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Think-4-EmCoDe framework: Highlighting key qualities in embodied co-design techniques for children

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ABSTRACT

Embodied, co-design and children-specific methods have been gaining traction in Interaction Design for Children, and their potential and benefits are well-established. Yet methods at the intersection of all three areas are scarcer. In addition, design researchers lack tools for the analysis and adaptation of existing methods, and the creation of new ones to suit the particularities of the design project at hand. Here, we present the *Think-4-EmCoDe framework* for the design and analysis of embodied co-design methods and techniques for children, which foregrounds key qualities in embodied interaction design research: *(1) embodied awareness; (2) reflective imaginary; (3) emergence; (4) embodied memory; (5) situated relationality; (6) contingency; (7) playful engagement; (8) play practice; (9) developmental scaffolds; and (10) social dialogue.* The framework has been developed drawing from several theories, methods, and frameworks in the areas of co-design and embodied design approaches. This framework allows designers to focus on both general design qualities for embodied experiences and the specific child perspective. We illustrate the use of the framework through the analysis of three design techniques and discuss its potential as an inspirational tool to understand, adapt and refine embodied co-design techniques for children.

1. Introduction

The benefits of involving children as co-designers have long been acknowledged in the Child-Computer Interaction community (Druin, 1999; Iversen & Dindler, 2013; Scaife et al., 1997b). Particularly, when working with children, adult designers cannot rely on their own childhood experiences to inform technological designs (Yip et al., 2017). Children contribute with their own perspectives on body sensations, feelings, emotions, needs, and personal motivations around experiential artifacts. In the design for interactive technologies, designers can benefit from children's expertise in "playfulness and natural movement" (Schaper et al., 2019) because they are used to constructing knowledge and meaning by exploring the world through their own bodies (Ackermann, 2004). However, selecting the right technique or method, adapting it to fit the purposes of the research project at hand, making the process age-adequate, and creating a new method are not trivial.

In the Child-Computer Interaction community, designers and practitioners have resorted to tools to reflect upon their design and research practices with children such as tools and guidelines (Schaper et al., 2019; Van Mechelen et al., 2016; Walsh et al., 2013), evaluation criteria (Kelly et al., 2006; Kender et al., 2020; Kinnula et al., 2018) and concepts-to-think with (Frauenberger & Good, 2012; Iversen et al., 2017; Karoff, 2013). Some of these techniques and methods focus on and are particularly helpful to guide work involving children in general (e.g. (Kelly et al., 2006; Scaife et al., 1997a)), involving them as co-designers (e.g. (Druin, 2002; Iversen et al., 2017)), or involving them in particular ways, such as engaging their bodies (embodied design techniques, e.g. (Alborzi et al., 2000; Hemmert et al., 2010; Höysniemi et al., 2005; Landry et al., 2012; Markopoulos et al., 2008; Schaper et al., 2018)). Nonetheless, despite the wide panorama given above, works at the intersection of the areas of co-design and embodied design approaches for child-computer interaction are still nascent. Further, it is often not evident which technique to choose, and how to adapt it to suit the purposes of a specific project (Schaper & Pares, 2021). Working at the intersection of these areas brings benefits from each of these individual areas. Yet this intersection also adds up – and even intensifies – known

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challenges of those areas. For example, embodied design techniques deal with the complex challenge of articulating and making actionable abstract felt-experiences in design which is just more difficult with children. Designing for embodiment involves understanding users' sensations of bodily, spatial, and social aspects of the experience which are difficult for children to grasp, as well as to communicate to others. Moreover, there is a need for techniques that allow aligning the design features and contents of the embodied activities with children's comprehension level (Malinverni & Pares, 2014). Antle (2013) claimed that the design of embodied learning technologies for children often ignores the variability in their cognitive development and behaviors, and the contextual variables that influence the situated use of interactive products for them. Finally, interaction design practices can benefit from an embodied approach in general, despite the final interactive experience not being an embodied experience. For example, embodied design methods, leverage and make the most of the hands-on physical involvement of designers, making sure that their sensorial, felt and lived experiences shape the design process and outcomes. In this work, we focus on embodied interaction as "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" (Dourish, 2001) and the fact that tangible interaction is embedded in real space (Hornecker, 2010). In other words, our research draws on approaches that investigate the tangible, social and spatial interactions between humans, physical objects and interactive environments.

In this paper, we contribute to research at the intersection of embodied, co-design and children-specific methods through a framework that provides researchers and designers with lenses to critically reflect upon and work with embodied design techniques for children. The *Think-4-EmCoDe* (Thinking for Embodied Co-Design) framework foregrounds ten key qualities in embodied interaction design research: (*1) embodied awareness; (2) reflective imaginary; (3) emergence; (4) embodied memory; (5) contingency; (6) playful engagement; (7) play practice; (8) developmental scaffolds; (9) social dialogue; and (10) situated relationality*. The framework is intended to help researchers and designers understand existing techniques in this intersection; for example, through facilitating structured and systematic analysis of the benefits and weaknesses of existing techniques. Further, it allows researchers and designers to select, and iterate on existing techniques, or even create new ones to suit their design and research needs.

In this article, we first present previous work on frameworks that provide different approaches in Embodied Interaction Design and explain how the *Think-4-EmCoDe* framework has been developed merging several theories, methods and frameworks of the areas of co-design and embodied design approaches. Further, we describe the ten qualities that this analytic tool provides and illustrate the use of this framework applying it to analyze three embodied co-design techniques that informed different application areas of interaction design projects with children. Finally, we reflect upon the potential of this framework as an analytical tool to understand, redesign and adapt embodied co-design techniques for children.

2. Frameworks for Embodied Interaction Design

Designing embodied experiences demands designers to think about users, technologies and interactions from different viewpoints compared to traditional technologies (e.g. Graphical User Interfaces or WIMP-based systems). Several scholars have proposed different design frameworks to support this process. One focus lies on frameworks that are oriented towards analyzing how embodied interaction can support specific tasks or reflect upon specific qualities of it. Another direction entails frameworks that propose concrete practices and activities based on the notion of embodiment to facilitate the design process.

Examples of frameworks that analyze how embodied interaction can support specific tasks are for instance, Hornecker and Buur's (2006) framework for the analysis of Tangible Interfaces to support cooperative work and collaborative learning. Specifically, the authors stressed that central themes such as tangible manipulation, spatial interaction, embodied facilitation and expressive representation can support the co-construction of knowledge and collaboration. Klemmer et al. (2006) discussed the affordances that Embodied Interaction can offer to support thinking through doing, performing specific tasks, collaborative activities and risk-taking. Other works are inspired by Merleau-Ponty's (1962) phenomenological concept of the "lived body", i.e. how humans are able to engage with their surroundings and develop skills while acting in the world. For example, Svanæs (2013) used Merleau-Ponty's perspective on perception and felt-experience to derive possible design implications. Specifically, the author pointed out how *embodied perception* (i.e. human-artifacts interactions whose nature is perceptual and bodily) and *kinaesthetic creativity* (i.e. use the body to think about future solutions) can constitute two core resources to inform design. Building on Merleau-Ponty's theoretical standpoint, Hummel et van Dijks (2015) introduced a set of design principles for developing embodied sense-making technology as design scaffolds. The aim was to support social coordination in action and mutual inspiration between design partners.

Frameworks that propose concrete practices and activities based on the notion of embodiment to facilitate the design process are, for instance, Wilde et al. (2017) work who explored an approach consisting of evocative questions to describe the fundamental properties of embodied ideation methods. These questions focused on features related to the ways in which design techniques can disrupt and destabilize practitioners' performance of a task and their significance in terms of the emergence and embodiment of an idea. Malinverni (2016) presented a framework aimed at helping the interaction designer to switch perspectives and look at general design aspects of this interaction paradigm from a multitude of angles. Other scholars used somatic practices such as Feldenkrais (Loke et al., 2013), Mindfulness (Françoise et al., 2017), Dance (Alaoui et al., 2015; Schiphorst et al., 2013) and Somaesthetics (Höök, 2010; Höök et al., 2016) to develop theories and practices around core mechanics and experiential artifacts. Françoise et al. (2017) stressed the importance of kinaesthetic awareness in embodied design to understand the subjective experience of the user. Alaoui et al., (2015) focused on movement qualities during dance performances. Höök (2010) researched in an autoethnographic study the qualities of horseback riding. The aim was to provide knowledge for the design of digital technology that is grounded on fostering physical experience; e.g. rhythm, balance, link movement, and emotion.

