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Unveiling young children's collaborative communication in hands-on problem-solving

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Abstract

Collaborating and solving multi-level problems are pivotal skills that education should emphasise from the early years. Previous studies of young children's collaboration have highlighted language as a key factor. However, young children often struggle to articulate their ideas verbally in collaborative situations due to their developing language skills. This communication challenge is particularly prevalent in inclusive classes with diverse skill levels and learning needs. This study investigates the collaborative communication of 4-6-year-olds during a hands-on, collaborative problem-solving task where 15 teams ($N=49$) from three inclusive early childhood education (ECE) groups built towers without teacher support. Video recordings of four teams were selected for detailed analysis to demonstrate various collaboration methods. The multimodal analysis was employed to identify verbal and nonverbal interactions, actions, and problem-solving stages, and co-occurrence network analysis was used to capture the nuances of the team process over time. The findings revealed that embodiment, materiality, peer support, and examples were vital to the children's hands-on problem-solving process. Although all teams could work according to the assignment, we identified four examples of developing collaboration: solitary problem-solving without collaboration, side-by-side interaction as a step toward collaboration, actions as a means of collaboration, and goal-oriented, verbally interactive collaboration. The study highlights the need for ECE to broaden the pedagogical understanding of teaching and learning methods of young children. Along with teacher-led teaching, children should be offered opportunities to focus on collaborative problem-solving that promotes ownership of learning, encourages children to work together on open-ended challenges, as well as to practice and learn communication skills.

Keywords Collaboration · Co-occurrence network analysis · Collaborative communication · Hands-on problem-solving · Multimodal analysis · Young children

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Introduction

Collaboration refers to a situation in which participants actively and synchronously work together, employing various methods to solve a problem or build common knowledge to reach a shared goal (Fawcett & Garton, 2005; Hennessy & Murphy, 1999; Sormunen et al., 2023a). This process allows participants to generate shared meaning and understanding when participating in domain-specific activities (Sjöberg & Brooks, 2022). Previous studies of young children's collaboration have focused on language, highlighting it as a key factor for the implementation of it (e.g., Thompson & Moore, 2000; Vygotsky, 1978). Additionally, research has explored the roles of social relationships and friendships (e.g., Kimhi & Bauminger-Zviely, 2012; Pino-Pasternak et al., 2018; Svinth, 2013); joint ideation and knowledge building (e.g., Sjöberg & Brooks, 2022); and activities framed within specific contexts, such as computer-aided tasks or challenging puzzles (e.g., Butler & Walton, 2013; Lim, 2012). However, young children often struggle to articulate their ideas verbally in collaborative situations (Vriens-van Hoogdalem et al., 2016) due to their developing language and communication skills. This challenge is particularly evident among bilingual children (Vriens-van Hoogdalem et al., 2016) and those with special educational needs (Jamison et al., 2012). Such barriers are common in inclusive early childhood education (ECE), which is intended to identify and remove obstacles to participation while prioritising the inclusion of vulnerable groups, such as minorities and marginalised groups (Ainscow, 2020; UNESCO, 2016). Recent research has expanded to examine young children's collaboration and problem-solving through the lens of technological learning tools, including gameplay and design (e.g., Danby et al., 2018; Sjöberg & Brooks, 2022), robotics (e.g., Sullivan & Bers, 2016), human-robot interaction (e.g., Charisi et al., 2020), and artificial intelligence (e.g., Yang, 2022). Despite research advancements, the full range of young children's communication (e.g., speech, gestures, and embodied expressions) in collaborative situations remains insufficiently studied, even though communication between children is closely linked to their social and cognitive collaboration. Here we use the term collaborative communication, which is characterised by mutual engagement, where participants support each other verbally, especially in an interactive, structured environment (Feudtner, 2007; Hurlburt et al., 2025).

The ability to collaborate and solve multi-level problems is a pivotal twenty-first-century skill that the OECD (2017) has recognised as critical to efficiency, effectiveness, and innovation in the modern global economy (Griffin & Care, 2015). While collaboration is key to social and cognitive development, knowledge about young children's face-to-face interaction in various forms is imperative, especially in ECE, during which children's language and collaboration skills are still developing, especially in the material world of problem-solving. Understanding how young children engage in complex dynamics is essential to developing fluent collaboration skills (Pino-Pasternak et al., 2018; Vriens-van Hoogdalem et al., 2016).

The present study was intended to investigate how collaboration occurs in 4–to 6-year-old children's hands-on problem-solving process as they co-create a joint artefact in 2–4 4-child teamwork. The term "hands-on learning" is typically used to refer to experiential learning or learning by doing, which encourages all kinds of children to participate, share expertise, and practice collaborative competence on a deeper level (Yliverronen et al., 2018). It is assumed in this study that in the absence of ECE teacher guidance during the problem-solving process, children must find a way to collaborate among themselves (Mercer & Littleton, 2007).

This study examines children's communication during collaborative activities during collaboration without prior expectations, hypotheses, or guiding the children, except for a short assignment. The aim is to investigate, as authentically as possible, how children organise their collaboration in a familiar environment when solving a given problem (Meinefeld, 2004). More precisely, the study addresses the following research questions:

1. What kind of collaborative communication can be identified in teams' activities during their problem-solving processes?
2. What forms of developing collaboration can be found in children's collaborative processes?

Before presenting further details regarding the methodology and findings, we will elaborate briefly on the theoretical perspective on young children's collaboration and early hands-on problem-solving, which is the basis for the empirical data used in this study.

Young children's collaboration and communication

Children are naturally interested in one another and willing to work together (Butler & Walton, 2013; Lillemyr et al., 2011). Collaboration between children typically occurs in informal situations, such as play and games. Research conducted by Parten (1932) and others (e.g., Scarlett et al., 2005) indicates that participation in social interactions tends to increase with age. Hierarchical play is established when a young child moves from a less complex, singular type of play (solitary play) to a more involved, partner-dependent type of play (parallel and associative play) and then to cooperative play (Jamison et al., 2012). Furthermore, Jamison et al. (2012) highlight that children with disabilities affecting their verbal, cognitive, and physical development may encounter challenges when attempting to achieve higher levels of play. Likewise, collaborative tasks aimed at young children can be integrated into various contexts and activity goals. However, they all share the playfulness and the importance of play in common, as young children possess skills that enable joint action and a common framework (Kimhi & Bauminger-Zviely, 2012; Vygotsky, 1978). Therefore, learning is linked to the strong aspects of the child's developmental stage (e.g., imagination, social skills, and linguistic development), and children can perform even demanding tasks collaboratively (Pramling Samuelsson & Asplund Carlsson, 2008).

A shared understanding is typically created through language, a dominant tool for doing, speaking, acting, and thinking (Mejía-Arauz et al., 2018). Language is used to present ideas, interpret experiences, and construct explanations. Children's linguistic expression skills are of considerable importance not only for the success of a joint activity but also for their motivation to participate in collaborative activities (Laitinen et al., 2017). Because children often lack the words to express themselves verbally in social situations (Vriens-van Hoogdalem et al., 2016), they use non-verbal communication, such as gestures and embodied expressions, to support their speech. The use of gestures (Wu, 2013) is an essential part of children's speech development, speech-supporting expressions, and play related to speech in face-to-face interactions (Mulvihill et al., 2021; Vygotsky, 1978). Pointing with a finger, nodding or shaking the head, or describing an idea with a hand movement are typical expressions children use as part of their communication (Hostetter & Alibali, 2008; Kita et al., 2017).

