the left]: Well now it did not go to there [the right direction]. But it is better now.	
Musa [on the right]: It is better now. It is. Now we have to move these closer. But it is going to this way? [interrogative]	Moves the teal tile closer to the spot where Indi just drove off the route. Points from the blue tile towards the teal and looks at Pierce. Pierce seems thoughtful and provides no answer.
Kurt [in the middle]: Like this?	Moves the last yellow tile slightly.
Musa: Yep, how should we do that? Let's move this here.	Moves the yellow tile closer to teal.
Kurt: Put it onto it	
Musa: There is a gap. Here is also a gap. Okay let's try it!	Points the challenge card 10. Kurt puts the Indi on the route.
Pierce: Okay we'll see now.	

Figure 9. Team 2's Significant Event of Not Completing the Challenge Card 10

Discussion

The present study introduced a novel approach by employing more competent cross-age peer tutors to support young learners and promote technological literacy in ER activities. As recognised earlier measuring technological literacy is found problematic (Avsec & Jamšek, 2016; Garmire & Pearson 2006). Also, the current study was lacking to measure technological literacy. Instead, the study used Garmiere & Pearson's (2006) AMTL to introduce ER task with the Sphero Indi robot aiming to support technological literacy. This ER task and Sphero Indi robot was investigated as a meaningful technology to mediate development (Papert, 1980). The explicit focus was on tutors' mediation practices in guiding the ER task.

The results identified three mediation practices: tutor-directed, tutee-directed, and collaborative. Six team's distinct characteristics of mediation were emphasizing these practices: (1) *gentle mediators*, (2) *persistent facilitator,* (3) *strict mediators*, (4) *linear instructors*, (5) *humour-based mediators*, and (6) *hesitating mediators*. These characteristics reflected the unique approaches of each team's tutors in guiding ER activities, highlighting different practices of mediation. Especially, collaborative mediation practices of *gentle mediators* and *persistent facilitator* were recognised potential to support technological literacy.

Tutors in Teams 1 and 2 demonstrated collaborative mediation with joint verbal and non-verbal practices. *Gentle mediators* (Team 1) emphasised collaboration and empathy, aiming to involve young learners while allowing them to experiment, and focused on ensuring understanding through thorough explanations of the ER activities. This commitment to learning and active participation aligns with recognised benefits of cross-age peer tutoring (Tenhovirta et al., 2022). Creating a comfortable space for participation in the ER process has been recognised as an important factor for collaborative problem-solving (Taylor & Baek, 2018). This collaborative problem-solving as Papert (1980) suggest may nurture technological literacy.

Persistent facilitator (Team 2) adopted mediation practices that emphasised tutee engagement through questioning, encouragement, and avoidance of direct answers. The use of questioning to support learners' independent efforts in seeking solutions has been identified as a key element in earlier research (Belland, 2014). Interestingly, in the persistent facilitator mediation practices, struggles to complete the task highlighted and reinforced collaboration between the tutor and tutees. Programming the robot is considered a complex task for young learners; to promote the tutors' technological literacy and to maintain the task's meaningfulness, both the task and its guiding process should be sufficiently challenging for tutors. Similar findings have been reported for ER activities where collaboration was deepened through problem-solving and opportunities to challenge one another within the team (Sisman et al., 2022).

Tutor-directed practices were prominent in Teams 3–5. This mediation practices illustrate how more competent learners may adopt directive, knowledge-telling strategies (Berghmans et al., 2013) or attempt to solve the task independently, with minimal input from less competent peers (Tartas & Perret-Clermont, 2008). In the *humour-based mediators'* (Team 5) practices, distinct roles of the tutors were emphasised. A characteristic feature of this approach was maintaining a positive atmosphere through humour, which occasionally diverted attention away from the task. Such deviations, leading to irrelevant social interactions and reduced efficiency in the learning process, have also been noted in earlier research on collaborative ER, where teachers observed similar behaviour (Sisman et al., 2022).