Children have the particularity to explore and understand the world through their bodies (Ackermann, 2004). We argue that frameworks in embodied interaction for children need to address both the theoretical concepts of embodied interaction design and the involvement of children directly in experiencing, feeling and thinking through the body. The examples above provide interesting lenses to look at embodied interaction experiences and embodied design techniques. However, most frameworks have been developed for adult users and are often not equally applicable to children. Thus, our goal is to provide a framework for the design and analysis of embodied co-design methods and techniques for children that address children's specific needs and scaffold their age-specific abilities and skills as co-designers of embodied experiences. At the same time, children often struggle to explain their interaction design ideas to adults. It is well known that children are not young adults (Read & Markopoulos, 2013). As Pine et al. (2004) explained, it is particularly difficult for children until nine years old to produce explanations for their gestures due to their limited linguistic competence. At the same time, as Frauenberger and Good (2012) describe, interpretative approaches to younger children's input are often "prone to be unduly biased by the expectations and goals of the designers". The authors worked with children between five and seven years old. The focus on embodied design methods may reduce the risk of biased interpretations by allowing children to engage and communicate their design ideas and contributions in multiple ways than only verbally. In the next section, we will present our approach to address these challenges in a single framework.

3. Think for Embodied Codesign framework

Our framework named Think-4-EmCoDe (**Think**ing **for Em**bodied **Co-De**sign) entails ten qualities: (1) embodied awareness; (2) reflective imaginary; (3) emergence; (4) embodied memory; (5) situated relationality; (6) contingency; (7) playful engagement; (8) play practice; (9) developmental scaffolds; and (10) social dialogue. The goal of this selection was to embrace a holistic perspective on design qualities in embodied interaction research for children. For our research, we used design qualities as qualitative and descriptive aspects that allow designers to question, elaborate and make informed choices in thoughtful interaction design (Bardzell, 2010). We particularly aimed at integrating design qualities for co-designing with children, which can help: characterize the technique and evaluate or reflect on it. While any of these qualities alone is not necessarily unique nor fundamental in any particular technique, it is worth considering them, together as a critical constellation of possible characterizing core aspects of an embodied co-design technique for children.

3.1. Methodology

The *Think-4-EmCoDe* framework builds on several theories, methods and frameworks presented below (see also Table 1). In this section, we describe how the framework was developed by exploring its application on different exemplary design methods.

Development of the framework

The first author revised and identified 10 core concepts in related work that could constitute our framework. The selected core concepts were then presented to the third and fourth authors and during several meetings discussed and refined. Subsequently, the first author identified frameworks that used these core concepts and scrutinized their appropriateness as reflective tools to understand the selected concepts. These discussions yielded 10 design qualities compiling concepts from different theories, methods and frameworks. Each of the qualities responded to one core concept that was identified previously (Table 1). The first author elaborated then a preliminary version of the *Think-4-EmCoDe* qualities and explored their suitability as an analytic tool in the project Magical Movement (Schaper & Pares, 2016, 2021). The goal of the project was to engage a group of children and teachers from a theatre school in the co-design of a Full-Body interactive experience. The outcomes were again discussed with the third and fourth authors and a second version of the *Think-4-EmCoDe* qualities was defined.

Application of the framework

To evaluate the general effectiveness of the framework, we applied the *Think-4-EmCoDe* qualities to a selection of external examples of a well-established design technique with children (Schaper, 2019). For this purpose, we used the text description provided about the techniques in the original publications. In addition, we invited the second co-author to use the framework with one well-established design technique that she had co-developed in previous research. In the first meeting, we

Table 1
Core concepts to consider in the development of embodied co-design techniques.

Theoretical branch	Core concepts	Design Qualities
Phenomenology		
- Svanæs (2013) used Merleau-Ponty's analysis of perception and felt-experience: embodied perception; - Hummels and van Dijk (2015) framework; quality: 1st Person Perspective	Provide children with opportunities to feel body sensations in relation to a specific environment/situation because they make sense by interacting in the world through the body.	Q1: Embodied Awareness
- Hummels and van Dijks' (2015) framework: qualities: Interactive Imagery and Cognitive Scaffolds; - Wilde et al.'s (2017) framework for Embodied Ideation Methods; qualities: disruption and destabilization; - Malinverni et al. (2016) reflections upon the transformation of embodied experience into 'an-object-to-think-with'	Consider dynamics that allow children to reflect on their lived experience when using a technique because it allows children to experiment with different perspectives and transform them into knowledge.	Q2: Reflective Imaginary
- Wilde et al.'s (2017) framework for Embodied Ideation Methods; qualities: emergence and embodiment	Consider design thinking as embodied process of the lived experience because children use their bodies as an instrument to think with.	Q3: Emergence
- Svanæs (2013) used Merleau-Ponty's analysis of perception and felt-experience: kinaesthetic creativity; - Hummels and van Dijks' (2015) framework: quality: Traces	Support children in the translation of immaterial knowledge into visual, tactile and somato-sensory forms because they may express their thoughts in different embodied ways than adults.	Q4: Embodied Memory
- Merleau-Ponty's (1962) concept of the "lived body"; - Malinverni (2016) framework on design qualities for embodied interactive experiences	Consider the impact of the social and physical context on children's sensorimotor experiences and body actions because they are tightly linked to children's understanding of the world.	Q5: Situated Relationality
- Malinverni et al. (2016) reflections upon the transformation of embodied experience into 'an-object-to-think-with'; - Malinverni (2016) framework on design qualities for contingent enhancement;	Enrich children's sensorimotor experiences through appropriate technological solutions, which allow children to create meaning.	Q6: Contingency
Child Development		
- Hummels & van Dijks' (2015) framework on design principles for developing embodied sensemaking technology: quality: Catalysing Engagement ; - Hedegaard (2002) conception on dominating motives	Motivate children to participate in an activity by providing different modes of engagement that are meaningful to them.	Q7: Playful engagement
- Karoff (2015) four categories on children's play practice: sliding for devotion, shifting for intensity, displaying for tension and exceeding for euphoria	Consider children's play practices as an essential part of the creation process because it allows them to explore ideas and make connections between their experiences.	Q8: Play Practices
- Bekker and Antle (2011) proposed a framework of developmentally situated design (DSD) cards; - FACIT method (Walsh et al., 2013) dimension need for accommodation, technology level	Consider differences in abilities and skills between age stages and individual development because they determine in which way children are involved in the activity.	Q9: Developmental Scaffolds
Co-Design		
- Hummels and van Dijks' (2015) framework on design principles for developing embodied sensemaking technology: quality: Social Situatedness and Dialogical System; - reflections on co-design practices with children (Frauenberger et al., 2015; Iversen & Dindler, 2013; Schaper et al., 2019); Walsh et al. (2013) child-adult relationship, partner experience	Consider social dynamics during collaborative work and power relations between intergenerational design partners because they can limit children's participation.	Q10: Social Dialogues

explained to her how we used the framework to analyze other techniques. She elaborated then a descriptive text about the procedure and outcomes of her design technique and followed a template approach (Crabtree & Miller, 1992), i.e. used the 10 design qualities as key codes for analysis. The findings were documented in a table and discussed with all authors. These discussions led to adjustments in the description of the design qualities, core takeaways and guiding questions for designers (Table 2). In a second round, all three techniques were revised by the first and second author and they classified the strength of the techniques to achieve the design goal into the degrees high (H), middle (M) and low (L). These three levels were understood as follows. High (H): The technique led to a high achievement level of the design goal; middle (M): the technique partially led to the achievement of the design goal; low (L): the technique did not lead to the achievement of the design goal (see details codebook in appendix).

Refinement of design qualities descriptions

After that, all researchers discussed the outcomes until a common agreement on the degree of strength of each quality was achieved. In the next step, the same researchers went back to the definition of the *Think4EmCoDe* framework, re-analyzed if the qualities were able to capture the most salient aspects of the techniques and made corresponding refinements of the quality descriptions until a final version of the qualities (Table 2) and the codebook was elaborated. In the following section, we will describe the theoretical underpinning of our framework and then illustrate which findings the application of the *Think-4-EmCoDe* qualities led using three techniques.