The development of gestures is closely related to the development of language skills, and gestures enhance language development; they also support spoken expression and improve young children's concept acquisition (Capone & McGregor, 2004; Iverson, 2010).

Early-years hands-on problem-solving

The concept of problem-solving refers to the ability to produce something new, a curious and open-minded mindset, and the process through which problems are solved (Sawyer, 2021). Vygotsky (1978) described problem-solving as a characteristic social skill of humans that is learned through social interaction. A typical problem-solving process involves identifying a problem, conducting research, designing and implementing the most suitable solutions, and evaluating their effectiveness (Diamond, 2018; Sawyer, 2021). According to Sawyer (2021), from the moment of insight to that insight's implementation, a problem-solving process is not linear because problem-solvers face unpredictable changes. New things are identified, perceptions of the problem often change, and further questions and ideas arise. Discussing and sharing ideas supports learning in many ways, such as fostering deep understanding and multiple ways of thinking (Sawyer, 2018).

Young children possess a natural ability to imagine, invent, and create so that they can grasp a wide range of concepts through concrete, hands-on experiences (Turja et al., 2009; Vygotsky, 2004). They develop problem-solving skills through concrete making, in which they can identify problems relevant to their own experiences, break them into smaller sub-problems, explore various solutions, and practically test and implement their ideas (Fox-Turnbull, 2019). This process often extends beyond trial and error, incorporating everyday peer interactions. Collaboration and dialogue play a crucial role in helping young children externalise their thoughts, share ideas, and refine their reasoning and verbal skills (Fox-Turnbull, 2019; Mercer & Littleton, 2007). In fact, Hong and Diamond (2012) show that problem-solving strategies adopted in the early years include modelling, imitation, and parallel play. A diverse range of material resources, combined with imaginative environments and hands-on activities, support learning in the early years (Mehto & Kangas, 2022) and form a pedagogically rich environment (Dere, 2019; Sormunen et al., 2023a). Furthermore, engaging with materials emphasises problem-solving when children are able to use various materials during the problem-solving process (Sundqvist & Nilsson, 2018). Therefore, the problem-solving task is also a learning environment for interaction and participation.

A wide variety of learning tasks entangled with problem-solving and hands-on elements can be created based on imaginative environments and hands-on activities (Kangas et al., 2022; Sormunen et al., 2023b; Vartiainen et al., 2024). These kinds of activities support making and learning for one another, negotiations, and problem-solving related to the task when children often work in their zone of proximal development (ZPD) with support from more competent peers (Vygotsky, 1978). The strength of hands-on activities lies in their ability to combine procedural problem-solving activities with talking and providing feedback to peers, while simultaneously generating concrete results (Hennessy & Murphy, 1999). In hands-on problem-solving tasks, team members regulate their activities by encouraging one another, dividing work tasks, and resolving difficulties and disagreements. The joint material object encourages children to negotiate, seek compromise, work together, and maintain team cohesion, which can be harnessed to support children's social participation. In addition, previous research with primary-school-aged children indicates that children with diverse working styles or orientations often collaborate productively. This may provide an encouraging example for children still developing these skills (Yliverronen et al., 2018; Webb et al., 1998).

Methods

The present study was intended to investigate, as authentically as possible, how children organise their collaboration in a familiar operating environment when solving a given problem. The present study was conducted in Finland, where high-quality ECE covers ages 0 to 6 (i.e., the first years of a child's life, from infancy until the beginning of elementary school). ECE is mainly implemented in ECE units in multi-professional teams consisting of at least one teacher with an academic bachelor's degree and two assistant teachers with lower educational degrees. Finnish ECE fosters an inclusive environment that encourages all children's full participation, ensuring that pedagogical support is tailored to meet each child's diverse needs, creating a suitable setting for every individual (Harju-Luukkainen et al., 2022; UNESCO, 2016). The study concentrated on a municipality-maintained ECE unit in an urban area of Western Finland in the spring of 2023. The four participating ECE groups of 4–6-year-olds were inclusive: there were children with various demographic backgrounds and learning needs (see Harju-Luukkainen et al., 2022).

Participants and ethical considerations

The research procedure adhered to the Guidelines for Ethical Review in the Human Sciences (Finnish National Board on Research Integrity, TENK, 2021), and participation in the study was entirely voluntary. In line with Johnson and Christensen (2014), the parents, who acted as the participants' legal guardians or next of kin, provided written informed consent, granting permission for their children to participate in this study. The parents provided written informed consent, granting permission for their children to participate in this study. They were fully informed about the study, the data being collected, how they would be used, and the possibility of withdrawing from the study at any point. The ECE unit's staff obtained research permits to protect the privacy of guardians and children.

Of 49 children with their guardians from the ECE units, four different groups (4–6-year-olds) were permitted to participate in the study. Each group's teacher assembled 15 teams randomly, using four 4–to 6-year-old ECE groups, taking the research permits into account. We relied on the teacher's pedagogical expertise and understanding of the children when assembling the teams and did not provide any specific instructions. To protect children's anonymity (Farrell, 2016), the researchers did not have access to the children's identification information (such as names and gender); they only had information regarding the children's age group and the ECE teachers' descriptions of the teams to protect children's privacy and anonymity (Council of Europe & European Union Agency for Fundamental Rights, 2022; Farrell, 2016).

After the data collection began, the researcher explained the research procedure to the children in an age-appropriate manner (Johnson & Christensen, 2014). The children were informed that they could tell the researcher to stop filming and documenting their actions at any point. Because the study involved young children, researchers paid careful attention to children's nonverbal signs indicating potential discomfort with being filmed.

Data collection procedure

The researchers designed the activity for data collection, connecting the problem-solving task to the National Core Curriculum for ECE and Care (Finnish National Agency of Education [FNAE], 2022) and Pre-Primary Education (FNAE, 2014). In particular, it was based on the learning areas "exploring and interacting with the environment" and "emphasising children's personal observations, experiences, and meaningful encounters in the learning environment," which help children understand cause-and-effect relationships and develop as thinkers and learners. The activity also considered the pedagogical guidelines of the curriculum, which promote children's curiosity and eagerness to explore, experiment, and participate in practical activities (FNAE, 2014; 2022). The problem-solving task and the data collection procedure were pilot-tested with a team of four 5-year-old children in a different ECE unit.

Approximately one week before the data collection, all the children were read the classic fairytale "The Three Little Pigs" (adapted from Sullivan & Strawhacker, 2021) to activate their thinking schemas. The eight ECE teachers (academic bachelor's degree) carried out this initial phase with their groups of children according to the researchers' instructions and teaching materials, which were designed to support teacher-led learning discussions. The teaching material included a PowerPoint presentation of images of buildings, some of which were structurally weak, such as huts made of hay and twigs. In contrast, others were strong, such as the Eiffel Tower. Each slide included guiding questions that helped the children examine the structures and facilitate discussion about how the structures remain standing. Before the data collection began, the teachers confirmed that they had introduced the theme to the children as instructed.