The *hesitating mediators'* practices emphasised strong tutee-directed practices, with tutors providing minimal support to the young learners. Belland (2014) recognised that effective scaffolding requires providing the right type and amount of support at the appropriate time to enable learners to develop their abilities. In contrast, hesitating mediators offered insufficient guidance, preventing learners from completing tasks that exceeded their current capabilities. Previous research in young learners' STEAM contexts highlights the importance of engagement and exploration within playful environments that stimulate questioning and curiosity (Greca Dufranc et al., 2020). However, as demonstrated in the *hesitating mediators'* mediation practices, offering excessive autonomy without adequate support resulted in learners struggling to complete the tasks independently. Tenhovirta et al. (2022) emphasised the challenges posed by cross-age peer tutors' limited competency and knowledge.

Conclusion

The findings of the current study highlight the use of both verbal and non-verbal mediation, as well as the incorporation of tutor- and tutee-directed approaches. Although, the actual development of technological literacy was not measured in this study, the joint implementation of tutee- and tutor-directed practices, alongside joint verbal and non-verbal mediation, can contribute to support technological literacy. This joint mediation and collaboration may create a learning environment conducive to a deeper comprehension of technology. Based on the findings of this study, such an environment is referred to as a *hot spot for technological literacy* (HSTL). Each team is located in relation to HSTL (see Figure 10).

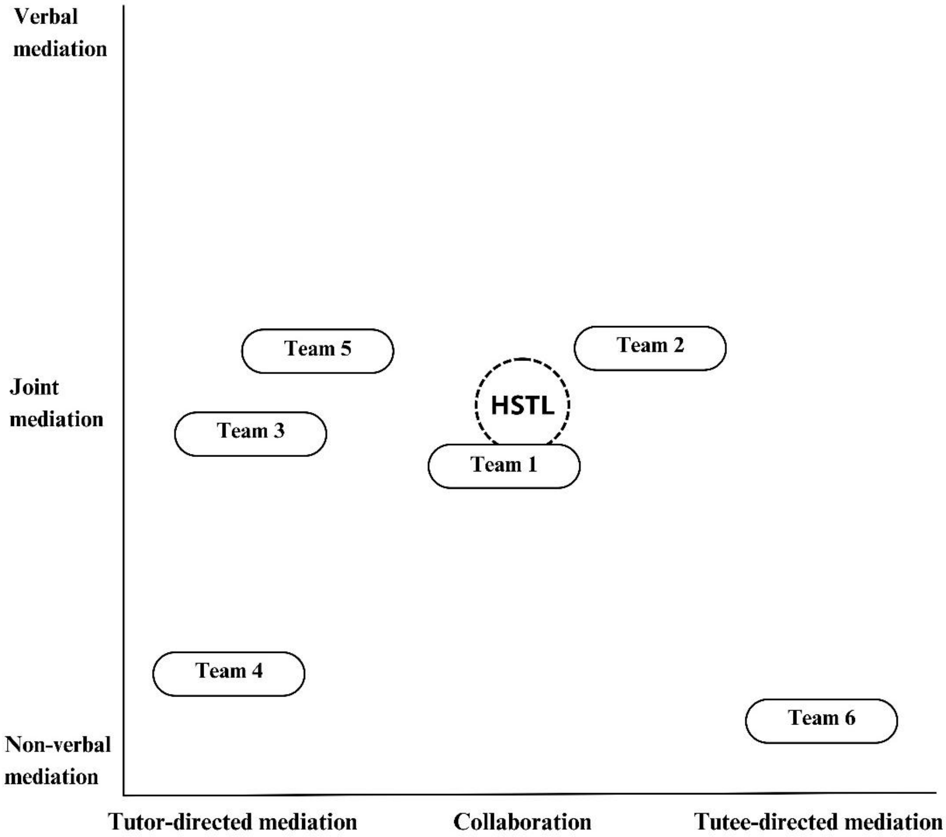


Figure 10. Cross-age Teams in relation to HSTL

To develop cross-age peer tutoring as a pedagogical practice and achieving this hot spot to support technological literacy, the study concludes the following practices in STEAM education: (1) integration of verbal and non-verbal mediation, (2) facilitation of collaborative actions combining tutor and tutee-directed mediation practices, (3) organisation of activities in small groups or asymmetrical pairs, and (4) focus on enhancing tutors' individual expertise in both the content and the methods for mediating it effectively.