3.2. Identifying core concepts

Three main branches of theoretical underpinning inspired our framework: (1) phenomenology-inspired embodied theory, (2) child development theory and (3) theoretical reflections on co-design practices with children. We made this selection because these three branches unpacked useful and generative intermediate-level knowledge (Barendregt et al., 2017) about essential qualities that embodied design techniques need to provide for children. We will now outline the origins and meanings behind the core concepts of each branch and then contextualize them within previous research that has inspired our framework. A description of the relationships between the theoretical branches and the identified core concepts can be found in Table 1.

Phenomenology-inspired embodied theory

Our focus on phenomenology-inspired embodied theory was motivated by the fact that design practices arise "through being attentive to experiences that emerge in the here and now" (Frauenberger et al., 2010). In other words, from a theoretical perspective, phenomenology focuses on the designer's "lived experience" during the creation process. Further, phenomenological theory offers opportunities for systematic reflection on the lived experience (Shi, 2013). Particularly, frameworks based on Heidegger (1962) and Merleau-Ponty's (1962) work provide reflections on how we make sense in and towards the world through the body. These principles align with the way children situate themselves and interact through their bodies within the world (Ackermann, 2004). At the same time, our approach is rooted in a phenomenological

Table 2
Description of the Think-4-EmCoDe qualities.

Description of Think-4-EmCoDe qualities	Core take away	Questions that researchers should be asking
Q1: Embodied Awareness understood as the internal understanding of people's own felt-experience and supports thinking of design solutions that involve the body, physical space, and other bodies, in motion and through situated action.	Which body sensations are stimulated and how they change body awareness; how they can be supported by a design prototype	How does the activity help children to experience bodily sensations? How do they impact body awareness? How do they inspire design(ing)?
Q2: Reflective Imagery understood as the capacity of promoting reflection from different perspectives on the design task to obtain a holistic view on the available possibilities of solutions.	If the technique opens new ways of thinking, perceiving, and acting; if alternative design ideas and ways of doing emerge.	How does the activity help children reflect and take different perspectives while designing? How do new ideas emerge from the activity?
Q3: Emergence understood as the ideas that come up through using the technique and their unfolded embodied meaning.	Design ideas (interaction, content, visual aspects) become apparent during the performance of an activity.	How does the activity support the emergence of design ideas?
Q4: Embodied Memory understood as the produced design elements or body knowledge of people's lived sensations that leave traces in their understanding about design qualities of an interactive experience.	Existence of traces of embodied action that are generative. These can be immaterial, e.g. sensations that linger with participants or material, e.g. drawings, photos, artefacts.	What kinds of materials do the children produce during the activity? Which kinds of sensations can children remember after the activity? How are they generative?
Q5: Situated Relationality understood as the comprehension of relationships and dependencies of situated interactions between people and the world when designing.	Impact of the physical and social contexts during the emergence of an idea.	How does the activity allow children to explore interactions between people and spatial features of the environment?
Q6: Contingency understood as the coupling achieved between our bodily actions, the physical world, and the digital stimuli that meaningfully augments our sensorimotor experience through digital technology.	How a certain technological solution leverages the situation at hand (activity, physical space, etc.) and enriches user's sensorimotor experience.	How does this technique support experiencing/thinking about/augmenting the relation between our bodily actions, the physical world, and the digital environment?
Q7: Playful Engagement understood as the capacity to stimulate children's innate desire for play and motivation to participate in an activity.	Which kinds of activities motivate children to join and participate actively in it; what is playful about them and how playfulness plays an important motivational role.	How is the activity motivating for children? What aspects are (dis)engaging?
Q8: Play Practice understood as children's rhythms of bodily and social doings related to the surrounding space.	Which kind of play do children do, e.g. quiet play activities (puzzles, drawing) or activities involving high body movement and spatial exploration (performance).	What kind of play does this technique elicit? How is this instrumental for design?
Q9: Developmental Scaffolds understood as the support for children's age specific cognitive, physical, social, and emotional abilities in the design.	Which skills and abilities children need to perform to engage in the co-design activity.	Is the activity suitable for age specific skills and abilities?
Q10: Social Dialogue understood as the capacity to promote empathy and a collaborative attitude between the participants of a design activity.	Generative and fruitful dialogue among children, and between children and adults. Which participation rules, collaboration strategies, and social dynamics support this dialogue.	How does the activity spark social interactions and dialogues between participants?

perspective on design thinking. According to Diethelm (2019) design thinking is an embodied process of experience, i.e. knowledge and meaning of our world are constructed through experiences of the lived body. As a consequence, design thinking techniques should allow designers to use their body as an instrument to think with. In design practice, the act of thinking may not only be expressed through verbal language but in visual, tactile and somato-sensory forms (Loke & Robertson, 2011). The communication on a multimodal level has shown to be particularly valuable when working with children because they offer an additional window into children minds (Goldin-Meadow & Alibali, 2002). During the design process, children often struggle with communicating explanations of complex design ideas to adults due to their different ways of expression (e.g. role-play, drawings, etc.). The phenomenological perspective on design provides means of engaging children in different ways with the design experience, experimenting with it and transforming it into an object of knowledge (Malinverni et al., 2016).

From the work in embodied interaction design presented above (Chapter 2), we found hardly any framework that was built on these child-specific core aspects (Table 1). With the exception of the FUBI-method (Schaper et al. 2019) that provides stepwise guidelines for using research methods to guide an iterative process and make adequate design choices in Full-Body Interaction design with children. The main focus of the method lies on helping intergenerational design teams in learning how to use their body to express interaction design ideas, to transfer intangible outcomes into tangible prototypes and evaluate the potential of embodied interactive experiences. The method also allows design teams to reflect upon their expectations and values that they bring into the design process related to children's participation, learning goals and context appropriateness. Despite the important contribution as framework in this field, the method has shown limitations in offering reflective tools to make refinement on the design techniques employed within the design process. Malinverni et al. (2016) described possible paths through which children can transform embodied experience into an 'object–to-think-with' and delineate the different resources for meaning making that they employed. Malinverni (2016) also argued for the need of a contingent enhancement of the user's sensorimotor experience through digital technology, i.e. the creation of meaning augmentations through combining body actions, the physical world and the digital stimuli. Other frameworks such as Wilde et al.'s (2017), Svanæs (2013) and Hummels and van Dijk (2015) focused on the role of the body as a mediator for the design idea which plays an important role in general in embodied interaction design. Furthermore, Hummels and van Dijk (2015) provided design qualities that allow adult designers to use tools to stimulate reflection and analyse material and immaterial outputs that result from the design thinking process. Thus, from a phenomenological perspective, core concepts of embodied design techniques for children may particularly *(1) support children in connecting to their lived experience and body sensations in a specific environment or context; (2) consider dynamics that allow children to reflect on their lived experience when using a technique; (3) consider design thinking as an embodied process of the experience; (4) support children in translating immaterial knowledge based on their embodied experience into visual, tactile and somato-sensory outputs; (5) understand the impact of social and physical environment on children's sensorimotor experiences and body actions; and (6) enrich children's sensorimotor experiences through appropriate technological solutions.*

Child development theory and play

The focus on embodiment both broadens and changes the possibilities of designing for children's technologies. Novel design approaches in this field need to provide ways that are better tuned to children's developing abilities (Antle, 2009). Therefore, designers must consider core aspects in child development theories that offer a comprehensive account on potential requirements for the development of embodied design techniques. First, several scholars have expressed theories around the claim that children make meaning through action. For example, Piaget suggested that people construct their knowledge from active experiences requiring both physical and mental actions (Piaget, 1955). Dewey (1968) and Kolb (1984) described a process by which hands-on opportunities in an active learning environment drive knowledge. Bruner (1962) claimed that human cognition is not exclusively conceived as an in-mind process, i.e. that knowledge begins with enaction. In summary, these theories point towards the fact that children use their bodies as instruments for understanding real-world contexts by exploring their environment through sensorimotor experiences, gestures and movement (Ackermann, 2004; Goldin-Meadow, 2011; Kontra et al., 2012). Second, these behavioural patterns are mirrored in children's play practices. Children play because they have a deep desire to understand the world. While playing, they are developing skills in all areas of development: cognitive, physical, communication, social and emotional. Play allows children to try out new ideas and make connections between their previous experiences and active engagements with their environment. Many scholars have highlighted the advantages to involve children in the design of technologies through the use of playful design techniques (Dindler & Iversen, 2007; Giaccardi et al., 2012; Sylla, 2019). According to Ackermann (2015) playfulness is an essential aspect in the creative process because it allows to look at things from unusual angles by breaking loose from the habitual, e.g. performing playful exaggerations. From an epistemological perspective, design techniques need to promote abilities that are deeply rooted in the values of play practise such as active participation, exploration and testing ideas. From the perspective of developmental psychology, Hedegaard's (2002) suggested that children's dominating motives and motivations to take part in an activity are related to endorsements, performances, and collaboration with other peers. Finally, children have different cognitive, motor, social, emotional, and communication abilities than adults (Fails et al., 2012). In addition, since children are continuously developing and improving their abilities, designers also need to consider children's developmental variations between different age stages. Hence, from a developmental perspective, core concepts of embodied design techniques for children need to consider*; (1) which are children's motivation to engage in an activity; (2) children's play practices as essential part of their creation process; (3) differences in abilities and skills of children between age stages and individual development.*