The second and third authors collected the data over four days during the following week in two separate rooms. At the beginning of each team's data collection session, the researcher gave the children a problem-solving task that somewhat resembled the original tale: "Help the three little pigs build the highest possible lookout tower, from which it will be easy to see the wolf coming." This narrative framework for the collaborative problem-solving task aimed to spark the children's imagination (Sormunen et al., 2023b). In accordance with Finnish ECE pedagogical practices, the children were offered lightweight, safe, and easy-to-use materials, including paper straws and plasticine, newspaper rolls, wooden blocks, and sticks for construction (Sormunen et al., 2023b). More details of the materials are shown in Fig. 1. The joint discussion of the task lasted about 5 min.

The 15 teams were allotted a maximum of 20 min for the problem-solving task. All teams were given the exact instructions: "You have all the materials on the table (shown earlier) to use. You must consider building a tower as high as possible so the wolf cannot blow it down." Initially, PowerPoint images were projected onto a wall to support the team's problem-solving process. The teams did not have the opportunity to see the creations of other groups before, during, or after the process. They were allowed to discuss the construction task freely afterwards; however, this was not considered relevant to the study. Finally, the teams assessed the durability of the towers with the researcher by blowing on them with a hair dryer, representing the wolf.

Material	Quality	Number
Wooden stick	diameter 1 cm	20
Wooden ice cream stick	length 15 cm	30
Wooden blocks (pine tree)	measures 5 cm x 3 cm x 2 cm	8
Grill skewers (sharp end removed in advance)	diameter 3 mm	30
Cardboard roll	length 20 cm, diameter 4 cm	10
Cardboard straw	length 20 cm	30
Newspaper rolls	fastening with tape	10
Homemade plasticine balls	diameter 2-3 cm	30
Tape strips	length 4 cm	10

Fig. 1 Data collection setting and materials for the problem-solving task

We utilised the approach of Derry et al. (2010) to select rich cases for in-depth analysis. When a study aims to explore a particular phenomenon in depth, it is crucial to choose groups that accurately represent that phenomenon. According to Derry et al. (2010), the selection of video material should be purposeful rather than random, guided by specific research questions and theoretical underpinnings. While this study does not aim for generalizability, the selected cases must be both theoretically and contextually representative to enable justified conclusions. The process of choosing rich cases was as follows.

After data collection, the first three authors engaged in a discussion where the second and third authors outlined the problem-solving processes of all 15 teams for the first author, emphasising the unique characteristics of each team. They also reviewed excerpts of the teams' work, paying particular attention to the interactions and collaborative actions among the children. During this phase, it became evident that the videos of the teams displayed considerable similarities. Based on this discussion, four teams were selected as the most representative of the entire dataset for a detailed analysis. The chosen teams demonstrated the most distinct behaviour patterns in their activities and seemed to implement various collaboration methods. The teams also consisted of children at various support levels, enabling us to depict the diversity of inclusive groups. Information about the composition and characteristics of the teams was obtained from the ECE teachers during the data collection days. Team A consisted of two 4–5-year-old children who often played together. Team B included four 4–5-year-old children who required additional learning support, especially practice in considering others. This team's ECE teacher wanted to be present during the activity to ensure that the children had a familiar adult on hand. Teams C and D were from the same group. Their ECE teacher assembled these teams based on timetables. Both teams consisted of three 6-year-olds who typically do not seek to play with one another in play situations.

Data and analysis

The empirical data consisted of four teams' video recordings during tower construction. Video recording is an appropriate method of studying hands-on problem-solving situations because it makes many small phenomena and events visible (Walsh et al., 2007). With the help of video, it is possible to record the activities of a child group in a space in which they move from one place to another, and the situation includes a wide variety of interactions (Hedegaard et al., 2008). Each team's construction was recorded using two cameras. One camera was integrated into the classroom's recording system, while the other was placed adjacent to the children's construction area on the floor (Table 1).

The data analysis proceeded iteratively in three phases (Fig. 2). To improve external validity and reliability, all authors participated in the data analysis process and agreed on the analysis procedures (e.g., Derry et al., 2010). The following subsections describe the data analysis phases in more detail.

Phase 1: transcriptions

In the first phase, the first and second authors transcribed one team's video recording into episodes, each lasting 30 s. However, the children's actions were quick and often involved simultaneous thinking, resulting in segments that were too lengthy. Consequently, attempts were made to create 10-second and 5-second episodes, with the 10-second duration proving to be the most effective for capturing the phenomenon. As a result, the final episodes were set to 10 s and recorded verbatim in an Excel spreadsheet. Then, the second and third authors carried out the final transcription of the other three teams. Each team's video record-

Table 1 Background information and data of participating teams

Team	Children on the team	Length of recording (min: s)	ECE teacher's description of the team	ECE teacher's role
Team A (4–5-year-olds)	2	10:31	Children typically play a great deal with one another.	Not present
Team B (4–5-year-olds)	4	10:16	All children require additional support with learning and regular practice in considering the needs of others. Children usually do not seek to play with one another.	Present
Team C (6-year-olds)	3	14:03	Children typically do not seek to play with one another.	Not present
Team D (6-year-olds)	3	13:42	Children typically do not seek to play with one another.	Not present
Total	12	48:32		

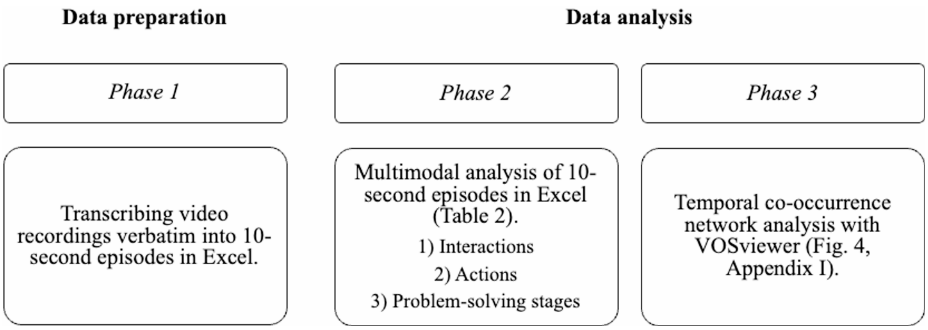

Fig. 2 Phases of the data preparation and analysis

ings lasted approximately 10–14 min, resulting in a total of 48 min and 32 s of footage. This amounted to 291 individual 10-second episodes, in which each child's speech was written in the appropriate column, leaving the cells for speechless moments blank. During the transcription, we found that verbal interactions between children were limited in the unfamiliar test situation. However, we noticed that the blank episodes contained many nonverbal interactions and actions. These notions were considered in the next phase.

Phase 2: multimodal analysis

In the second phase, the transcriptions were enriched using a multimodal analysis grid created by Taylor (2014) from three perspectives: interactions, actions, and problem-solving stages. The aim was to determine how collaboration is present between children, how the collaboration develops during the problem-solving process and individual differences in the teams' problem-solving processes. The procedure followed a similar path to Phase 1, with the first and second authors conducting the preliminary analysis, while the second and third authors conducted the final analysis. To implement investigator triangulation (Archibald, 2016) and to determine the interrater reliability of the classification, the fourth author, who was not present in the data collection, independently coded the same video materials. The second author and fourth author discussed the findings and minor differences regarding interpretation and refined the code names. Finally, the analysis process was discussed among all researchers until a consensus was reached.

