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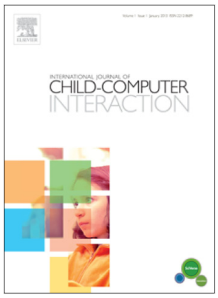

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A review of selected methods, techniques and tools in Child-Computer Interaction (CCI) developed/adapted to support children's involvement in technology development

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ABSTRACT

Child-Computer Interaction (CCI) explores the design of systems that reflect the nature of children's growth and cognitive development, and the opportunity for children's involvement in the design process through developing their own technology in collaboration with researchers and designers. In this paper, we focus on the potential roles played by children in the design process, and we review various CCI methods, techniques, and tools that have been developed/adapted to support children's involvement in design. In particular, we offer a systematic mapping and description of the methods, techniques, and tools from User-Centred Design (UCD), Learner-Centred Design (LCD), Participatory Design (PD), and their overlaps. Through a review of these different approaches to design interventions, we discuss some of the elements involved in the reviewed co-design activities, i.e., the age and number of the involved individuals or the settings and contexts of the design activities. We also examine the level of information (or lack of) offered in the reviewed publications and highlight areas that require more attention. As a result, we hope to offer a resource that could benefit and inspire future designers/researchers in the CCI field in selecting design activities for collaborative work with/for young individuals in developing and testing different interactive technologies. We also hope to identify requirements for future research that will help to improve and expand current knowledge in the field of CCI.

Keywords:

Children
Child-Computer Interaction
User-Centred Design
Learner-Centred Design
Participatory Design
Technology development

1. Introduction

Child-Computer Interaction (CCI) is a multidisciplinary area of research concerned with child-computer and communication technologies interaction, which enjoys the contributions of developmental psychology, learning science, product and interaction design, computer science, etc. [1, 2]. As a research discipline within Human-Computer Interaction (HCI), CCI is focused primarily on establishing the requirements for the design of new interactive systems and interfaces to be used by children. One of the emerging roles of CCI is also to examine various methods to facilitate the participation of children in the design of interactive technologies [3]. Involving children in the design

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of various technologies requires a good knowledge of CCI theory along with available design activities developed/adapted to support the design practices. As a new discipline (the first Interaction Design and Children (IDC) conference was held in 2002 [1, 4]), the field enjoys a diversity of co-design approaches [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15], but still lacks works that more systematically map and compare the various design activities in an attempt to help their selection and adaptation when designing with children. Systematic reviews on the design methods and techniques developed to support the participation of young individuals in the technology development process already exist [16, 17]. However, these studies revolve around users with special educational needs and/or disabilities (SEND)[2] and developmentally diverse children[3].

This work is focused on typically developed children with no special needs, and in this sense, it links with the seminal work of J.P. Hourcade [1]. In his book 'Child-Computer Interaction', the author discusses a wide range of topics related to CCI – from the formation of the community and IDC conferences to child cognitive development, design, and evaluation methods for/with children, the design of technologies for young individuals with special needs, and challenges and future opportunities. This paper links with his discussions on the design and evaluation methods developed in CCI and used in different stages of a User Centred Design (UCD) (i.e., identifying needs and establishing requirements, developing design ideas, prototyping and evaluating prototypes). Our contribution is to more systematically map how different design interventions support different roles of children's involvement and engagement, i.e., tester, informant, and design partner. We also discuss some of the differences between User-Centred Design (UCD), Learner-Centred Design (LCD), and Participatory Design (PD) to help designers/researchers identify how the various methods, techniques, and tools facilitate children's participation and engagement. The first two sections (2 and 3) respectively offer a discussion on HCI and children and a review of the UCD, LCD, and PD approaches that have been adopted/adapted when designing interactive technology for children. In these approaches, the young individual is conceived not only as the user of a piece of technology (a technology that needs to match their abilities and limitations), but also as an active participant in the design of the technology itself. We then consider how young individuals, when acting as design participants, can play the roles of tester, informant, and design partner [14], and further review a series of methods, techniques, and tools that have been developed in CCI to support these roles. In section 4, we offer a framework adapting Sanders' map of different methods in HCI [18]. In our proposal, the methods, techniques, and tools fall within the three main approaches of UCD, LCD, PD, and their intersecting zones. In our discussion and conclusion, we offer an analysis of all the reviewed methods, techniques, and tools by discussing some of the important factors that should guide the planning of design activities with children. These range from the number of children involved to the ages of such children, and from the setting and context of the various co-design activities to the phases of the design process where children are more (or less) commonly involved. As a result, we suggest a set of requirements to be followed by the researchers in the CCI community when they explore children's involvement in the designs and report about it in their scholarly publications. With this work, we hope to offer other researchers and designers who need to work with young individuals a critical framework to guide and better plan their interventions.

[2] In the two articles in question, four areas of different educational needs were defined, i.e., 1) communication and interaction, 2) cognition and learning, 3) social, emotional, and mental health difficulties, and 4) sensory and/or physical needs. These needs are often caused by the child having Down's syndrome, profound cognitive disabilities, anxiety disorder, cerebral palsy, visual impairments, hearing impairments, attention deficit (hyperactivity) disorder (ADD/ADHD), etc.

[3] These are children that may have ADHD, autism spectrum conditions (ASC), Down's syndrome, cerebral palsy, intellectual disabilities, or combinations thereof.

2. HCI and children

It is difficult to pinpoint the moment when CCI was established. The great number of studies and publications investigating children and technology for the first IDC conference in 2002 [1, 4] can reasonably mark the beginning of a growing field. At the beginning, CCI was more concerned with the technology used in child education. In line with this view, Read and Bekker [19] proposed that the CCI is “a study of the Activities, Behaviours, Concerns and Abilities of Children as they interact with computer technologies, often with the intervention of others (mainly adults) in situations that they partially (but generally do not fully) control and regulate” (p. 7). CCI, however, later matured as a discipline that also focuses on methodology, seeking to find out how to design and evaluate interactive technologies not only ***for***, but also ***with*** children [4, 19, 20]. This “dual role” of CCI was pointed out by Read and Hourcade [3], who believed that both roles are concerned, first, with the methods that facilitate the development of many different types of interactive technologies, particularly for young users; and second, with the methods, techniques, and tools that help to involve children in various design activities (p. 2481). Design methods defined for adults in HCI would not be applicable to designing with children because of the developmental differences; the methods would need to be redesigned for children [1, 2, 4, 21, 22]. It is also important to note that children are more likely to use technology for playing, learning, and communicating as opposed to doing work as adults [2, 19], and this also reflects on the organisation of the design process and its activities. As a growing and quickly transforming new discipline that supports the work between young users and researchers, CCI urgently needs “to start to develop a theory” [23, p. 689] and develop research that aims at developing appropriate guidelines and methods for the participation of children in design process [4, 24].