Several scholars have used these core concepts and transferred the knowledge into qualities that allow to design for and understand specific aspects of embodied experiences for children. For instance, Bekker and Antle et al. (2011) proposed a framework of developmentally situated design (DSD) cards as a tool to provide age specific information about developing cognitive, physical, social, and emotional abilities readily accessible for designers. Antle (2013) gave an overview of the affordances that Embodied Interaction offers for learning such as offloading cognition in the world, using movements to help children think, etc. Abrahamson et al. (2011) proposed a framework to use embodied interaction to support learning of mathematical concepts. Malinverni et al. (2016) presented an approach that could help designers to observe children's embodied experience in the process of meaning construction. Karoff (2015) analysed play practice from a phenomenological view of play and mood perspectives that invite children to a specific playful situation. Specifically, she focused on two dimensions: *play practices* and

play moods[1].

Theoretical reflections on co-design practices with children

Over the last decade there has been a conceptual shift on children's empowerment as users and future designers of interactive technologies (Frauenberger et al., 2015; Iversen & Dindler, 2013; Walsh et al., 2013). Specifically, in Child-Computer Interaction research, young users are more often considered experts of their own practice and needs (Iversen & Dindler, 2013). However, recently several scholars criticized that practices in design research still show a tendency for taking the risk that only designers make the core design decisions (Iversen & Dindler, 2013) and that children's participation may "become decoration" (Iivari et al., 2015). Children's roles in the design process can be strongly influenced and determined by the stakeholders' views on childhood (Skovbjerg et al., 2016) and their expectations of children's skills and cognitive capacities (Mazzone et al., 2012). These assumptions run the risk of adult researchers and designers making all the design decisions without really addressing children's needs, i.e. they might select the core aspects of the study, interpret data from the sessions and draw conclusions. An alternative starting point to prevent this hazard is given by the original Scandinavian Participatory Design approach which embraces three political ideals: democracy, emancipation, and skilfulness (Iversen & Dindler, 2013). In practice, these underlying values shape the dialogue between stakeholders and designers and the way how design techniques are used. Thus, from a co-design perspective, *core concepts of embodied design techniques for children should carefully examine (1) the social dynamics during collaborative work and (2) the power relations between adults and children.*

Building on these core aspects (Table 1), scholars have proposed several frameworks to define and examine children's roles in a design team. Each approach involves specific values in terms of children's participation and not in terms of the techniques and practices that are employed. In the early stages of the emergence of Participatory Design, users were involved to understand their use of technologies and how they affected their lives (Iivari et al., 2015). Later, the participation of both adult and child users was extended to roles such as design partners, informants, and testers (Nesset & Large, 2004). Each of these roles has its own function, depending on project resources, designers' philosophy and intentions. The role of "design partners" arises from the idea that every stakeholder contributes with their own expertise during the design process (Druin, 2002). Scaife and Rogers (1998) presented the informant design model which implies children's involvement at design stages where their input is considered as appropriate and critical. Read et al. (2002) proposed the IBF Participatory Continuum Model that distinguishes between design experts (academics) and domain experts (children and/or adult helpers). Furthermore, Iversen et al. (2017) claimed that a commitment to political participatory design requires the definition of a new role for children in participatory practices – the role of protagonist. Walsh et al. (2013) proposed the FACIT (**F**ramework for **A**nalysis and **C**reation of **I**ntergenerational **T**echniques) method. This framework aims at guiding the description of co-design techniques and provides specific values that are relevant to co-design teams. The framework focuses dimensions that concerns the intergenerational participants (partner experience; need for accommodation), dimensions that concern the problem space being addressed (design space; maturity of the design), and dimensions concern the technique itself (cost; portability; technological level; physical interaction). These are valuable and important aspects in the co-design with children, however, they do only partially address aspects related to embodied interaction. Specifically, the dimension that refers to the physical interaction of participants during an activity and allows designers to categorize the activity from low to high involvement. However, to analyse the unfolding potential of embodied interaction and the different aspects that it entails, we claim that a finer nuanced analytical tool is needed. Other scholars specifically focused on embedded values in co-design practices with children. For instance, Frauenberger et al. (2015) proposed a "tool-to--think-with" to enhance the notion of accountability and rigor in the design process. The authors aimed at encouraging design practitioners to reflect upon the collaborative work in a design team, decision making and outcomes in a transparent way. Van Mechelen et al. (2016) proposed the GLID method to increase internal rigour and transparency in co-design practices and go beyond the surface level of ideas by identifying participants' values embedded in design outcomes. Schaper et al. (2018) highlighted the need to consider stakeholder's assumptions on children's participation in the design as a means to establish collective values among stakeholders and to better empower children in the design process.

Despite this rich panorama of frameworks, we have shown that only a few researchers (Schaper et al., 2019; Walsh et al., 2013) tackled the challenge to provide approaches that merge the intersection of embodied interaction, co-design and child-specific methods. Thus, the goal of this article is to provide the Child-Computer Interaction community with a novel framework that complements existing approaches in embodied interaction co-design research. In the next section, we present our approach called the *Think-4-EmCoDe* framework, a reflective tool to understand the benefits of embodied co-design techniques and classify them into design qualities that clearly describe their potential. A summary can be found in Table 2. In this article, we used 10 *Think-4-EmCoDe* qualities to extrapolate the potential and weaknesses of exemplary embodied co-design techniques presented in the next section. It is important to note that the framework constrained a specific age group since it can be used for children at all ages. The quality "developmental scaffold" specifically aims that considering age-specific aspects and in consequence age-specific differences in children's development.

4. Application of the Framework

In this section, we briefly describe three embodied co-design techniques and an application scenario for each one: *Body Shadows* (Schaper & Pares, 2016), Participatory Embodied Sketching for Circus Training (*PES4CT*) (Márquez Segura, Turmo Vidal, et al., 2019a); and *KidReporter* (Bekker et al., 2003). We selected these three techniques to illustrate the variety of application areas for the framework described above. The first technique has been developed in our research group. The second technique is an external example within the works of the second author, who co-designed the technique and hence had fine-nuanced details of the technique that may or may not have been published earlier. The third technique is an external example based on information extracted from a

[1] These categories build on children's rhythms of bodily and social doings related to the surrounding space. The play practices illustrate opposed ways of engagement within a play activity and differently shape children's use of body movement and spatial characteristics of the environment. Each way of engagement promotes different levels for the capacity and acceptance of mindful thinking, collaboration, and creativity. *Sliding for devotion* describes "quiet play" activities such as doing a puzzle, play with Lego or drawing activities. During this play practice children perform repetitive and continuous movements with little changes and variations. Consequently, the children involved make little use of space. They are very focused on their actions. *Shifting for intensity* describes active play such as sliding down a hill or jumping on a trampoline. During this play practice, children perform repetitive movements that over time creates unpredictable surprises for other players through rapid changes of movement speed, direction, and height. *Displaying for tension* describes play situations with informal performing such as role-play, dance or singing. During this play practice, children focus on showing off themselves, putting themselves on a "stage" and to let the others players look at, learn from or critique the performance. The goal is to show 'one's own style' and through this attract the attention of the audience. *Exceeding for euphoria* describes movements that stand in contrast to the notion of repetition such as bizarre doll play, "jackass tricks" and "stories of frivolity". The play practice is characterized by 'an intense expectation of silliness' and to come up with new acts of going wild to maintain the euphoric mood (Karoff, 2015).

publication. This choice was meant to show the applicability of the framework to external works. However, there are limitations coming from the fact that none of the authors were involved in this technique. We may have missed or not reported aspects that were important regarding the qualities of our framework, or might have misread details reported. Furthermore, some assumptions may be speculative and not directly evident in the information provided in the publication. We will first describe the procedure of each technique and then highlight how the ten design qualities unfolded.