Limitations

The mediation practices identified in this study cannot be generalised to a wider context due to the small sample of teams, all drawn from a single school. Small sample sizes and limited numbers of dialogues are also recognised as challenges inherent in micro-level analysis (Ash, 2007). Nevertheless, the study provides valuable insights into the pedagogical practice of tutoring ER activities within Finnish STEAM education. Ash (2007) emphasised theory-driven selection of methods when conducting micro-level analysis of video material. The ER intervention and the Sphero Indi task were grounded in theories of AMTL and constructionism (Garmire & Pearson, 2006; Papert, 1980), incorporated peer tutoring and collaboration research (Tenhovirta et al., 2022; Yliverronen et al., 2018), and focused explicitly on mediation (Vygotsky, 1978; Wertsch, 2007), thereby enhancing the credibility and value of the findings. However, the themes in the analysis schema were sometimes overlapping, and in the absence of a definitive theory for interpreting meanings, the results cannot be considered standardised (Schreier, 2012).

The teacher-researcher positionality of this study is explicitly acknowledged. As Greca Dufranc et al. (2020) noted, collaboration and effective communication in peer interactions during ER activities require careful preparation. Accordingly, the ER intervention was meticulously planned, and the training process for the tutors was conducted consistently across all participants. Teaching during the ER intervention focused on programming content and ER, not on mediating practices. To enhance the credibility and authenticity of the findings, instruction during the ER intervention focused on programming content and ER rather than on how to mediate activities to young learners. Kennedy-Lewis (2012) highlighted the challenge faced by teacher-researchers in defining their dual role as practitioner and scholar, particularly regarding the extent of participation and support in the research setting. In this study, the teacher-researcher provided minimal instructional support, intervening in teams' activities only when necessary. The guidance provided to tutors followed Sisman et al.'s (2022) principles of indirect support, avoiding direct contribution to learners' task performance.

Consistent with previous research (Berghmans et al., 2013; Tartas & Perret-Clermont, 2008), the tutors in the current study employed various mediation practices. One possible explanation is that, as the intervention did not provide explicit guidance on mediation practices, the tutors had to develop their own approaches based on individual expertise, prior knowledge, and previous experiences. This study did not examine the tutors' individual orientation towards learning or their intrinsic motivation for ER. Previous research suggests that in science learning and ER, learners' intrinsic interest in the content plays a significant role (Kang & Kim, 2024; Tsagaris et al., 2019). Collaborative ER has also been shown to enhance critical thinking, STEAM interest, and self-efficacy in learners of the same age as the tutors in this study (Mosley et al., 2016). To better understand the origins of tutors' mediation practices and to guide cross-age peer tutoring practices towards the HSTL, future research should investigate tutors' individual orientation and motivation for learning technology more closely.

Recommendations

To support technological literacy, future STEAM research and practice should consider creating more opportunities for non-verbal mediation and the use of material stimuli. From both the research data and analysis perspectives, incorporating the Indi instruction cards and challenge cards into the ER learning task proved effective. Future studies should include tasks that involve challenges and problem-solving rather than step-by-step instructions, as this would allow for a more detailed investigation of tutors' mediation practices. Additionally, supplementary tools – such as grid mats for hands-on ER (cf. Cervera et al., 2020) or empty tiles and tiles with question marks – could enhance both the tutors' mediation practices and young learners' engagement and learning outcomes.

Verbal mediation aiming to promote tutees thinking should prioritise open-ended questioning, encouragement to experiment, and fostering of a positive atmosphere through empathy and individual attention – factors recognised in previous research on young learners' STEAM (Korkeaniemi et al., 2023; Nemiro, 2021; Tzuriel, 2021). To facilitate the mediation process, providing tutors with a list of key open-ended questions could be beneficial. Embodied interaction has been found essential in collaborative STEAM for young learners (Yliverronen et al., 2018).