The first labelling of the 10-second episodes focused on verbal (Mercer & Littleton, 2007), non-verbal (Hostetter & Alibali, 2008), and embodied interactions (Vriens-van Hoogdalem et al., 2016; Wu, 2013), and the second focused on children's actions (Danby et al., 2018; Pino-Pasternak et al., 2018). The children's actions were further analysed to determine their problem-solving stage (Diamond, 2018; Sawyer, 2021). The findings comprised 794 entries. Six types of verbal and one type of non-verbal (embodiment) interaction were identified. Because the 4-year-old children were still developing linguistically, creating an embodiment code that included all non-verbal forms of interaction seemed necessary. This embodiment code included facial expressions and gestures, expressions of emotion, and a look that enhanced communication. In addition, eleven types of actions and four problem-solving stages (Table 2) were identified.

Table 2 Coding framework

Category	Code	Indicative behavior
Interaction	Asking help	Voluntarily requesting help
	Cooperation initiative	Requesting cooperation verbally
	Embodiment	Non-verbal interaction (e.g., showing facial expressions and gestures, expressions of emotion, or a look that enhances communication)
	Feedback	Giving positive or negative verbal feedback, commenting
	Idea	Presenting an idea verbally
	Offering help	Voluntarily offering help verbally
	Self-reflection	Reflecting on one's actions, speaking out loud, speaking privately
	Strategy	Proposing a strategy of action verbally
Action	Assisting	Providing assistance, "a helping hand" collecting materials for joint work
	Collecting materials	Fetching, bringing, taking, collecting, thinking about material choices
	Demonstration	Explaining and showing the structure/idea, material, or structure experiments
	Imitation	Promoting cooperation through activity/model
	Making own product	Making own product, testing
	Making joint product	Making a joint product, testing
	Monitoring	Watching others' activities, watching materials
	Movement	Moving from one place to another
	Off-task	Being out of action, playing, talking about things unrelated to the task
	Surrogate function	Performing irrelevant functions that do not promote the own or joint product
	Wordless participation and observing (WPO)	Observing action nonverbally, belonging to a team
Problem-solving stage	Evaluate	Looking at the almost-finished tower, appearing in the final phases of the process
	Improve	Assessing almost-ready construction, appearing in the final phases of the process
	Make	Building a tower
	Think	Reflecting on the task and thinking about solutions and subsequent steps

Phase 3: temporal co-occurrence network analysis

In the third data analysis phase, the data was summarised in graphical form using temporal co-occurrence network analysis to determine the relationships between children's interactions, actions, and problem-solving stages. Temporal co-occurrence network analysis enables the detection of connections between forms of collaboration and their potential targets and helps in understanding complex data (Sormunen et al., 2019). Traditional co-occurrence network analysis has been applied in education involving social networks to enhance our understanding of social relationships in classrooms (Grunspan et al., 2014) and disciplinary and interdisciplinary learning (Kangas et al., 2022; Sormunen et al., 2023a).

Because the object of interest in this study was children's interactions and actions during various stages of the problem-solving process, we adopted Mercer's (2008) perspective on the importance of examining the temporal dimension in interactions between children to understand their nuances.

The temporal co-occurrence network graphs were constructed with VOSviewer, an open-source software for data visualisation (Waltman et al., 2010), typically used for constructing and visualising bibliometric networks. Following a bibliographic data analysis procedure using the default attributes provided by the software (van Eck & Waltman, 2012) allowed us to view the complex multimodal analysis visually with temporal co-occurrence network graphs. For the analysis, the original multimodal analysis coding form was converted into a bibliographic database file (Scopus file type), in which the time entry was expressed in the publication year column, a child in the first author column, and code categories as keywords (Fig. 3). Because the time entries of the teams' work varied from 49 to 81 in number, time entries were divided evenly into three periods (in the year column: beginning 1, middle 2, and end 3). This allowed us to differentiate the time required to start work, the time taken to build the tower, and the time needed to complete the problem-solving process. As a unit of analysis, author keywords were used, and the full counting method was applied, in which each co-occurrence link had the same weight. The relatedness of items was determined based on the number of projects in which they occurred together, resulting in a network of 23 keywords, with a minimum of two co-occurrences per keyword. The keywords were mapped and clustered into a final temporal network graph based on occurrences and link strength (Fig. 5; Appendix Table 3).

Multimodal analysis				
Time entry	*Child*	*Interaction*	*Action*	*Problem solving stage*
00:10	Yellow	Idea	Collecting materials; monitoring	Think
00:20	Yellow	Idea; embodiment	Demonstration	Think
00:30	Yellow		Demonstration; monitoring	Think
00:40	Yellow		Collecting materials	Think
00:50	Yellow		Making own product; monitoring	Make

Temporal co-occurrence network analysis		
*Year**	*Author*	*Keywords*
1	Yellow	Idea; collecting materials; monitoring; think
1	Yellow	Idea; embodiment; demonstration; think
1	Yellow	Demonstration; monitoring; think
1	Yellow	Collecting materials; think
1	Yellow	Collecting materials; monitoring; think

*Year refers to the stages 1 to 3 of the process.

Fig. 3 Example of converting a multimodal analysis coding sheet for temporal co-occurrence network analysis in VOSviewer

Findings

The present study investigated, as authentically as possible, how 4–6-year-old children organised their collaboration in a hands-on problem-solving process without adult scaffolding. All teams succeeded in building, the heights varying between 20 and 41 cm (Fig. 4). The teams with the youngest children, 4–5 years old, build the towers of the highest (Team A) and the lowest (Team B). Team B (children with additional support needs) built the lowest tower, which was also the most durable and remained standing throughout the test. Their tower was constructed from six wooden blocks and five wooden sticks on the tower's edges. In teams of 6-year-olds, where the participants did not typically play together according to the teachers' descriptions, Team C's 40-cm joint product survived the blowing test. It was made of cardboard rolls, plasticine, wooden sticks and blocks, and a triangular support structure, like the Eiffel Tower, which narrowed toward the top of the tower. In Team D, each child worked on their own tower, and the highest of them was 32 cm, and survived the blowing test. Its lower part was formed by six wooden blocks, on top of which a cardboard roll was attached to plasticine. However, the collaborative efforts could not be detected simply by considering the outcome of the task, the children's ages or their ability to play together. The episodes of each team's process reveal nuanced and varied processes within each team. In the following, we report the findings regarding the collaborations in accordance with the research questions, using excerpts from the children's verbal interactions.

Teams' collaborative methods during the Problem-Solving process

To answer the first research question regarding how the teams collaborated during their problem-solving processes, we analysed 48 min and 32 s of video data with 794 analysis entries. Appendix Figure 7 provides a detailed description of the identified interactions, actions, and problem-solving stages and their frequencies.