Technique 1: Body Shadows

The technique *Body Shadows* is a variation of bodystorming based on physical theatre practice. In contrast to shadowgraphy and hand-shadow techniques, actors use their bodies to create the visual effect of shadow images on a projection wall or a piece of cloth. From a pedagogical perspective, researchers have highlighted the benefits of body shadow play to foster the capability of corporeal expressiveness and body awareness. López-Villar and Canales (2007) stressed that shadow theatre is particularly powerful in child education because it hardly requires previous training and specific movement skills. We used the technique for the design of an interactive storytelling experience (Schaper & Pares, 2016, 2021). The goal was to offer 12 children (m=7; f=5; 11-12 yrs) a different way to express themselves while designing. We also aimed at better understanding ideas about content, which they had previously developed in drawings. Specifically, they were asked to draw a scenario of Shakespeare's play *A Midsummer Night's Dream* and then to visually represent their idea for the scenario through their body shadows. We were interested in obtaining interaction design ideas for physical actions between players and with the virtual environment. Before the session, we had set up a white projection screen using a blanket and spotlights to light it from behind. We turned off the main lights of the room and gave each group five minutes to bodystorm their group performance. After that, each group performed a final proposal in front of the rest and explained their ideas.

Technique 2: Participatory Embodied Sketching for Circus Training (PES4CT)

The term *Embodied Sketching* (ES) (Márquez Segura et al., 2016) characterizes design activities focused on experiencing and designing future embodied core mechanics, i.e. actions that will be constitutive of, or essential to, a future technology-supported activity. It includes different kinds of embodied design activities that heavily rely on engaging with one's body and with each other. One of these forms is a *Participatory Embodied Sketching* activity (PES) with end users working with technology prototypes, which are tested and built upon considering what actions they can afford, support, and entice. While this activity could be seen as a more traditional user test of early mock-ups, it is first and foremost a joint co-creative design activity wherein prototypes are used as design material.

This technique was used in the context of the Super Trouper Project, which focused on designing technology to support the training of children (9-12 yrs) with sensory-based motor disorder (SBMD) (Márquez Segura, Turmo Vidal, et al., 2019a; Turmo Vidal et al., 2020). As part of this project, a collection of Training Technology Probes (TTPs) was tested and iterated with 7 children. The TTPs are simple wearables designed to help understand and work with essential aspects of one's body, movements, and training, such as (1) body alignment on different planes; (2) qualities of breath (intensity, duration, and symmetry of inhale and exhale); (3) movement qualities and patterns (rhythms, speed, and acceleration); and (4) focus during training. They were designed for, integrated, and used as part of two sets of 6 physical training sessions run with 3 circus artists, teachers, and pedagogues from Cirkus Cirkör, in Stockholm. These sessions were considered part of an iterative design process using PES (PES4CT), testing, developing, and creating TTPs; and refining the training activities with children and instructors. Hence *both* the technology and the training exercises were design targets. A training session would typically involve 30 min of warm-up games/exercises, 1h of training (with(/out) the TTPs), and 30 min of group reflection including a semi-structured interview to gather the children's feedback. At each session, the children engaged with a couple of circus disciplines (e.g. balance, floor acrobatics, juggling, aerials) and TTPs.

Technique 3: KidReporter

The technique *KidReporter* (Bekker et al., 2003) proposes a playful activity for children in which they investigate a specific topic by pretending to be a journalist of a newspaper team. The technique combines several techniques that allow eliciting information from children such as interviews, questionnaires, taking photos and writing descriptions. Bekker et al. (2003) used the technique to collect requirements for the design of an interactive game aimed to teach children about animals during a zoo visit. In the study participated 63 children (f=35; m=28; 9-10 yrs) participated. The main goal was to develop a newspaper about the Artist Zoo in Amsterdam. First, all the children visited the zoo. After that, they were asked to choose between three roles: (1) photographer, (2) reporter, or (3) article writer. The group of photographers walked around the zoo and each child took four photos of animals they liked and provided a description of why they had selected them. The group of reporters conducted interviews amongst each other based on 16 questions (10 pre-defined, 6 individually chosen). The children audio-recorded then the answers to the questions. In the article writing group, each child selected their own topic for the article from a range of themes (e.g. reproduction, territories, smells, etc.). Finally, all children were asked to fill in a questionnaire with predetermined open and closed questions. Based on the obtained information of the different activities, a designer summarised the results in a newspaper.

4.1. Applying the Think4EmCode qualities

In this section, we will describe how we applied the 10 Think4EmCoDe qualities: (1) embodied awareness; (2) reflective imaginary; (3) emergence; (4) embodied memory; (5) situated relationality. (6) contingency; (7) playful engagement; (8) play practice; (9) developmental scaffolds; and (10) social dialogue. Therefore, we illustrate how each design quality unfolded within each technique and refer specifically to the ten design qualities by numbers (Q1 through Q10), and their degree of relevance, e.g. a very relevant play practice will be coded as (Q1|H) and less relevant play practices as (Q1|L) (see also codebook in the appendix). A summary of the strengths, weaknesses and future directions of each technique can be found in Table 3.

Q1: Embodied Awareness: Understanding internally people's own felt-experience and supporting thinking of design solutions that involve the body, physical space, and other bodies, in motion and through situated action

The application of the quality *Embodied Awareness* illustrated how the three techniques stimulated certain body sensations, changed children's felt-experiences and how these sensations were contextualized within the design goals of an interactive prototype. The *Body Shadows* technique encouraged the children to explore sensations related to the notion of "connectedness" when superimposing shadows of different body parts without focusing on the characteristics of a specific prototype (Q1|M). For instance, one group represented with their bodies the scenario of a gathering at the royal court of magical creatures. Two children used their hands placed against their heads to simulate pointed ears as if they were fairies. The possibility to experience and control subtle changes in posture, playing with the nuances of movement changes allowed them also to focus on aspects related to their felt-experience and interactions between their bodies.

In the *PES4CT* technique, the children explored wearing several TTPs together on different body parts, which positively impacted their awareness of the notion of balance, however, this aspect was not specifically measured (Q1|M). Nevertheless, the instructors could observe children making adaptations to their movements in the exercises. Among others, the children experimented on a balancing board with different kinds of support (gym bars, a spotter, nothing) or balanced

Table 3
Overview of the strengths, weaknesses and future directions of the three techniques Body Shadows, PES4CT and KidReporter.

	Strengths	Weaknesses	Future directions
Body Shadows	- Supports children's reflections - manifests felt-experiences into material and immaterial outcomes - makes relations to other participants and their physical environment - motivates children to participate in the activity - generates fruitful social dynamics among design partners	- supports less the generation of interaction design ideas - did not allow to make conclusions about digital augmentations that could be adequate for the interactive experience	- promote exploration of different play practices and the enactment of movement variations (e.g. slow-motions vs. high speed) may allow children to embed a deeper meaning into the elements of the shadow performance - explore shadow play with objects to modify the appearance of their shadows - use the effect of superimposing between different actors to explore social interaction and qualities of shared interaction space
PES4ACT	- facilitates social dialogues between children and instructors - supports reflective imagery and embodied awareness - promotes emergence contingency and situated relationally and supporting integration and emergence of play engagement - leverages useful play practices for the purpose of training and the needs of our target group	- no straightforward access to children's embodied memory and embodied awareness	- focus stronger on measuring the impact of ideas by using the TTPs to record the children's actions, which we could be mapped and contrasted to video recorded behaviour, think aloud techniques or mini-interviews after each exercise - modify to TTPs better support embodied awareness and memory of children in action. For example, they could implement retrospective feedback, providing representative outputs of an exercise after it is finished.
KidReporter	- forces "photographer" to concentrate all senses on the sense of sight - helps to gather children's divers' interests and input on a final product - enriches children's memories of the visit by observing multimodal impressions - supports exploring the spatial qualities of a location	- focus on taking pictures and reduces the time on elaborating design ideas - imbalance in the design partnership between the designer and the children - children's motivation to participate in the technique may be driven by their interest in the zoo	- encourage children to video record or document and explain their choices in the specific location - involve children in the entire creation process of the final product - explore different playful variations of the technique by complementing it with other activities and using it in different contexts

Table 3 (*continued*)

	Strengths	Weaknesses	Future directions
	through the bodies - supports children decision-making process	rather than using the technique	

different kinds of objects (from a feather, to a club, or a plate on a stick) while they were wearing the prototypes (e.g. the TopBalance and FrontBalance[2]). For instance, some children used the TopBalance on top of their hand to augment tilt while balancing a feather on top of that TTP. Another child wrapped the FrontBalance around a club he was balancing (Fig. 2b).