Children’s development and their needs are obviously very significant aspects when they are to be involved in the design of interactive technologies. Based on their design experience with this young population, some researchers have highlighted that designing products that do not take into account the child’s development (e.g., interface, task and features) may be ineffective in the context of use or may even cause harm [4, 24, 25]. This strongly reaffirms the importance of developing recommendations in HCI when the adult participants are replaced by young individuals. For example, children develop their cognitive skills (for example, gaining new skills in areas of literacy, science, or mathematics, as their thinking abilities and intentional processes are different at different ages) and fine motor skills (that is, actions performed with the small muscles in the hands, fingers, and wrist that exercise control and are used for holding a pencil, for holding and showing proficiency with scissors, or for dressing a doll properly) at varying ages [24, 25], thus explaining the disparity between children’s abilities to interact with technology.

In this sense, we argue that it is important to develop guidelines to support not only better interactions in using with children products targeting specific ages and developmental stages, but also guidelines to select/adapt appropriate co-design activities to support more effective child participation in the design of various products. Considering child development, and the fundamental nature of childhood and well-being, Markopoulos and his colleagues [26] suggested that while “childhood is generally defined by biological age, the differences across cultures and societies that impact on children and childhood cannot be ignored” (p. 4). They also argued that the methods in HCI “need serious revision” when the participants are children [ibid., p. xviii]. In another study, Read and Markopoulos [2] emphasised that CCI is still an ongoing process, and the needs of empirical work on different aspects of children’s technology design could help to develop new methods to explore and study CCI phenomena. The themes in CCI that are currently being discussed include interaction techniques, evaluation methods, and design practice [ibid.]. For Read [27], CCI “has not yet reached that level of maturity as an academic subject – there are neither enough people, nor is there enough knowledge to have that level of debate" (p. 268); hence, this suggests that further studies in the field of CCI are highly recommended.

3. UCD, LCD, PD and children

For Norman [28], UCD is an iterative "process" that places the users at the centre of the design (p. 185). This process typically consists of four different phases (1st - Research on the users' needs and the context of use; 2nd - Design exploration; 3rd - Prototype building; and 4th - Prototype evaluation) that aim to address, meet, and serve users' needs to optimise the product quality design [29]. A specific International Organization for Standardization (ISO) 9241-210:2010 [30, 31] has also been developed with reference to these four phases and with a special emphasis on user participation in the development of new technology. The conventional UCD process examines users as testers and evaluators after the technology or prototypes have been designed. As a result, the involved participants have little or no control throughout the process of exploring the design space and developing a design [32]. When applying this approach, the actual contribution or feedback will only shed light on the positive or negative characteristics in finalised designs as per the user's feedback [33]. In contrast, adopting the 'Scandinavian model' of PD for equal participation during all phases of the systems/products development means participants have more responsibilities. These responsibilities are derived from a stronger assumption of equality amongst the participants for working with designers as equal design partners [34]. LCD is similar to UCD; however, guided by the educational theory and assuming that everyone is a learner, the users are replaced by learners [35]. Learners can be at different ages; they can be children, students, or professionals who have diverse learning needs. Scaffolding strategies in LCD suggest that the developed technology should work as a vehicle incorporating features that help learners to gain adequate knowledge and skills of a new work practice; it should be adapted to the learner's needs, style of learning, and context of use [ibid.].

The early discussions about the role of children in UCD focused on the technology's impact and on the young individuals' role as testers, evaluating designed technology before it is released to the public [14]. Based upon young users' direct involvement with technology developers, Markopoulos and Bekker [20] remarked that traditional UCD is more focused on the HCI principles related to adults and less on issues linked to children. They highlighted that the "standard user centred design approaches need to be adapted when we consider the specific needs of children", as well as when the focus is on a special target of users, such as the elderly or people with disabilities, to address their cultural influence, characteristics, and needs (p. 148). More iterations of the UCD are needed when designers develop software-based applications and products that have a higher level of interactivity, and the number of children involved in the evaluation practices must be planned carefully [26].

Based on "an analysis of the literature" and on her "own research experience with children", Druin [14, p. 3] suggested a model that examines the roles of children in the design process as user, tester, informant, and design partner, as presented with four circles in Fig. 1.

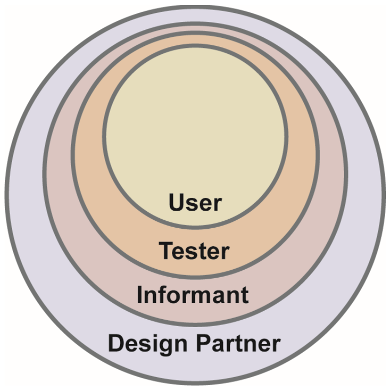


Fig. 1**. Roles children can play in the design process - Druin's model**

In the article 'The role of children in the design of new technology', Druin [14] highlighted that each of these roles "offers a different degree of empowerment", the contribution in design and children's participation respectively increases as we move from the inner to the outer circle (p. 29). For example, in performing the user role, children play with a final product that is released onto the market but have had no involvement in the technology design. The role of adults is to collect data through making observations and taking notes, pictures, and videos, as this will help to understand how the technology affects the young user. Playing the role of tester, children test the initial prototypes of "emerging technologies" after they have been created, and the goal is to suggest improvements and re-design in accordance with their recommendations [ibid., p. 9]. Researchers or industrial professionals may conduct observations or ask questions related to technology features and use. The role of informants was influenced by the Informant Design (ID) [15]. When playing the role of informant, young participants produce various inputs to the design process (typically only at the very beginning of the product development), but their engagement is not that of equal design partners: they are 'native informants', who offer information to the designers, but have no say on what the designers develop. In the last role – the design partner – children are equal stakeholders throughout the entire design process of new technology design, like adults in PD[4].