The data contained most of the expressions in the action category (41.3% of all expressions). *Making own products*, *collecting materials*, and *making joint products* were the most predominant codes in the action category. Although embodied activities are an integral part of ECE, the data also showed a great deal of verbal and non-verbal interaction among the children. In the interaction category (20.0% of all expressions), non-verbal *embodiment* and verbal *feedback* were most prominent in the data. The various ways of helping included *ask-*

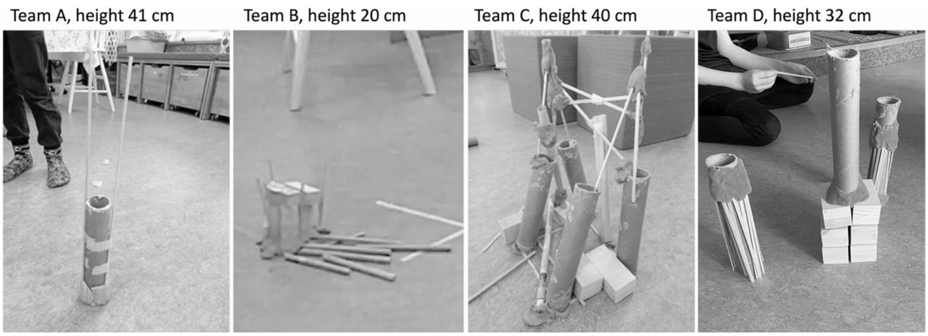

Fig. 4 The towers constructed by the teams and their respective heights

ing for help and *offering help*. Among the problem-solving stages, *making* could be identified from the children's work, and *thinking* could also be observed.

The most central codes of the analysis categories are shown in Fig. 5, which illustrates the complete temporal network of co-occurrences between all teams' interactions, actions, and problem-solving stages (see also Appendix Table 3). Codes occurring frequently in the data appear prominently. The two largest, most central, and most significant codes based on total strength were the stages of the problem-solving process: *make* and *think*. *Embodiment* was the most significant in the interaction category, while *making own product* was the most important and also the most common code in the action category.

The most important codes in the complete network are located in the middle of the network (Appendix Table 3, total link strength). *Embodiment* was at the centre of the network because it had numerous connections with other codes, being the most central code in the interaction category. The thickness of the lines between the codes indicates the number of times the codes occurred together. The *make* code had a solid connection to the *making joint product* and *feedback* codes, whereas the *think* code had a solid connection to the *collecting materials* and *monitoring* codes. In the context of ECE, the problem-solving process contained embodiment, materiality, and support from peers and using examples, all of which are vital parts of children's hands-on process.

The colours in Fig. 5 indicate the three time periods of the video recording, ranging from blue (the beginning, 1.0) to green (the middle, 2.0) to yellow (the end, 3.0). *Imitation*, *collecting materials*, and *think* appeared especially commonly at the beginning of the problem-solving process. At the same time, in the middle phase, the children's work was dominated by the codes for making (*making own product* and *embodiment*). In the final phase of the problem-solving process, collaboration between children (*making joint prod-*

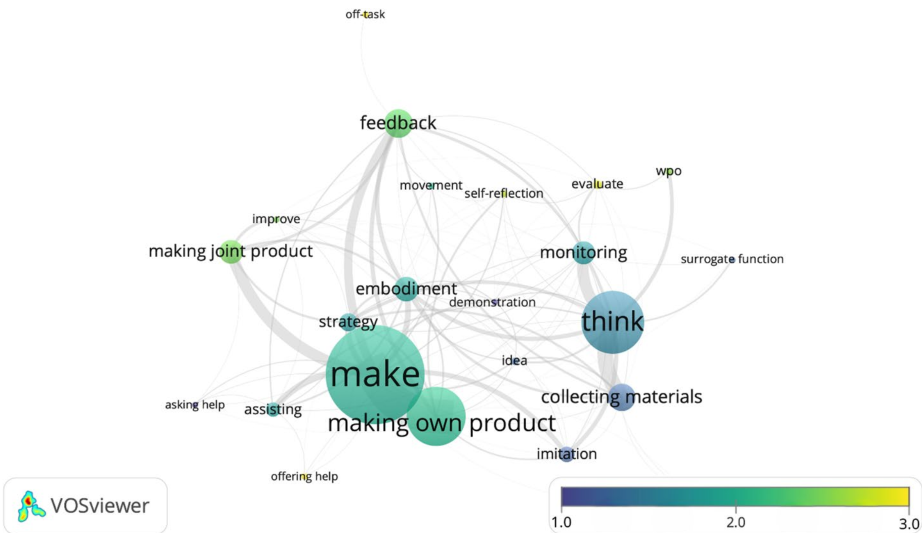

Fig. 5 The complete temporal network of co-occurrences between interactions, actions, and problem-solving stages. The size of the code represents the number of occurrences, the thickness of the lines between codes indicates the number of links, and the colours indicate the three time periods of the video recording (visualisation and colour bar). Colours range from blue (the beginning, 1.0) to green (the middle, 2.0) to yellow (the end, 3.0)

uct) and reflective speech (*feedback*, *self-reflection*) increased. In addition, in the last phase of the problem-solving process, *evaluate* was emphasised, as well as *wordless participation* and *surrogate function*.

Four examples of developing collaboration in hands-on problem solving

To answer the second research question, we present four examples demonstrating the developing collaboration in hands-on problem-solving through temporal co-occurrence network graphs (see Fig. 6). These four teams exhibited the most distinct behavioural patterns in their activities, utilised various collaboration methods, and consisted of children of various support levels. This diversity enabled us to depict the diversity of inclusive teams.

1. Solitary problem-solving without collaboration (Team D).
2. Side-by-side interaction as a step toward collaboration (Team A).
3. Actions as means of collaboration (Team B).
4. Goal-oriented verbally interactive collaboration (Team C).

Example 1: solitary Problem-Solving without collaboration (Team D)

Of the four selected teams, Team D's collaboration was the weakest. The team consisted of three 6-year-old children, who usually did not seek to play with each other in their group. Team D took longer than the others to begin, because no one took the initiative to start teamwork. They positioned themselves in a semi-arc (partially back-to-back) so that they could not see one another's faces and could hide their structures behind their bodies. In

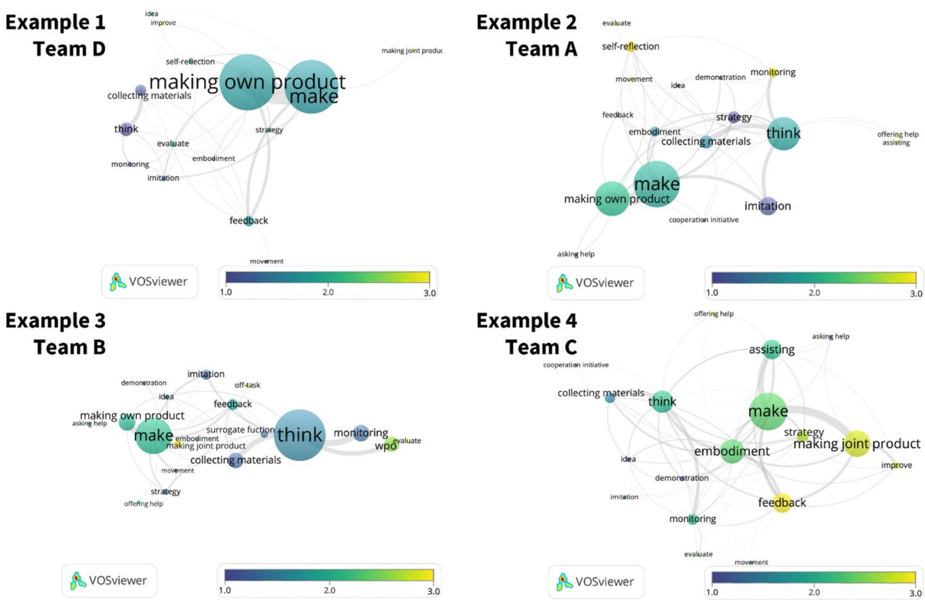

Fig. 6 Complete temporal co-occurrence network graphs between the interactions, actions and problem-solving stages of four examples of developing collaboration in hands-on problem-solving