In the *KidReporter*, we believe that the technique seemed to force the children in the photographer role to concentrate on the sense of sight without focusing on the characteristics of a specific prototype (Q1|M). In a sense, the children explored a physical space that was familiar to them by adopting a different lens of perception. The camera became a tool that helped the children to fragment their view and focus on concrete aspects within the environment, for instance, they took the enclosure of the animals in the zoo.

Q2: Reflective Imagery: Promoting reflection from different perspectives on the design task to obtain a holistic view of the available possibilities of solutions

The application of the quality *Reflective Imaginary* highlighted which new ways of thinking, perceiving, and acting each technique opened. During the *Body Shadows* technique, the children switched between the roles of performers and the audience which gave everyone the chance to compare different ways of performing shadows and apply this knowledge to their own enactments (Q2|H). The children in the audience had to pay attention to the performance of their peers and build their new actions upon the previous ideas. Thus, the children first imagined their own performance and felt-experience while they observed the enactments of their peers on stage. This process gave them time to think their movements through and become familiar with them which led to new movement variations.

During the *PES4CT* technique, the children liked copying and comparing their performance, giving feedback, and setting challenges for one another (Q2|H). These opportunities were given during warm-up exercises (Márquez Segura et al., 2021), e.g. one exercise involved moving like different animals according to the color codes of a bracelet with a LED light. Different children were moving in different ways at the same time, and there was some degree of control over movement changes both by the instructor and the children. Also, since the TTPs were attachable in different ways and to different body parts or objects, the exercises could lead to different kinds of movements and performances.

In the *KidReporter* technique, the designers gathered children's diverse interests and inputs in the format of a final product, a newspaper. Therefore, the children participated in several activities such as taking photos in the zoo of the animals that they liked, interviewers among each other and article writing about their interests. We assume

[2] FrontBalance TTP. Augments tilt in the frontal plane through haptic and visual feedback: tilting towards one side triggers vibrations on that side. It also triggers changes in the LED ring: with no tilt, the central LED is lighted up; depending on body tilt, it moves towards side LEDs of the ring incrementally. The FrontBalance TTP was originally conceived to support thinking about balance and weight distribution in vertical positions, e.g. used as a belt, it would tell if the hips were or not squared. The TopBalance TTP augments tilt on horizontal surfaces, such as the top of the head, the shoulders, or the belly or back on some exercises on the floor, e.g. doing planks, or a bridge pose, or standing on all fours (knees and hands on the floor).

Fig. 1. A group presenting a royal court with a king and his servants and the corresponding drawing.

that the participation in the different activities may have allowed the children to understand different perspectives on the same topic by comparing the photos, descriptions and articles taken by their peers (Q2|H).

Q3: Emergence: Generating Ideas through using the technique and their unfolded embodied meaning

The application of the quality *Emergence* illustrates how the range of design ideas (interaction, content or visual aspects) became apparent using each of the three techniques. The *Body Shadows* technique allowed the children to represent visual ideas of the prototype in different formats but it did not lead to interaction ideas (Q3|M). Specifically, the children were first instructed to produce a drawing of their idea and then to represent it with their bodies. The outcomes showed that the drawings were often overloaded with symbols and small details (Fig. 1). Representing the same content through shadows allowed them to concentrate on the main aspects of their drawings and thus to extend and refine them.

The *PES4CT* technique supported the children in finding new ways of using and wearing the TTPs on their own (Q3|H) (Turmo Vidal et al., 2020). The TTPs were also evocative, spurred creativity and triggered more training-focused ideas, like mini-game challenges. Some were initiated by the instructors to scaffold challenges and exercises, e.g. they suggested using the Blower TTP, a headset that reacts to blow with audiovisual output, while doing crunches and trying to light up as many lights as possible (Márquez Segura, Turmo Vidal, et al., 2019a). Another child wore a laser on his forehead and taped a cardboard plate on top of a balancing stick to remind him to look up instead of down at their hand.

The *KidReporter* technique showed to provide ideas to the designers, i.e. they obtained information about children's preferences in relation to game types (in-house games, outside activities and electronic games) and skills related to navigation, the informal language they used and depicted possible gender differences; however, it did not reveal any specific requirements in relation to the interaction design of the prototype (Q3|M).

Q4: Embodied Memory: Producing design elements or body knowledge of people's lived sensations that leave traces in their understanding about design qualities of an interactive experience

The application of the quality *Embodied Memory* revealed the existence of traces of embodied action in different formats between the three techniques. The *Body Shadows* technique produces both material and immaterial outcomes (Q4|H), i.e. the designers recorded videos and took photos of children's performance which could be used to inform refinements for the design ideas. Similarly, the technique allowed the children to easily repeat shadow performances that they had explored building on their previous felt-experience.

Instead, the other two techniques manifested in "immaterial" outcomes, i.e. sensations and felt-experiences. The warm-up games during the PES4CT technique helped the children prime and sensitize to the subsequent training (Q4|M). Posteriorly, the instructors and the researchers reflected on the value of the warm-ups to prepare the children physically, socially, and mentally (Márquez Segura et al., 2021). The *KidReporter* technique very likely has led to children's memories of the visit which were enriched by multimodal impressions of the zoo visit such as tactile experiences, smells and visual impressions (Q4|M).

Q5: Situated Relationality: Understanding relationships and dependencies of situated interactions between people and the world when designing

The application of the quality *Situated Relationality* showed how each technique supported the relationship between participants and their physical and social environment during the emergence of an idea. In the *Body Shadows* technique, the children started to play with different distances to the light source to increase or minimize the size of their shadows and in relation to other participants (Q5|H). For instance, one group represented in their drawing several trees, human figures walking in different directions and a small hand. During the technique, the group incorporated a large-sized hand in their scenario by acting with a real one right in front of the light source. Superposing bodies during their interaction with each other allowed the children to play with the notion of connectedness to represent still images of interaction ideas.

In the *PES4CT* technique, the children used the TTPs to place them on each other's bodies and on objects in the environment in order to explore their affordances (Q5|H). By encouraging the children to individualize their challenges, instructors also encouraged children's playful exploration of training activities and reflections on their own strengths and challenges. At the same time, connecting with others and objects from the environment allowed the children to understand their individual experience during the exercises, e.g. of the act of balance.

In the *KidReporter* technique, the children in the photographer role explored the spatial qualities of the zoo through their bodies and collaborated with their peers during the interviews (Q5|H). The spatial exploration of the zoo may have given them also an intense feeling of presence and motivated them to look for a wide range of sensorial clues to support their explanations (e.g. smell of the environment, pat the fur of some animals, etc.). Furthermore, they interacted with other zoo visitors, e.g. asking them for directions since they were not able to understand the signs in the zoo.

Q6: Contingency: Coupling achieved between our bodily actions, the physical world, and the digital stimuli

The application of the quality *Contingency* revealed that only the *PES4CT* technique allowed the children to understand how the technological solution employed could enrich their sensorimotor experience (Q6|H). While using the technique, the children were very creative in exploring if and how the technology could support their training. For instance, children wore TTPs on different body parts than those they were first introduced to, finding new uses and training value (Turmo Vidal et al., 2020). In general, the instructors helped curate the exercise variations children came up with, encouraging those that fit the training well, and adapting those that did not.

Instead, the *Body Shadows* and *KidReporter* technique did not require

Fig. 2. (a) A child appropriates a juggling club using the FrontBalance to augment tilt; b) One child uses that TTP to do crunches, on which another child comments; c) A child uses the Movement TTP to walk the wire.

the use of a specific prototype and, consequently, may not have led to specific experiences that would support children's understanding of how to connect their ideas to a specific technological solution (Q6|L).

Q7: Playful Engagement: Stimulating children's innate desire for play and motivation to participate in an activity

The application of the quality *Playful Engagement* illustrated how each technique motivated the children to join and actively participate in it. During the *Body Shadows* technique, the children were engaged in pretend play and the 'acting-as-if' of physical actions which went beyond an ordinary movement exercise (Q7|H). For instance, one group enacted a scenario in a wizard restaurant where the chef and the waiters experienced the reactions of an explosive fog meal. This process allowed them to dive into the realm of an imaginative and aesthetic experience.