It might be argued that all roles fall under the category of informant, as any involvement of the child will produce some sort of information for the designers to take up and act upon. The difference in the role mostly concerns the conditions under which the information is obtained and what information is provided: children as users and testers are involved in settings that pre-empt their involvement, children are typically undergoing tests that are the same across all the participants, the participation is planned, and the participation is rather passive and is on the designers' terms (the only difference being that the users are confronted with a final product while the tester is given a prototype, so the

[4] Along with the model, Druin [14] suggested three dimensions (e.g., relationship to developers, relationship to technology, and goals for inquiry) that help designers to identify the child's role in the design process as well as to select an appropriate design approach for working with young individuals. The first dimension explains the relationship between children and designers when developing new technology; this could be indirect, for generating feedback, supporting dialogue, and elaborating upon ideas. The second dimension deals with children's involvement in the different stages of the technology development, so the young individuals can contribute not only with ideas, but can even build prototypes or products. And the third and final dimension - the goals for inquiry – is concerned with the purpose of the study, which may range from developing theory, questioning the impact of the design, or trying to better understand the usability and/or design of a system. It is worth noting that Druin's model and the three dimensions for identifying the user's role in design were critically discussed [22, 36]. Fails and colleagues [22], for instance, suggested adding three further dimensions (i.e., partner location, scale of content, and relationship to physical) for identifying and employing methods and techniques when involving children in interactive technology design.

input of a tester can actually be factored into an iteration of the prototype). Informants are more open, but still behave according to the terms used by the designers, who ask questions and set up specific activities for the elicitation of specific types of input that are needed from their perspective. The design partner role is the most open as, when genuinely done, it empowers the participant to influence the direction of a project at the start and throughout the whole process (thus influencing not only the goals, but also the language of the project within the infrastructural limits of the project (e.g., agreed outputs with financing bodies)). It is important to note, however, that these roles are indicative and constitute theoretical abstractions that often overlook the actual practicalities of involving children in a design process. In discussing a project using ubiquitous technology to support storytelling, Marti and Bannon [37] reported that the UCD approach with children can often be more complicated than anticipated and that it is difficult to identify or assign clear roles or those role shifts, as it is difficult to sustain these throughout the whole process. Bearing in mind the defined four roles of children in the design process [14], they found that not all children are open to participate as informants or creative designers when they need to talk with unfamiliar adults (designers). In the POGO project, the authors reported that children (6-8 years of age) who were constantly involved in the design process did not fully comprehend how ubiquitous technologies would support narrative activities. To overcome these obstacles, the design concepts were developed by professional designers taking inspiration from user observations. They produced fourteen visions of narrative environments illustrating how the various technologies may facilitate the storytelling process and mediate children's communication. Then children, teachers, and technology developers were invited to evaluate the proposed solutions. This experience suggested that user-centred and user-involved designs are highly influenced by the work environment, age, and skills of the young users: "User participation should always be regarded as a value; it should be tailored to the knowledge and the abilities of people involved in the design process. Users need to be prepared for playing their role effectively, for contributing with their domain knowledge to the project, for defining concepts, for evaluating and comparing solutions and identifying usage problems according to their abilities and possibilities to participate in the design process." [37, p. 14]. In this line of argument, Barendregt and her colleagues suggested an extension of Druin's model called the Role Definition Matrix [36] as a result of which "children might change roles during a project" (p. 581).

In this study, we use the roles that individuals played in the design based on the information given in the reviewed articles, and these mostly conform to Druin's nomenclature: tester, informant, and design partner. The focus, however, is on the methods, techniques, and tools that enable these roles to be taken by the participants. In this sense, we argue for a shift of attention from the 'theoretical roles' that might be desired by the designers for their participants, to the selection of the different methods and techniques with the aim of actively involving users in some or all phases of a design process.

4. A Review of selected methods, techniques and tools in CCI

4.1. Criteria used for selecting co-design activities developed/adapted for designing with children

The process of selection and analysis of various co-design approaches developed/applied by researchers to design technologies with/for children was carried out between 2013 and the end of 2015. During this time, we reviewed the available literature and publications in the fields of HCI and CCI (i.e., conference proceedings/papers, journal articles and books) published in the ACM digital library and Google Scholar databases between 1996 and 2015. The keywords used for searching and identifying relevant studies were "design process", "methods, techniques and tools for design", "children" and "interactive technologies". The search was complemented by checking the reference lists of all selected papers for similar readings. The criterion for inclusion was only if all of the three following factors appeared to be true: 1) examined children's participation in the development of interactive technologies, 2) described different methods, techniques, and tools that have been developed/adapted and that have involved children in the design, and 3) discussed the roles children played in the design process. Our initial review included 36 papers. All the papers were read by the first author of this article. Only twenty-seven sources [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 22, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52] met the criteria for inclusion, and these were used to create the selection of diverse co-design activities. For clarity, we would like to offer some examples of articles that did not match the criteria for inclusion. For example, the article by Isola and Fails [53] focuses on the role of families in the design process instead of the role of children. Jensen and Skov's [54] work is a review of research methods in the design of children's technology published in journals and conference proceedings between 1996 and 2004. The aim of their review was to "classify existing research papers according to applied research methods in the design of children's technologies" by using a two-dimensional matrix: research methods and research purposes (p. 80). This approach helped the authors to identify eight research methods (namely, case studies, field studies, action research, lab experiments, survey research, applied research, basic research, and normative writings), but the article does not discuss in detail the co-design activities used to design technologies with children. Design approaches developed specifically for developmentally diverse children also exist, but they are also not included in this review. For instance, de Faria Borges and her colleagues [55] proposed a PD4CAT[5] approach to design assistive technology for a child with cerebral palsy, and Benton et al. [56] suggested an IDEAS[6] framework for supporting participatory design with children with Autism Spectrum Disorders (ASD). Kärnä et al. [57] introduced a Child in the Centre (CiC) framework to address the active role of children with special needs and their parents when developing technology to support their daily living activities in different settings, i.e., at schools, at therapy services, at home, etc. While acknowledging these works, this study is intended to be primarily focused on approaches developed for a more general child population; therefore, these works are not included in this review. The PD4CAT and IDEAS frameworks are already discussed in both the systematic reviews by Benton and Johnson [16] and Börjesson et al. [17].

All of the design activities discussed in the reviewed papers were adapted in order to use UCD, LCD, or PD with a child population. For this reason, we labelled the whole set as 'co-design with children' and we ordered the approaches, methods, techniques, and tools in a map. As we will soon discuss, the proposed map does not include all the co-design activities developed in CCI; rather, it offers a visualisation of selected methods, techniques, and tools that fall into UCD, LCD, and PD and their intersecting zones.