terms of time, the children began acting and moving to *collect materials* at the beginning of the middle phase of the problem-solving process. This observation, made in the multimodal analysis, is also visible in the temporal co-occurrence network graph (Fig. 6), where the code colour of *collect materials* is located in the colour bar between 1.0 and 2.0. Initially, the most typical *think* code was strongly connected with *collecting materials*. Children's thinking and reflection took place through materials. In the middle phase of the process, the emphasis was on making, specifically *making own product*, which appeared the most often in the team's data. There was a robust connection between this and *make.* All these facts indicate a minimal amount of collaboration.

However, when we consider the temporal manifestation of the codes, actions were preceded by *imitation* and *monitoring*, as well as initiatives of non-verbal interaction of *embodiment*. Although the children on Team D mainly built their own towers, the data show some interaction between them and a few occurrences of *making joint products*. The verbal interactions of these children were most often *feedback* and *self-reflection*. In fact, one of the group members actively reflected on their own actions and positively evaluated the self-made product. Still, otherwise, the minor discourse of the team had negative tones: *"That's cheating! It's difficult being the best builder – you took them all!"* --- *"Mine's strong*, *mine's probably the strongest. No one probably dares to challenge it... the wolf won't..."* The team's activities did not include demonstrations related to helping others or planning discourse. Also, two children did not speak at all during the construction.

Example 2: side-by-side interaction as a step toward collaboration (team A)

In contrast to Team D, the children of Team A were used to playing together. In the construction task, they repeated the well-established roles of active leader and accompanying follower. A wordless friendship between the children could be perceived based on looks, facial expressions, laughter, and closeness. On Teams A and D, each team member built their own tower, but a significant difference could be identified in the quality of their collaborations. In fact, the temporal co-occurrence network graph in the upper right corner of Fig. 6 indicates that the *cooperation initiative* occurred directly at the beginning of the problem-solving task. The location of the *monitoring* and *imitation* codes at the beginning of the temporal process indicated that the children's work emphasised the making stage of the problem-solving process, especially *making own product*. The children worked side by side, building utterly identical towers. *Demonstration* supported by rich verbal interaction (*cooperation initiative*, *strategy*, *asking help*, and *idea*) are also present in Fig. 6 (all codes in shades of blue). Although they did not build a joint tower according to the task, their activity included various forms of demonstrative and imitative collaboration: the younger child was the leader, and the older one was an imitative follower. The leader-child had confidence in his skills; however, he also took the initiative, developed ideas, and presented them for quite a long time in the we-form until he switched to the reflective self-form and private speech: "I'm *a real engineer. We'd need a lot of these [wooden sticks]. We'll make a tower out of these."* --- *"I'll put these on the sides so that the wolf can't blow it over."* However, the follower child seemed to enjoy working. Therefore, these roles were likely based on the children's personalities and levels of skill and collaboration development. As a result, by the end of the process, the children *assisted* and *offered help* to one another.

Example 3: actions as means of collaboration (team B)

The four members of Team B, 4–5-year-old children with diverse learning needs, showed acceptance of one another by working closely together physically. The activity was peaceful and did not include any negative comments or striving for leadership. The working atmosphere of the team was agreeable, although the children could collaborate only sparingly. The activities of Team B focused on functional collaboration (collecting materials, imitation, and movements), with less verbal and non-verbal interaction (Fig. 6). The children's activities emphasised considering others, which they had been taught about often before. The temporal co-occurrence network graph in the lower left corner of Fig. 6 shows how the problem-solving process began with action.

Regarding time, only one code was present at the beginning of the process (*demonstration*, in the darkest shade of blue) when one of the children attempted to initiate collaborative activities. However, he quickly gave up and began making his own product: *"Stilts… for the pigs' home. They'll like this home. Should we make the stilts tall?"* The actual construction began, including the codes for *imitation*, *collecting materials*, *surrogate functions*, and *monitoring* (other codes in shades of blue in Fig. 6). The second child followed along mainly by watching and only participated in the joint activity for a while at the end of the activity: *"Would it work now? ... It works!"* The third child focused on making his own product, as well as a few repairs for the other child's product: *"Wolfy*, *wolfy --- The wolf can't blow this [over] --- Look*, *wolfy!* The fourth child immediately assumed the role of observer, and he did not initiate collaboration. However, this child placed himself close to the other children in the same circle to observe the activity. Given his gestures, the child likely felt that he was participating in the activity, which is typical of children working in the ZPD (Vygotsky, 1978).

The discussion within the team was minimal and consisted mainly of single words or word phrases focusing on the presentation of *strategy* and *idea*s. The children seemed to spend time thinking about the task throughout the process; in this case, they participated without words (*wpo* = *wordless participation and observing*), observed and *monitored* the team members, and *collected materials.* All of these have thick lines to the *think* code. However, the team members also had substitute activities (*surrogate functions*, e.g., a child tangles pieces of tape together and spins them) and play (e.g., playing with a wolf hand puppet). Although the team's joint activity started slowly, *making joint product* was mainly present in the final phase of the process (see Fig. 6, only code in yellow). The children quietly moved to build a joint tower without verbal agreement after one of the children made progress on the task.

Example 4: goal-oriented verbally interactive collaboration (team C)

Compared to the other teams, Team C's collaboration was the most developed and diverse. The collaboration of preschool 6-year-old team C consisted of both verbal and non-verbal interaction and activity in a balanced way. According to the team's ECE teacher, all of these children were very social and considerate of others. The verbal interaction between the children started right from the beginning (Fig. 6, codes shades of blue). The children a*sked* *for help* and gave *cooperation initiative*s, which also involved *demonstrating* and *imitating* actions. Different forms of collaboration were emphasised in the team's activities from the beginning. All team members had good verbal skills, which enabled encouraging discourse and the verbalisation of ideas and activities, especially in the early phase of the process.

The team made a joint product in which they not only understood the importance of diagonal and transverse support structures in the tower's construction but also showed the capability to organise the problem-solving task: allocating the time they had available for construction: *"Oh my gosh, no, no, nouh --- because we don't have much time --- just a bit more, [we] gotta hurry [while attaching the last parts]."*

Their active construction of the tower began with *ideation.* The problem-solving process was emphasised by *making* with a solid connection to the *making joint product* code and a reasonably strong connection to *assisting.* However, *embodiment* seemed to be an essential part of children's non-verbal interaction initiatives, as it was located in the middle of the network image: *"What, if we used these?" [demonstrates with wooden sticks and makes eye contact with others]. "We'd combine these like this" --- "How about we'll take this [plasticine] and then it'll stay upright." --- "I'll get supports" --- "Should we put these here like this?" [demonstrates and looks at a group member]. Crooked, so it'll hold better. You too can place two [of them]."*

In Team C, a task-oriented, rich internal group discussion arose in which the children were able to produce a joint product based on the assignment. Notably, the team members were 1–2 years older than the members of Teams A and B. However, the children's ages do not explain their abilities or the quality of collaboration, because another team of 6-year-olds (Team D) had the fewest activities of collaboration.