The *PES4CT* technique showed that the children's engagement with the circus training was playful in nature and designed with the intention of providing open-ended play (Q7|H) (Márquez Segura, Waern, et al., 2019). Specifically, the inclusion of technology and game-like activities made it easier and more enjoyable for the children to think of new play forms of the TTPs. Further, all of those play forms were part of the training protocol, and were included in warm-up games[3] played as sensitizing activities at the beginning of the sessions. Also, circus training is consonant with playification in that it is performed in a social context but almost entirely without competitive aspects, fostering a sense of relatedness while avoiding competition and scoring. A part of the circus training is that every performer or performance group must develop their own 'act'. Circus training is also spectacular, allowing the children to feel that they are doing something grand and special due to the performative nature of circus (Márquez Segura, Turmo Vidal, et al., 2019a).

The authors of the *KidReporter* technique did not describe children's motivation to participate or experience during the activity. However, the children actively contributed to the different tasks (Q7|M). Thus, we assume that the activity was engaging but may be improved by providing a broader variety of tasks that include different ways of bodily explorations of the zoo.

Q8: Play Practice: Distinguishing between children's rhythms of bodily and social doings related to the surrounding space

The application of the quality *Play Practice* indicates the variety of bodily and social behaviours that the children expressed while using each of the three techniques. The *Body Shadows* technique promoted a play practice related to the view of '*sliding for devotion' (Q8* | M) i.e. after finishing the drawings, the children discussed briefly how to represent their ideas with body shadows on the stage, and positioned then themselves quickly with a pre-defined composition in mind. Their bodies moved very slowly and hardly expanded their subjective space to make small adjustments in their postures. The children enjoyed this playful way of exploring their movements together in a slow rhythm.

The *PES4CT* technique showed to be very performative and allowed different play practices at different moments (*Q8*|H*)*. On the one hand, the technique helped the children of being at focus and "on the stage" when performing (*displaying for tension)*. This was both by design but it also resonated with the play practices initiatives of the children. For example, they excelled at coming up with their own particular ways of training during "solo" or "parallel" exercises. On the other hand, the technique enabled fantasy play (a combination of *displaying for tension* and *exceeding for euphoria*). For example, during and after warm-up games and other exercises employing laser wearables, children engaged with pretend play acting as if they were "ironman". Further, the technique promoted and involved conscious movements and repetitive actions which relate to the view of play practice *sliding for devotion*, for its focus, flow, and common agreement on meaningful actions.

The *KidReporter* technique may likely have promoted a play practice related to the views of *'sliding for devotion'* and *'display tension'* (Q8|H), depending on the role that the child was assigned to. The children in the reporter and article writer role needed to be focused on their tasks. Their activities did not involve physical activities in the zoo itself but retro perspective reflections upon the visit (Bekker et al., 2003). In other words, the children were asked to revisit the zoo physically and mentally (i.e. writing descriptions of photos, articles and record interviews of animals and aspects of the zoo that they were really interested in).

Q9: Developmental Scaffolds: Supporting children's age-specific cognitive, physical, social, and emotional abilities in the design

The application of the quality *Developmental Scaffolds* highlighted which skills and abilities children from an age-specific or individual user group (e.g. special needs) were able to perform during each technique. In the *Body Shadows* technique, we focused on children (11-12 yrs) who were physically very capable to perform more complex movements and used the performance as a way for self-expression (Q9|M). For instance, one group played with their shadows in relation to the possibilities of scale. In their drawing, they had previously represented a magical forest with two characters climbing up the trees. Through the technique, they represented one of the trees by the shadow of a human torso in a large scale. Specifically, they explored different sizes by changing the distance between them and the light source and reflected on which strategy could work best to convey the desired visual effect.

The *PES4CT* technique provided accessible physical challenges (Q9|H) for the children (9-12 yrs) with very different manifestations of

[3] These included games with and without technology and were meant to be motivating play practices that prepared children mentally, physically, and socially (Márquez Segura, Turmo Vidal, et al., 2019a) to the subsequent training (Q1-Q6,Q8-Q10).

Sensory-based Motor Disorder (SBMD). This was related to the flexibility and adaptability of the TTPs, and the creative initiative of both children and instructors, who found interesting variations of usage in service of the playful training activity (Márquez Segura, Waern, et al., 2019). For instance, a boy used 2 Movement TTPs (providing audiovisual feedback on pace), one on the chest, one on the wrist to help him walk the tight wire. He mentioned that he could distinguish both sounds well (the one on the wrist beeped more frequently due to the rapid balancing movements of the hands). Still, it was clear that children needed to balance those play forms with radically different others, such as engaging with energetic actions involving fast changes of movement speed, direction, and height and silly actions that were just fun but non-consequential for training. The instructors and the researchers embraced those more ludic play forms as they naturally happened since they understood they were important for the children. Importantly, these techniques were successfully explored with children who struggled with issues access and control of the proprioceptive senses, i.e. with balance and postural control; sense of movement, speed, or force; and motor planning, coordination, and execution. The technique involved them in playful and open-ended sensory experiences, that helped them children develop their sensory capacities (Márquez Segura, Turmo Vidal, et al., 2019b).

In the *KidReporter* technique, the consecutive steps of the activity might have helped the children (9-10 yrs) to think about why they had chosen these aspects and through their explanations, it may also have helped their decision-making process (Q9|M). On the other hand, children's input also allowed the design team to understand what kinds of animals and topics children of this age group were generally interested in (Bekker et al., 2003). The authors did not report on the participation of children who may have had limitations in relation to their cognitive, physical, social or emotional abilities.

Q10: Social Dialogue: Promoting empathy and a collaborative attitude between the participants of a design activity

The application of the quality *Social Dialogue* showed how three of the techniques sparked generative and fruitful dialogue among the children and which participation rules, collaboration strategies, and social dynamics support this dialogue. In the *Body Shadows* technique, the children coordinate with each other to achieve visual effects through their shadows and received constructive feedback from their theatre teachers in order to improve their performance (Q10|H). Often, children's dialogues were mutual agreements happening in silence without the need for verbal interactions, just by observing each other's postures and finding a complementary bodily representation. Before the exercise, the theatre teachers had instructed the children in the procedure of the technique. Then, the children freely explored their ideas in the first performance, followed by a feedback round with their teachers and peers. In the second performance, they had the freedom to integrate this feedback, if they found it appropriate for their ideas.

The *PES4CT* technique promoted social dialogues among the children, and also with instructors who considered supporting children's feeling of being empowered while moving were as a key design factors during the training classes (Q10|H) (Márquez Segura et al., 2021). These interactions lead to proposals about the usages and TTP appropriations by one another. Among others, the technique included several warm-up exercises which were joint exercises intended to create focus, bodily movement, and group cohesion among the participants. At the same time, the instructors focused mostly on letting the children explore and enjoy the circus exercises than on achieving accurate performances. Through this focus, the children experienced empowerment during the movement exercises and enjoyed expressing their proposals. Also, the fact of providing choices and allowing the children to find their own unique ways of expressing themselves framed their variations as opportunities to create something special, individual and worth admiring.

As previously described, in the *KidReporter* technique, Bekker et al. (2003) observed that the role-play activity created an atmosphere in which the students felt more comfortable giving their opinion with relatively little influence from authority figures, such as guides, teachers or opinionated classmates. In a sense, they did not feel self-conscious about providing their opinion, nor were they afraid of what others might think. This atmosphere may have created fruitful and generative dialogues between child and adult participants. However, the children were not involved in the creation of the final newspaper, i.e. the designer selected the design ideas and made the final decisions (Q10|M).