4.2. Sander's concept and its application for the classification of methods, techniques, and tools

We argue that when design teams plan design activities for/with children, it is important to examine closely which of the existing design approaches, methods, techniques, and tools suggested in CCI would work best with the characteristics of the young users, their various needs, and indeed, their expected roles in the design process [58]. This section offers a review of the selected methods, techniques, and tools within UCD, LCD, and PD used in CCI. Through this, we explore how the different methods, techniques, and tools support young participants to play different 'roles' and activities in the design of interactive technologies.

[5] PD4CAT supports participatory design with users for developing customised solutions. In this case, the method was modified to develop assistive technology for a child with cerebral palsy who has verbal and motor impairment but understands what others are talking about.
[6] Interface Design Experience for the Autistic Spectrum (IDEAS).

As mentioned, we decided to offer an overview of the methods, techniques, and tools in the form of a visualisation adapted from Sanders (Fig. 2) as well as in a series of colour coded tables (1, 2 and 3). Before moving to the visualisation and the first table, we would like to define what is meant by methods, techniques, and tools. We do this by drawing on another work by Sanders et al. [59], who articulate the distinction as follows:

- ***A method*** is a collection of techniques and tools that used to design different technologies with participants and that are linked to the large design philosophy of CCI (UCD, LCD, or PD being some of the available *philosophies* or, as we used in this paper, *approaches*).
- ***A technique*** is a collection of tools used in a particular way for a specific purpose (e.g., probing the user, understanding the user, or generating ideas). Different techniques can be used while working with one tool. Usually, the techniques give clear descriptions of how the tools are used in the design process with the participants (e.g., children).
- ***Tools*** are different "material components" that are used in design activities [59] (e.g., a deck of cards, an individual probe in a set of design probes, etc.)(p. 196).

To illustrate these notions, Sanders et al. [59] offer some examples in the same paper. For instance, a deck of picture cards is a tool. Each different approach to using such a tool with participants, i.e., sorting the cards, using the cards for building a collage or for developing and telling a story, etc. is called a technique. A tool could be used as a part of different techniques and methods. The ability of a tool to afford certain roles for the participant is therefore not assured, but rather, it depends on the context of its application within a technique and a method; in our case, we refer to how the authors of the papers report its use in the text. The combination of tools and techniques "that are strategically put together to address defined goals within the research plan" is considered a method [ibid., p. 196]. Methods refer to the larger design approaches (or philosophies), which, in this work, are limited to UCD, LCD, and PD.

It is important to stress that all the authors of the reviewed articles share the same terminology especially when it comes to the terms 'approach', 'method', and 'technique', though not all of them offer the same clear-cut distinctions between techniques and tools. We double-checked all the papers' contents with respect to Sanders' distinctions [59], and we classified methods, techniques, and tools as follows: when an author describing a design process used the words 'methods', 'techniques' and 'tools', we first checked if the use would fit Sanders' categories. If so, we adopted the same categories as used by the authors. When information about methods, tools, or techniques was not available or when the separation between techniques and tools was not clear in the original text, then we adopted Sanders' categories and positioned the methods, tools or techniques in the table accordingly[7].

[7] This happened in four occasions: usability evaluation activities discussed by Van Kesteren et al. [6], Problem Identification Picture Cards (PIPC) [42], CARSS (Context, Activities, Roles, Stakeholders, Skills) [13], MESS (Mad Evaluation Session with Schoolchildren) [9] and Storyboarding [44, 45, 46]. Van Kesteren et al. [6] described Co-Discovery, Peer Tutoring, Thinking Aloud, Active Intervention and Retrospection as "methods" for usability evaluation. In applying Sanders' nomenclature [59], these methods are here presented as techniques within the usability evaluation 'method'. Barendregt et al. [42] discussed the PIPC as a "method" that was developed and used "to increase the amount of information expressed by young children during an evaluation" (p. 95). Following Sanders' terminology [59], we identified the PIPC as an evaluation technique in which a set of cards have been designed and used to facilitate the usability evaluation process with young participants. The CARSS [13] was suggested as a framework supporting learner-centred design practices with young individuals while the MESS [9] are days with different events for children where design and evaluation sessions are held. In both papers, the authors [9, 13] pointed out different techniques and tools used for working with children; this is why they are classified and visualised as methods in the map. Regarding the last one, Storyboarding, the authors had different opinions; Emotional [44] and Electronic [46] were discussed as methods while Comicboarding and Magicboarding [45] were described as participatory design techniques. When we applied the definitions given by Sanders et al. [59], we identified Storyboarding as a method with four different techniques.

Following this logic and language, we further drew on Sanders et al.'s map of design approaches [18, 60] and organised our findings into an adapted version of their map. In the map that we propose, we position design methods (big coloured circles) and techniques (small black dots) in CCI for co-designing with children[8]. These are arranged according to the various degrees of involvement as a tester, informant, and design partner [14]. We do not consider the role of the 'user', as this role does not afford any participation and input in the design process.

[8] The tools are included in Table 1 but not visualised in Fig. 2 for two main reasons. The first reason is readability; adding tools within techniques would make the map too busy and difficult to use. The second reason is that while reviewed authors reported on the methods and techniques they used, only a subset of authors offered more detailed accounts of what specific tools and materials were used in applying the described techniques. Moreover, as we have said already, the same tool could be used in different ways and for different purposes within different techniques or in the context of different design approaches, so their position in the map cannot be pinned down in a definitive way.