In the current study, explicit roles for the tutors were not predetermined. Yliverronen et al. (2018), for instance, identified four roles in children's design tasks, based on their level of participation: leader, partner (co-leader), follower, and observer. Within cross-age peer tutoring, tutors are expected to assume the expert role of providing guidance to their younger peers (Tenhovirta et al., 2022). Assigning roles or deliberately dividing responsibilities prior to the tutoring session could emphasise collaboration in ER activities – a practice found beneficial in earlier collaborative ER research (Demetroulis et al., 2023; Nemiro, 2021). Shared responsibility between the tutor and learner is a key element of effective collaboration and mediation (Tartas & Perret-Clermont, 2008). Thus, predetermined roles are recommended in tutoring practices.

The current study recommends that focusing on tutors' individual competencies is critical when tutoring young learners in ER activities. In addition, a more thorough training of tutors on how to mediate the tutees in a way that promotes technological literacy – and how to avoid simply acting as directive teachers – is recommended. The cross-age ER activities concluded the four-week ER intervention for the tutors. From the tutors' perspective, three weeks of learning the basics of programming and robotics may represent a relatively narrow timeframe. From young learners' perspective, small-scale integration of ER with tutors may be important to stimulate thinking (Cervera et al., 2020; Sung et al., 2023).

Statements and Declarations

Acknowledgments/Notes: The article is derived from the dissertation thesis of the first author. During the preparation of this article use of AI was avoided. The authors used Microsoft Copilot to provide language editing and proofreading on individual sentences. All suggested revisions were reviewed and edited with human-centred approach. The authors take full responsibility for the content of the publication.

Author Contributions: The first author had main responsibility for designing the study, collecting the data, conducting the data analysis and implementing the educational robotics intervention. The second author contributed to writing the theoretical background and discussion sections. The third author collaborated with the first author in conducting the data analysis. The fourth author provided proofreading and language editing for the manuscript. All authors have read and agreed to the published version of the manuscript.

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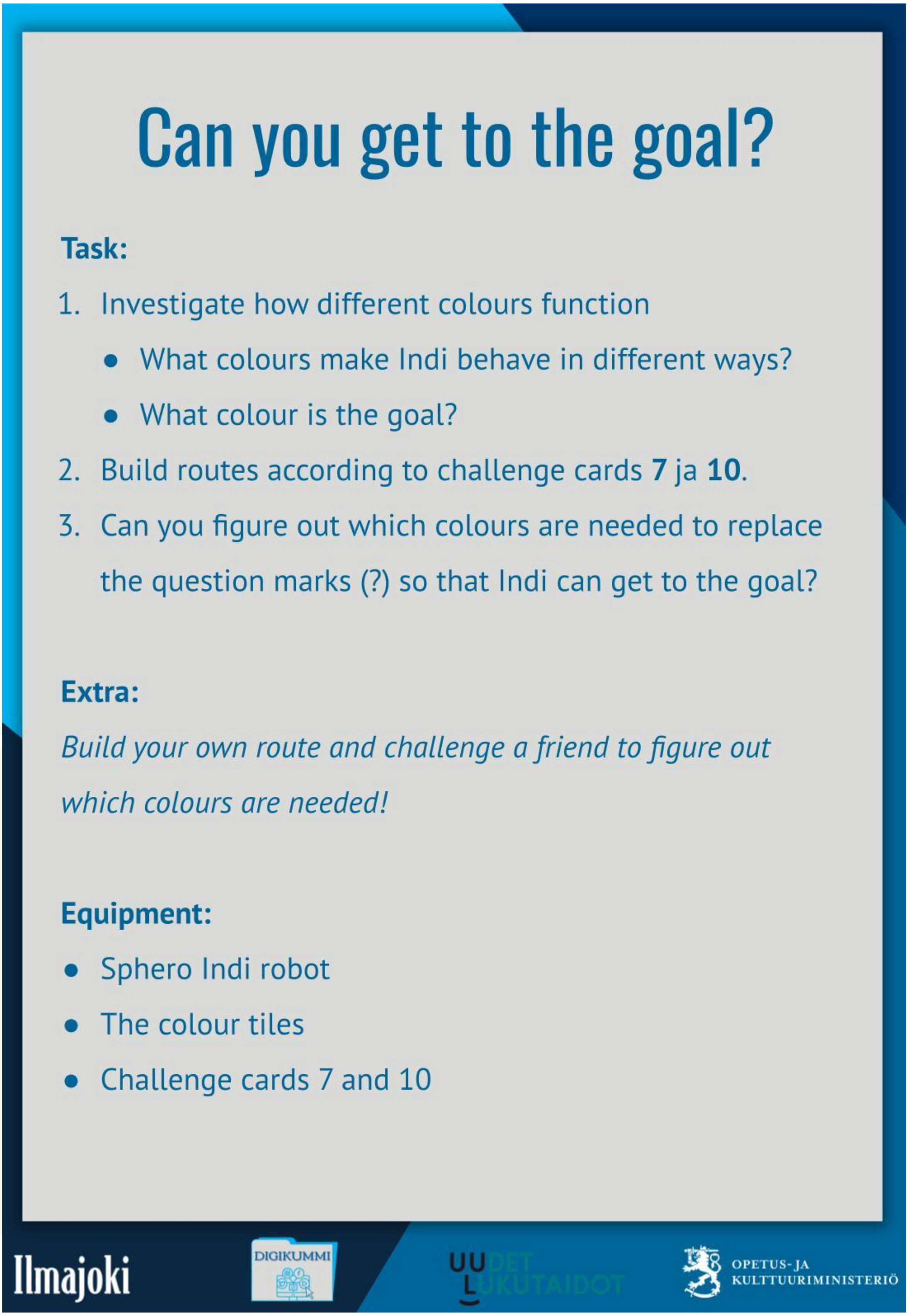
Appendix A. The Sphero Indi Task Sheet