4.2. Reflections on limitations and future directions

The three techniques presented several limitations in their use. The *Body Shadows* technique did not allow the children to translate their felt-experience into concrete interaction design ideas. To address this issue, the designer could guide the children with enactments working with slowing down or increasing the speed of the movements. This could evoke relevant body sensations and draw the audience's attention to different types of visual effects (Q1|M). On the other hand, the technique did not allow the researchers to make conclusions about digital augmentations that could be adequate for the interactive experience (Q6|L). In this regard, shadow practice using accessories (Montecchi, 2015) could allow the children to modify the appearance of their shadows and to think of other visual ideas. Another possibility would be to use the effect of superimposing not only with different body parts but also between different actors to explore social interaction and the qualities of shared interaction space. In the *PES4CT* technique, designers did not have a straightforward access to children's embodied awareness (Q1|M) and embodied memory (Q4|M) which were relevant aspects to training. This analytical research issue could be mitigated through the TTPs, recording the children's actions, which we could be mapped and contrasted to video-recorded behavior, think-aloud techniques, or mini-interviews after each exercise. Last, the *KidReporter* technique showed an imbalance in the design partnership between the designer and the children (Q10|M). Due to time constraints, the designer selected and defined the final content for the newspaper. A refinement of the technique could imply involving the children in the entire creation process of the newspaper from the research, evaluation, content selection, and design of the final medium. Our analysis opens the discussion of whether any embodied co-design technique with children needs to match all ten qualities (Fig. 3). For instance, *PES4CT* fared less favorably in children's embodied awareness (Q1|M) and embodied memory (Q4|M). However, while those were important design targets for final designs, they were less consequential in the early explorative stages of the project. Then, both the *Body Shadows* and *KidReporter* techniques lacked in informing the design process in relation to contingency (Q1|L). This was important for *Body Shadows*, as reflections upon meaningful digital augmentations were essential to concretize technological prototypes in that project. Instead, the *KidReporter* technique was used in the early stages of the design process with the goal of understanding children's interests and needs around a site-specific location. Hence, this lack was more relevant for the former.

5. Discussion

The *Think-4-EmCoDe* framework is a tool that foregrounds key aspects of embodied, co-design and children-specific methods by drawing on the benefits of an intersection of these three areas. It can be used retrospectively to articulate and describe the technique, and to understand the observed behavior in relation to their constitutive aspects. The framework facilitates reflection and evaluation of the technique by pointing to its strengths and weaknesses (Fig. 3). This analytical process may be relevant for researchers and designers to evaluate if they selected the right technique in relation to the design goals or how to adjust it to fit the purposes of the research project. We contend that the shortage or abundance of qualities needs to be assessed based on the goal and knowledge sought, and contextual contingencies of the project, including the stage of the design process, and logistic and time

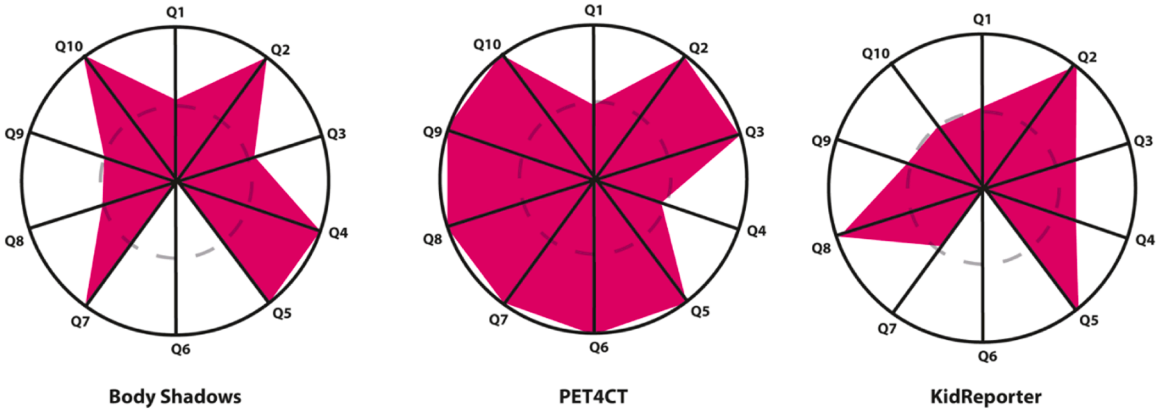

Fig. 3. Visualization of the potentials and limitations of the three techniques Body Shadows, PES4CT and KidReporter. Outer circle: technique led to a high achievement level of the design goal (H). Middle circle: Technique partially led to the achievement of the design goal (M). Center: technique did not lead to the achievement of the design goal (L). Reminder of the qualities: Q1: Embodied Awareness; Q2: Reflective Imagery; Q3: Emergence; Q4: Embodied Memory; Q5: Situated Relationality; Q6: Contingency; Q7: Playful Engagement; Q8: Play Practice; Q9: Developmental Scaffolds; Q10: Social Dialogue.

constraints.

As an intermediate-level knowledge form (Barendregt et al., 2017), the *Think-4-EmCoDe* framework can be judged in terms of whether it is *contestable* (novel), *defensible* (well grounded, empirically or theoretically), and *substantive* (relevant to the community, and with potential to be used outside the scope of a research group/project) (Barendregt et al., 2017). These are key assessment criteria for contributions that lie at the level of abstraction of our framework. Furthermore, the *Think-4-EmCoDe* framework adds to existing approaches in the community (Hummels & van Dijk, 2015; Karoff, 2015; Malinverni, 2016; Schaper et al., 2019; Walsh et al., 2013) through a constellation of ten complementary qualities that can serve multiple purposes, from characterizing an embodied co-design technique with children to evaluating and reflecting on its weaknesses. Particularly, we developed complementary qualities to those used in the two methods (Schaper et al., 2019; Walsh et al., 2013) that we acknowledged previously as the closes to our objectives. In regards to the FACIT PD framework (Walsh et al., 2013), our approach offers a more fine-nuanced perspective on aspects related to the embodied experience such as the potential of a technique to stimulate embodied awareness and to leave traces that embed embodied memory. Furthermore, we extend the FUBImethod (Schaper et al., 2019) by providing a tool for the reflective practice of children's design ideas.

We have used preliminary versions of the *Think-4-EmCoDe* framework in previous publications (Schaper et al., 2019; Schaper, 2019). In this article, the framework has gained a strong level of maturity. Moreover, we have developed a codebook (see appendix) which facilitates other practitioners to explore the potential and weaknesses of embodied design techniques for children in their own work. In its current form, the *Think-4-EmCoDe* framework makes a strong emphasize on phenomenology-inspired embodied theory (6 out of 10 qualities). This focus highlights the relevance of considering different aspects of the relationships between the surrounding world, sensorimotor experiences and emerging social interactions. Three qualities focus on child developmental theories embracing important aspects to motivate children's participation in a design activity by scaffolding on their natural play behavior and age-related and individual needs. Finally, the last quality focuses on reflections about children's role and empowerment in co-design practices. Throughout the development process, we adjusted descriptions and the order of several qualities since our discussions with the different authors revealed a certain ambiguity in some of them. For instance, we strengthened the difference between the quality *Embodied Awareness* (Q1) and *Embodied Memory* (Q4). Whereas *Embodied Awareness* refers to the capability of a technique to initiate felt-experiences, *Embodied Memory* observed how these felt-experiences are embedded in the material and immaterial outcomes. Understanding these differences is crucial for the designer to understand how a technique unfolds and can be improved to achieve the desired design goals.

Also, our framework highlights the dependencies between the different qualities. For instance, if the technique does not stimulate *Embodied Awareness* that would also mean that *Embodied Memory* cannot be manifested. Similarly, a technique needs to provide at least a middle level of *Playful Engagement* in order to support one or more *Play Practices*. Another important step was to order the sequence of the qualities according to the three theoretical underpinnings. In their current order, the 10 qualities build upon each other and are meant to scaffold a stepwise reflection on the different core aspects that the evaluation of an embodied design technique for children entails. In this regard, the framework has shown to be useful outside the context of a particular internal project, as proven by its use by our invited co-author, and the analysis of an external technique. This points to the transferability potential of our framework in other contexts in the areas of co-design and Child-Computer Interaction.

6. Conclusions and future work

The framework may provide a well-grounded scaffold that can help designers orchestrate the design partnership between intergenerational co-designers in a way that leverages core qualities of techniques in the areas of Child-Computer Interaction, co-design and embodiment. We also think that the *Think-4-EmCoDe* framework may have generative potential as a tool for designers to develop novel techniques for children (Schaper & Pares, 2021). This remains future work for us – we are currently working towards increasing accessibility and outreach of our framework through a set of quality cards, which could be used as design or evaluative material of techniques. We plan to develop, test, and refine this kit in workshops together with other designers. One main challenge remains that the use and communication of embodied techniques are often idiosyncratic (Wilde et al., 2017), i.e. the knowledge that emerges may be rather tacit than explicit which make some qualities difficult to describe. Hence, our kit needs to address ways of promoting a common vocabulary to make the analytical process shareable with and transferable by others. Yet, we encourage the design research community in Child-Computer Interaction to join us in exploring this facet of the framework. We suggest starting with a context- and project-specific design goal, then developing or adapting a technique considering how each quality may impact that goal, and how it could materialize in particular activities, supported by other contingencies such as design materials and spatial particularities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Supplementary materials

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