Discussion and conclusions

This study investigated how teams of young children (aged 4 to 6 years) with varying ages and support needs collaborated to solve a given hands-on problem-solving task. The primary objective was to illuminate the children's activities and collaborative approaches in a context in which they independently shaped their teams' strategies and solutions for the designated problem-solving task. Furthermore, we aimed to identify the similarities and differences in the activities of various types of teams. By enriching the multimodal analysis with temporal co-occurrence network graphs, we were able to capture the intricate nuances of team dynamics and collaboration over time—insights that traditional video analysis alone could not provide. Based on this study, children's collaborative problem-solving process was characterised by the active production of the given task, which was closely linked to thinking related to making. In their interactions, children use a great deal of nonverbal communication and embodied expressions in addition to speech. We found that developing collaboration in hands-on problem-solving tasks within teams is comparable to the development of children's hierarchical play (Jamison et al., 2012). However, in this study, collaboration seemed to be influenced more by age and friendships between the children who formed the team than by their learning support needs. The findings are consistent with those of prior research examining collaboration and play among young children. A strong idea in the ECE unit's operating culture is that children learn to collaborate with everyone, not just within established friendships.

Firstly, Kimhi and Bauminger-Zviely (2012) identified that effective collaborative problem-solving involves several key skills: cognitive skills, such as planning and inference; socio-cognitive skills, such as understanding a partner's perspective; and social skills, including peer interaction and verbal or nonverbal communication. An analysis of the teams' activities revealed that mutual discussion and verbal exchange significantly enhanced problem-solving in this study. In support of this, Thompson and Moore (2000) and Vygotsky (1978) emphasised the importance of communication in collaboration. Our findings demonstrate that children's rich vocabulary and fluent speech, combined with nonverbal communication, facilitate a shared understanding and coordinated actions, as noted by Vriens-van Hoogdalem et al. (2016). Additionally, private speech, as discussed by Mulvihill et al. (2021), aids children in planning their actions and maintaining task focus, with research indicating that private speech correlates with improved task performance among young children.

Secondly, it is evident from children's interactions that their collaborative efforts are influenced more heavily by their ability to initiate activities than their age, even with peers who may not be their closest playmates (Jamison et al., 2012; Scarlett et al., 2005). This observation is in line with the findings of this study and is closely connected to the development of socio-cognitive skills, which are emphasised in high-quality ECE. These skills include listening, considering others' perspectives, and sharing—fundamental aspects of successful play (Pramling Samuelsson & Asplund Carlsson, 2008). It is well known that play is integral to children's lives, making it impossible to separate play from collaborative activities. Authentic play is driven by children themselves, who define the narratives they create. Children aged 4 to 6 undergo a rich developmental phase, incorporating peer interactions, diverse roles, and imaginative elements into their playful activities (Jamison et al., 2012). This study considered these notions, and the narrative problem-solving task was based on the story of "The Three Little Pigs", which was designed to spark the imagination. The scenario incorporated the wolf, represented by a hair dryer, which was transformed into a figure that required preparation. Notably, the ECE encompasses more than playing and nurturing; it includes structured learning tasks initiated by educators. These tasks often stem from traditional teacher-led approaches, wherein teachers guide children's observations and cognitive engagement. While play can incorporate problem-solving skills, this is not always the case. The guided collaborative problem-solving scenario effectively integrates both dimensions.

Thirdly, as previous studies have observed, friendships play a crucial role in fostering collaboration among children (Pino-Pasternak et al., 2018; Svinth, 2013). Children naturally seek opportunities to play together across various contexts. As noted by Kimhi and Bauminger-Zviely (2012), children with special needs tend to solve problems more slowly, display more off-task behaviours, and use fewer coordinating gestures compared to their typically developing peers. These patterns were also evident in our study, particularly in Example 3 with Team B.

In collaborative learning settings, teachers are often attentive to situations where children struggle to initiate tasks. Our findings indicate that some children—and some teams—require more time to process and engage with the task. It is therefore important for teachers to allow space for children's independent agency and peer collaboration, enabling them to develop their skills at their own pace. Moreover, children demonstrated greater responsiveness and enjoyment when working with friends. This suggests that friendships and shared experiences can enhance collaborative efforts, supporting children with special needs in improving their problem-solving abilities within group contexts. Friendship was also reflected in children's enthusiasm to produce similar outcomes, engage in playful verbal exchanges, and share facial expressions and gestures. However, these dynamics present a challenge for educators: while children benefit from peer support, they also need time to organise their activities and develop the ability to collaborate with all peers—not just their friends.

In this study, we applied temporal co-occurrence network analysis to summarise the multimodal analysis in graphical form. It provided a comprehensive framework for examining children's activities and the relationships that influence them Sormunen et al., 2019; Mercer, 2008). Through these visualisations, we achieved a more profound knowledge of children's collaboration, going beyond what traditional qualitative descriptions alone could provide. Based on our experiences, the novel application of multimodal and temporal co-occurrence network analysis in collaborative research and practical activities with young children represents a significant methodological advancement in observing and understanding children's nuanced behaviours. Although our use of co-occurrence network analysis differed from more conventional approaches, the visualisations enhanced our understanding of young children's social interactions and the variety of collaboration, which are often challenging to observe accurately in real-time.

The importance of hands-on, collaborative problem-solving in ECE is considerable; however, perspectives on young children's collaborative activities have often been limited, primarily focusing on external observation (Farrell, 2016). Specifically, incorporating hands-on experiences in problem-solving tasks provides a new avenue for research, emphasising direct engagement. This approach allows children to explore and create developmentally appropriately (Hennessy & Murphy, 1999; Sormunen et al., 2023a) while revealing various unpredictable factors related to their behaviours and interests. Importantly, child-centred research must prioritise children's best interests (Farrell, 2016). This study's findings align with other research exploring young children's collaboration through varied content and methodologies (e.g., Kimhi & Bauminger-Zviely, 2012; Svinth, 2013; Sjöberg & Brooks, 2022). The findings of the study are highly relevant to early childhood pedagogy. As young children begin to develop collaboration skills, it is essential to create hands-on learning opportunities. Thoughtfully facilitating these experiences fosters collaborative abilities, which are also crucial to academic tasks. Thus, playful, hands-on activities provide children genuine opportunities for teamwork, collaboration, negotiation, and joint projects. This study showed that young children are capable of goal-oriented collaboration. Our responsibility is to guide them in this direction, even though such activities may require careful planning and preparation.