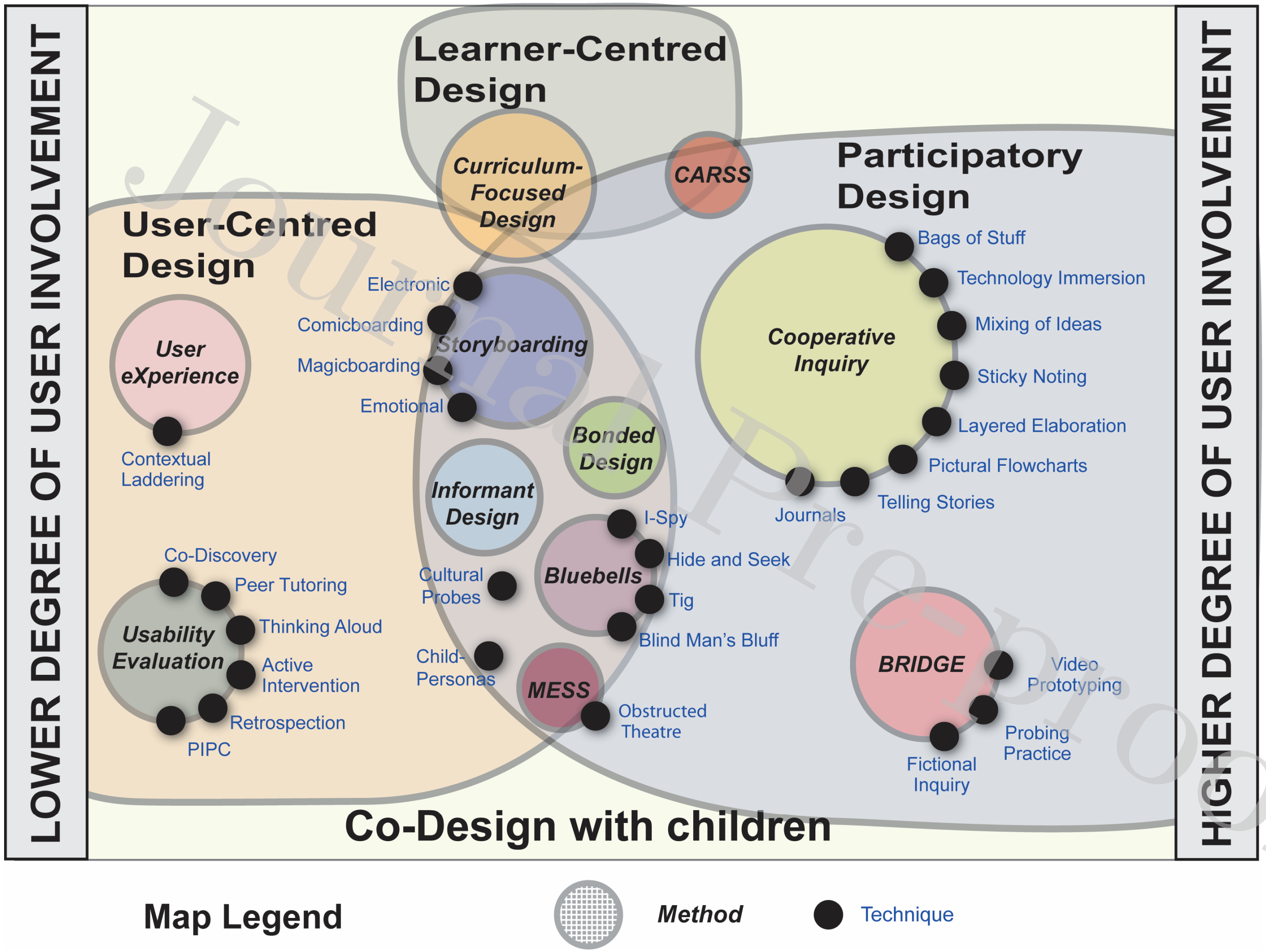


Fig. 2. **A map visualisation of the selection of methods and techniques in CCI (adapted from Sanders' evolving map of design practice and design research)**

4.3. Methods, techniques, and tools: description, purpose, and application

The proposed map offers three mains areas, referring to UCD, LCD, and PD, which partially overlap. We use this map to review the number of co-design activities in CCI that we have identified in our review. To further support our discussion of the methods, techniques, and tools enabling participation, we offer two colour coded tables that map the contents of our visualisation (i.e., the methods are listed in bold, while the techniques and tools are respectively shown in blue and green colours). In the first table, we show the different co-design methods, techniques, and tools that have been used with children (first four columns) along with the age of the young participants (fifth column) and their sample size (sixth column) as described by the authors in the reviewed articles. Left to right, we start with methods, techniques, and tools in UDC. The table is then followed by a brief explanation of each of the co-design activities. We continue our review with Table 2, where we report more details of the co-design activities as follows: the first column displays all methods, techniques, and tools; the second column provides information about the settings in which the designs were carried out; the third column offers a short description of the purpose of each study as reported in the original paper; and the fourth and final column shows the stage of the design process at which the methods, techniques, and tools were applied (i.e., establishing requirements, exploring designs, prototyping and evaluating). In both tables, we used NA (not available) to indicate the lack of information given by the authors in the reviewed papers, and ‘adults or researchers only’ when the mentioned method, technique, or tool is to be used by the designers/researchers only.

Table 1. **Table illustrating a selection of method, techniques, and tools along with target age and number of participants**

Co-design with children	Methods	Techniques	Tools	Target age	Number of participants
UCD area	***User eXperience*** [5, 40]	Contextual Laddering [5]		3-7	46
			This-or-That [40]	4-6	36
			Fun Toolkit [41]	-	-
			- Smileyometer [41]	8-9	24
			- Funometer [64]	3-4	NA
			- Fun Sorter [41]	6-9	28
			- Again-Again table [41]	8-9	24
	Usability Evaluation [6, 42]	Co-Discovery [6]		6-8	19
		Peer Tutoring [6]		6-8	19
		Thinking Aloud [6]		6-8	19
		Active Intervention [6]		6-8	19
		Retrospection [6]		6-8	19
		PIPC [42]		5-6	23
The intersecting zone of the UCD and PD	***Informant Design (ID)*** [15]			-	-
	- Phase one			7-14	78
	- Phase two (only with researchers/designers)			Adults or researchers only	Adults or researchers only
	- Phase three			9-11	60
	- Phase four			7-11	24
	Bonded Design (BD) [7]			8–12	73
	Bluebells [8]	Stage 1 - Before play: only with researchers [8]		Adults or researchers only	Adults or researchers only
		Stage 2a - I-Spy (Play stage with children) [8]		7-9	NA
		Stage 2b - Hide and Seek (Play stage with children) [8]		7-9	NA
		Stage 2c - Tig (Play stage with children) [8]		7-9	NA
		Stage 2d - Blind Man's Bluff (Play stage with children) [8]		7-9	NA
		Stage 3 - After play: only with researchers [8]		Adults or researchers only	Adults or researchers only
	Mad Evaluation Sessions with Schoolchildren (MESS) [9]			4-15	60
		Obstructed Theatre [43]		6-10	45
	Storyboarding [44, 45, 46]	Electronic [44]		8-11	111
		Comicboarding [45]		6-13	17
		Magicboarding [45]		6-13	17
		Emotional [46]		5-7	70
		Cultural/Design Probes [10, 11, 38]	Educationally-Focused [10]	11- 13	Two sixth grade classes
			Digital [11]	NA	NA
			For Child-Personas [38]	10-14	120
		Child-Personas [47]		9-11	44
The intersecting zone of LCD and PD	***Curriculum-Focused Design*** [12]			11	Pupils from one class
	CARSS [13]			7-12	57