Can you get to the goal?

Task:

1. Investigate how different colours function
    - What colours make Indi behave in different ways?
    - What colour is the goal?
2. Build routes according to challenge cards **7** ja **10**.
3. Can you figure out which colours are needed to replace the question marks (?) so that Indi can get to the goal?

Extra:

Build your own route and challenge a friend to figure out which colours are needed!

Equipment:

- Sphero Indi robot
- The colour tiles
- Challenge cards 7 and 10

Appendix B. Units of Analysis for All Six Cases after the Classification

	Team 1		Team 2		Team 3		Team 4		Team 5		Team 6		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Verbal mediation	*138**	*43**	*103*	*47*	*87*	*45*	*26*	*26*	*97*	*47*	*29*	*15*	*480*	*39*
Linear instructions	37**	27**	37	36	32	37	22	85	32	33	9	31		
Questioning	26	19	18	17	18	21	0	0	16	16	3	10		
Experimentation	35	25	15	15	6	7	0	0	6	6	4	14		
Individual attention	25	18	9	9	7	8	2	8	10	10	4	14		
Humour	5	4	4	4	6	7	0	0	27	28	2	7		
Confirmation or denial	10	7	20	19	18	21	2	8	6	6	7	24		
Non-verbal mediation	*163*	*50*	*86*	*40*	*97*	*50*	*55*	*55*	*79*	*39*	*131*	*68*	*611*	*50*
With the Indi robot	26	15	22	26	18	19	15	27	15	19	27	21		
The colour tiles	46	28	13	15	49	51	21	38	20	25	46	35		
The Indi instruction cards	26	16	15	17	5	5	0	0	6	8	3	2		
The Indi challenge cards	30	18	17	20	3	3	0	0	6	8	15	11		
The task sheet or cheat sheet	0	0	0	0	1	1	10	18	1	1	6	5		
Gestures	35	21	19	22	21	22	9	16	31	39	34	26		
Off-task activities	*22*	*7*	*28*	*13*	*11*	*6*	*19*	*19*	*29*	*14*	*33*	*17*	*142*	*11*
Distraction	7	32	11	39	4	36	2	11	12	41	5	15		
Frustration	0	0	12	43	3	27	6	11	0	0	6	18		
Teacher interference	5	23	5	18	2	18	4	21	0	0	15	45		
Tutors' collaboration	10	45	0	0	2	18	7	37	17	59	7	21		
Total units	*323*		*217*		*195*		*100*		*205*		*193*		*1233*	

* Units and percentages within Team's total units
** Units and percentages within topics