We did not attempt to generalise the findings of this study. We acknowledge that the small number of participating children, randomly assembled problem-solving teams according to the teachers' wishes, and unfamiliar situations may have affected the findings, even though we aimed to make the data collection situation as authentic as possible under research conditions. Moreover, while the application of multimodal and temporal co-occurrence network analysis provided valuable insights into children's interactions, there is a possibility that the subtle nuances of their activities were not fully captured in the video recordings. This may result in potential omissions or misinterpretations. These elements may introduce biases related to the researcher's observations and actions. Nonetheless, by integrating a hands-on element and a novel research setting, this study improves our understanding of young children's collaboration during problem-solving tasks. It also paves the way for future research in several regards. First, collaboration, as a cognitive skill in peer-mediated environments, is vital in promoting inclusive practices (Ainscow, 2020). Activities that require minimal language skills or emphasise non-verbal communication can enhance children's participation in joint activities (Vriens-van Hoogdalem et al., 2016).

Our study also offers practical insights for ECE. The findings highlight the importance of practising interaction skills from an early age. Peer interaction, which involves working together and exchanging ideas, experiences, and opinions, significantly contributes to children's social and language development. Educators can support this by recognising existing friendships and helping children build new ones. Children should be given time to initiate collaboration and explore different forms of communication. This can be encouraged by modelling the use of gestures, facial expressions, and other non-verbal cues. Joint construction tasks are particularly effective for developing peer interaction skills, as they naturally prompt children to communicate and cooperate. Open-ended tasks, combined with a limited selection of materials, foster creativity and problem-solving. These settings encourage children to invent, experiment, and work together to find solutions—making them ideal environments for practising collaborative skills.

Future research should explore how collaborative hands-on activities foster skills related to collaboration, acceptance, and adaptation to new environments, especially for children transitioning to unfamiliar cultural contexts. Second, multimodal analysis can effectively assess children's participation in collaborative situations, particularly for those at risk of exclusion. Future studies should investigate how varying task assignments and group arrangements affect children's collaborative behaviour development, for example, by utilising social network analysis. Conducting longitudinal studies will help monitor children's collaboration skill development and identify interaction patterns that may not be immediately evident. Understanding these dynamics is essential in comprehending how children's relationships evolve and how their collaborative strategies shift based on context and group composition.

Appendix I

Table 3 The weight and score attributes of the data

Category	Rank	Code	Occurrences	Links	Total link strength	Tem-poral average
Interaction	1.	Embodiment	98	19	205	2.0
	2.	Feedback	116	15	202	1.6
	3.	Strategy	74	13	142	2.2
	4.	Idea	32	11	65	1.9
	5.	Self-reflection	27	9	36	1.9
	6.	Asking for help	9	6	17	1.3
	7.	Offering help	5	5	10	2.6
	8.	Cooperation initiative	3	4	6	1.0
		Total	*364*	*82*	*683*	
Action	1.	Making own product	237	12	318	1.9
	2.	Collecting materials	111	12	179	2.2
	3.	Making joint product	96	9	147	1.9
	4.	Monitoring	93	13	130	1.6
	5.	Assisting	58	9	95	1.9
	6.	Imitation	63	10	87	1.6
	7.	Demonstration	22	8	47	1.2
	8.	Wordless participation and observing	31	2	30	2.3
	9.	Movement	20	7	24	2.0
	10	Surrogate function	16	4	15	1.6
	11.	Off-task	7	1	2	2.7
		Total	*754*	87	1074	
Problem-solving stage	1.	Make	397	18	569	2.00
	2.	Think	253	18	357	1.8
	3.	Improve	24	9	39	2.3
	4.	Evaluate	35	12	36	2.5
		Total	709	53	1001	

Appendix II

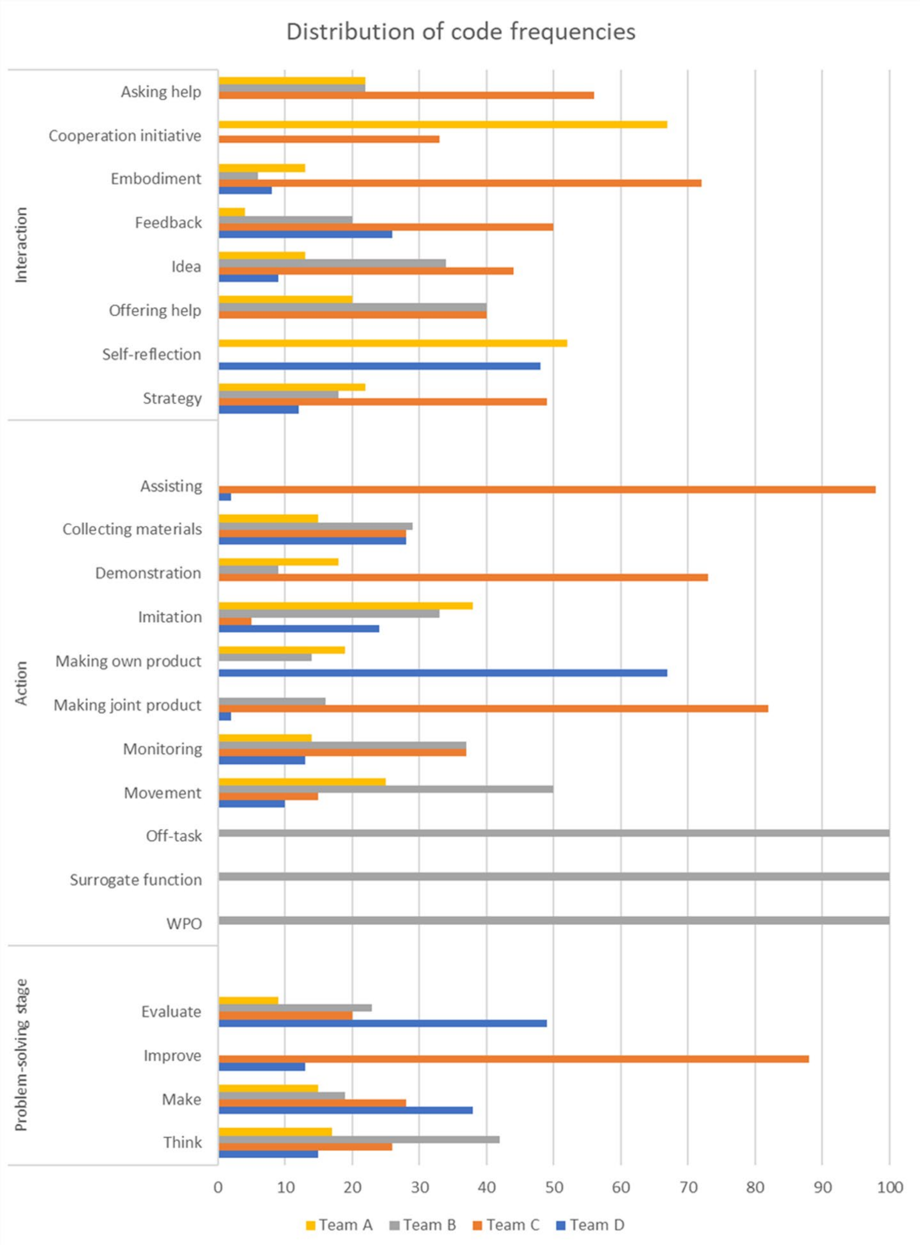

Fig. 7 Distribution of code frequencies among teams

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Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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