Co-design with children	Methods	Techniques	Tools	Target age	Number of participants
PD zone	***Cooperative Inquiry (CI)*** [14]			-	-
		Bags of Stuff [48]		7-11	NA
		Technology Immersion [14]		NA	25
		Mixing of Ideas [49]		4-6	11
		Sticky Noting [48]		7-11	NA
		Layered Elaboration [50]		7-11	6
		Pictorial Flowcharts [14]		7-11	NA
		Telling Stories [51]		7-11	NA
		Journals [22]		7-11	NA
			DisCo [52]	7-11	20
	BRIDGE [39]			-	-
		Video Prototyping [39]		NA	28
		Probing Practice [39]		NA	A class of 7th graders
		Fictional Inquiry & Mission from Mars [39]		10-11	7

4.3.1 UCD zone

On the left side of the spectrum, indicating a lower degree of young users' involvement we find UCD. As discussed, the key in UCD is the use of a variety of prototypes and physical artefacts for testing ideas with children. In this case, participation is confined to the actual test of prototyped ideas and, in this sense, the child plays the role of what Druin labels as tester [14]. In this zone, under the ***User eXperience,*** we find the technique of Contextual Laddering [5, 61] and two tools, Fun Toolkit [41] and This-or-That [40]. For ***Usability Evaluation***, we review six techniques (e.g., Co-Discovery [6, 62], Peer Tutoring [6, 63], Thinking Aloud [6], Active Intervention [6], Retrospection [6], and Problem Identification Picture Cards (PIPC)[42]) that are all used to evoke verbal responses from the children [6, 42].

It is important to highlight that in applying ***User eXperience*** and ***Usability Evaluation*** methods, designers strive to collect different data about the technology design. For example, User eXperience helps to understand how young individuals interact with a product (i.e., what they do and why) in order to achieve their goals and to identify children's emotional responses. Usability Evaluation facilitates the exploration of simplicity, consistency, guidance, direct feedback, and learnability of using an artefact. This approach produces data on the overall effectiveness and efficiency of the technology, and the identification of various problems to fix them. All these activities are used for the evaluation phase of a design process.

Based on the means-end theory [61], Zaman and Abeele [5] proposed "a specific interview and data analysis technique" called Contextual Laddering for product evaluation to test ***User eXperience*** and to suggest design improvements (p. 156). Also, the researchers developed an interviewing tool called This-or-That to identify what children like or dislike after they have interacted with some prototypes [40]. Fun Toolkit [41] comprised four instrument-tools: a Smileyometer, a Funometer [64], a Fun Sorter, and an Again-Again table, which are designed to measure the fun aspects and a child's engagement with various interactive products while they play with them.

In ***Usability Evaluation***, Van Kesteren et al. [6] assessed five evaluation techniques to explore their effectiveness in eliciting verbal comments from children, these are: Co-Discovery, Peer Tutoring, Thinking Aloud, Active Intervention, and Retrospection. The PIPC technique [42] is a combination of the traditional thinking-aloud method with pictures cards that help to provide young children with the necessary vocabulary to express the usability, fun, and problems in games with high levels of fidelity.

4.3.2 The intersecting zone of the UCD and PD

As we move from left to right on the map, the involvement of young individuals in the design increases, as they can take part in more activities and not only in the final evaluation. As a result of that, the UCD and PD intersection zone shows the intermediate position in which the positioned methods, techniques, and tools suggest that the children's involvement in the design is greater because they can play the role of informants [15] or of design partners. Large et al. [7] had some doubts regarding an actual partnership with children "in all aspects of the design process", because of "reservations about the extent to which full and equal cooperation can occur across the generational divide" (p. 80). Therefore, these design activities do not fully support the original spirit of PD. The reviewed methods dropping into this intersecting zone are ***Informant Design (ID)*** [15], ***Bonded Design (BD)*** [7], ***Bluebells*** [8], ***Storyboarding*** [44, 45, 46] and ***Mad Evaluation Session with Schoolchildren (MESS)*** [9], together with the technique called Obstructed Theatre [43]. ***Storyboarding*** also falls into this zone, proposing a more active role in design. The method was adapted for children to help in the brainstorming and evaluation sessions, and suggests four techniques, i.e., Electronic [44], Comicboarding [45], Magicboarding [45] and Emotional [46]. Cultural/Design Probes [10, 11, 38] and Child-Personas [47] are identified as techniques. Child-Personas helps in creating user abstractions of children aged 8 to 12 [47]. We included this technique because the author [ibid.] describes children's participation in the process of developing child-personas.

Informant Design (ID) can also cover some limitations of UCD (children used only as evaluators or testers) and participatory design techniques (equality of all team members) effectively in regard to children [65]. ID is "for the design of interactive software for non-typical users or those who cannot be equal partners (e.g. children)" [15, p. 346]. Each informant (child) shaped the design at different stages of technology development (at the beginning of the process, they identified the problems; in the middle stage, they reflected upon the design expectations; and in the end, they evaluated the prototypes). This method does not treat children as full partners because of the children's limited knowledge, experience, and time.

As described by Large et al. [7], ***Bonded Design (BD)*** is situated between ID and Cooperative Inquiry (CI), sharing a similar approach to CI, in that children should be actively involved in technology development, and suggests an "intergenerational partnership working towards a common goal" (p. 64). BD is based on the Zone of Proximal Development explained by Vygotsky [66] in combination with 1) Contextual Design and PD for adults and 2) LCD, ID, and CI methods for children. The name "bond" suggests that it "encapsulates the essence of what was experienced by all members of the design team" [7, p. 78]. Children and adults have an equal voice and unique individual expertise that is crucial to design successful interactive technologies. In BD, children can participate in all stages of the product development as design partners, but questions arise regarding how real the partnership with the adults is, positioning this method between ID and CI.

The ***Bluebells*** method is explained as a balance between child-centred design and expert design [8]. Bluebells used British playground games to develop the activities used in the method; it had three design stages called before, during, and after play, with the first and third stages (i.e., before and after play) being only for designers. Children were involved only in stage two (during play): this was the reason for not placing this method in the PD zone. Four different techniques were designed for that stage, their names being taken from children's playground games, i.e., I-Spy, Hide and Seek, Tig and Blind Man's Bluff.

The ***Mad Evaluation Session with Schoolchildren (MESS)*** method is very similar to Bonded Design and Bluebells; this places the method at the same intersection of the UCD and PD zone. In the MESS events for children, the organised activities fall into four categories, i.e., games, design, technology, and experiments, but focusing more on the fun-suggesting activities and the evaluation practices with the young individuals [9, 68]. During MESS days, children in the whole class participated in a series of design activities that were held at the university and planned by the researchers/members from the Child-Computer Interaction (ChiCI) group. The Obstructed Theatre technique was used in the Usability of Music for Social Inclusion of Children (UMSIC) project in one of the MESS days; it is a modification of the same technique used with adults [43].

Storyboards is a method in design that provides graphical narrative visualisations, usually including pictures, drawings, sketches, and words to illustrate a sequence of envisioned scenarios [67]. Four techniques can support children in design and evaluation, i.e., Electronic [44], Comicboarding [45], Magicboarding [45] and Emotional storyboarding [46].

Cultural Probes (CP) or Design Probes (DP) are described as artistic, playful, and provoking processes aiming to empower designers' imagination and knowledge [69, 70]. Probes are a collection of physical objects and tasks. Considered as tools for design and understanding, the users can play/manipulate the suggested activities to record their own experiences, thoughts, and ideas [71]. As a rational approach, the probes' main functions are to support UCD in collecting users' requirements for inspiration, information, participation, and dialogue, as well as to suggest a similar participatory notion to PD by offering equality between the user and the designer [71]. This statement determines the probes' technique position in the intersection zone between UCD and PD. As tools, they can be used to build the concept of design at an early stage of technology development. The Cultural/Design Probes technique was also adapted for children involved in various projects that are more concerned with the educational context in different settings as Educationally-Focused [10] and Digital Probes [11] and for Child-Personas [38] of children who like to play games.

Personas provides a vivid fictional archetype which is built on the collected knowledge of the real target group of users; it represents their needs, characteristics, and goals [72]. It is described as a "design tool as well as a communication device" in UCD that does not replace other activities in the design process [73, p. 169]. The Child-based personas technique [47] is for creating user abstractions of children aiming to understand them in a particular context. Antle [47] reported that for the development of Child-based personas, many children participated in the various design activities that were used in more than one stage of the UCD process (i.e., observations, interviews, design sessions, etc.); therefore, this technique falls within the intersecting zone of UCD and PD.

4.3.3 The intersecting zone of LCD and PD

LCD is an approach for designing various educational technologies and effective learning environments in order to support the needs of learners at different ages. The reason for including LCD in the selection, as well its position on the map, was influenced by the methods ***Curriculum-Focused Design*** [12] and ***CARSS (Context, Activities, Roles, Stakeholders, Skills)*** [13], which suggest different roles for children-learners, i.e., testers and design partners, so they belong to an LCD intersection with a PD zone.

The ***Curriculum-Focused Design*** method is a variation of CI; it has UCD and LCD elements where design and evaluation tasks are part of the lessons during school days [12]. It was designed to accomplish requirements in the National Curriculum in the UK and to work especially in school settings including staff work, timetables, etc.

CARSS is a method "for participatory, learner-centred design involving children", wherein their involvement in the design is as a child-learner [13, p. 384]. The method contains five main components, namely, Context, Activities, Roles, Stakeholders, and Skills, and participants have to have specific skills to be a part of the team. Exploring the context, the authors identified five constraints (e.g., curriculum, timetable, environmental, commercial and legal, and ethical) that are related to children's involvement in the LCD process. In the second category - Activities - in order to facilitate participants' work on different stages of the educational software design, a series of different events were organised, e.g., requirements gathering, design, and evaluation of prototypes. The various functions that design team members have during product development are described through the roles category. All individuals, such as parents, teachers, children, industrial partners, etc. who participated in the study, belong to the Stakeholders category. The "personal attributes and dispositions necessary to conduct successful design sessions" in participants, alongside the skills of adult design partners, are placed in the last category, Skills [ibid., p. 385].

4.3.4 PD zone

The PD zone contains all design practices that examine the design partnering role with children; here, they are involved in all stages of the technology design. The methods belonging to this zone are ***Cooperative Inquiry*** (***CI***) [14] and ***BRIDGE***[9] [39].

In the late 1990s, the PD approach was adapted for young individuals to facilitate children's involvement and work with designers. Grounded in the theories of cooperative design [74], contextual inquiry [75] and participatory design [34, 76], ***Cooperative Inquiry*** is one of the most popular methods for design with children developed by Druin [14]. Druin [77] affirmed that "while these methodologies offered an excellent starting point for us, we quickly found that they needed to be adapted and changed to suit our teams that included children" (p. 592). There are eight techniques and one tool that have been developed to support co-design practices in Cooperative Inquiry, i.e., Bags of Stuff [48], Technology Immersion [14], Mixing of Ideas [49], Sticky Noting [48], Layered Elaboration [50], Pictorial Flowcharts [14], Telling Stories [51], Journals [22] and DisCo [52].

Iversen and Brodersen [39] criticised the terminology used by Druin [77], clarifying that Cooperative Inquiry is "a method rather than a methodology", methodology being the logos (the logic or the discourse) to reflect on methods (p. 84). Based on a socio-cultural theoretical framework and on their criticism that many studies label young people as "cognitive incomplete" individuals when comparing them with adults, Iversen and Brodersen [39] developed the ***BRIDGE*** method, facilitating work with children "as participants in meaningful communities of practice" (p. 92). The difference with the "BRIDGE method is that it treats children as living their lives in meaningful socio-cultural dependant practices" and their participation is treated as that of "authentic stakeholders" [39, p. 86]. Applying many of the traditional methods used in PD, the authors developed a palette of design techniques for a period of no longer than 5 years, to facilitate their work on two projects, i.e., NetWorking.Kids and the iSchool. These techniques are based on the video prototyping technique, Technology Immersion [14], and fictional inquiry in a shared narrative space [39]. Video Prototyping [39] with children was influenced by a similar technique for adults [78, 79] involving the use of physical prototyping materials and of acting out how they work while video recording. The Probing Practice technique was explained as a continuation of the Technological Immersion technique with children in CI [14] and CHIkids Newsroom [80]. Fictional Inquiry in a shared narrative space is the third and last technique that was inspired by the "in-between" space for design collaboration by Muller and Druin [81]; the technique used is called Mission from Mars [39, 82].

Table 2 below offers more details on all the reviewed methods, techniques, and tools: these include the settings (where used), the purpose (why), and the design stages (when) as reported by the researcher in the original publication.

[9] BRIDGE is an abbreviation of Danish: BRuger Invol-vering i Design, GEntænkt

Table 2. **Settings, purpose, and design stages for each method, technique, and tool**

Methods, Techniques and Tools	**Settings**	**Purpose**	**Design Stages: 1st Research on the users' needs and the context of use, 2nd Design exploration, 3rd Prototype building and 4th Prototype evaluation**
User eXperience [5, 40] (method)	-	To collect information on how children interact with technology and their emotional responses, such as positive and/or negative feelings, fun, engagement, etc. while playing with the prototypes/products.	4 - Prototype evaluation
User eXperience - Contextual Laddering [5] (technique)	School settings	To investigate reasons for the users' product choices by using the question 'Why?'. Questions are used to explicate distinctions in two products (e.g., comparison), and to identify users' product choice (e.g., why a product was preferred over another).	4 - Prototype evaluation
User eXperience **-** This-or-That [40] (tool)	NA	To allow pairwise comparisons for preference evaluation. It contains five questions aimed at finding out what children like or dislike after they have played with several prototypes.	4 - Prototype evaluation
User eXperience - Fun Toolkit [41] (tool)	-	To measure the child's engagement with interactive products.	4 - Prototype evaluation
User eXperience - Smileyometer [41] (tool)	NA	To allow children to identify, by ticking on the corresponding face, their feelings regarding the experience. It uses pictorial representations of faces in a horizontal row together with text explaining the facial expressions.	4 - Prototype evaluation
User eXperience - Funometer [64] (tool)	NA	To represent the amount of fun experienced. It uses a vertical scale on which children need to draw a vertical bar to represent the amount of fun experienced.	4 - Prototype evaluation
User eXperience - Fun Sorter [41] (tool)	NA	To rank the technologies depending on the amount of fun the children had interacting with them. It uses a set of images for children to organise depending on how much fun they had while playing with the products.	4 - Prototype evaluation
User eXperience - Again-Again table [41] (tool)	NA	To gather children's opinions on whether or not they would repeat a certain activity again. It uses a table with three columns: Yes, Maybe and No.	4 - Prototype evaluation
Usability Evaluation [6, 42] (method)	-	To collect information on the effectiveness and efficiency of the various artefacts during their evaluation; this refers to the quality of simplicity, consistency, guidance, direct feedback, and learnability.	4 - Prototype evaluation
Usability Evaluation - Co-Discovery [6] (technique)	School settings	To stimulate spontaneous verbalisation and to increase comments during the evaluation. It involves two children collaboratively performing different tasks and having spontaneous verbalisation.	4 - Prototype evaluation
Usability Evaluation - Peer Tutoring [6] (technique)	School settings	To stimulate verbalisation on interactive issues. It uses role-playing with a tutor and a tutee for two sessions. Children play two roles: learner and teacher. In the first session, the young individual plays with a product to get experience by practising different tasks, while in the second session, the same participant teaches another child how to perform various tasks when they play with the product.	4 - Prototype evaluation
Usability Evaluation - Thinking Aloud [6] (technique)	School settings	To stimulate verbalisation of thoughts while performing tasks. It encourages young participants to verbalise their thoughts while doing tasks.	4 - Prototype evaluation
Usability Evaluation - Active Intervention [6] (technique)	School settings	To stimulate verbalisation on interactive issues. While the child plays with technology in performing various tasks, an evaluator asks him/her to answer questions related to his/her experience.	4 - Prototype evaluation
Usability Evaluation - Retrospection [6] (technique)	School settings	To recall thoughts and perceptions. It is based on a video record of the child's actions. After the child has watched some parts of the recordings, he/she is then questioned about his/her interaction with the product.	4 - Prototype evaluation

Methods, Techniques and Tools	Settings	Purpose	Design Stages: 1st Research on the users' needs and the context of use, 2nd Design exploration, 3rd Prototype building and 4th Prototype evaluation
Usability Evaluation - PIPC [42] (technique)	School settings	To identify levels of engagement and problems in games. It offers 8 picture cards to the children (Boring, Don't know/understand, Fun, Difficult, Take too long, Silly/Strange, and Scary). If while playing a computer game or interacting with a computer-aided prototype, the child detects a problem, the child can then select a card related to the experienced issue and place it in a box.	4 - Prototype evaluation
Informant Design (ID) [15] (method)	-	To design educational interactive technology for/with young individuals who cannot be equal design partners.	1 - Research on the users' needs and the context of use, 3 - Prototype building and 4 - Prototype evaluation
Informant Design (ID) [15] - Phase one	School settings	To empathise learning goals, and to help to identify the strengths and weaknesses of teaching practices (e.g., Asking particular questions on the current types of educational materials and practices used in school for biology supports the discussion on the educational process in biology).	1 - Research on the users' needs and the context of use
Informant Design (ID) [15] - Phase two	Adults or researchers only	To list the problems from informants' input to be used to specify product functionalities. This phase is only for HCI analysts, psychologists, and graphic designers.	2 - Design exploration
Informant Design (ID) [15] - Phase three	School settings	To develop low-fidelity prototypes based on the gathered specifications and children's suggestions, then testing and evaluating them. It allows working in pairs in order to elaborate ideas through scenarios or games, build an interface, and envision interaction features through interacting with low-fidelity prototypes. It uses art and craft materials (colour-printed pond, backgrounds, and cut-out images of pond, animals, plants, etc.) to foster a group discussion around the interactive elements that should be offered with the product.	3 - Prototype building
Informant Design (ID) [15] - Phase four	Testing the prototypes at school and laboratory settings	To test hi-tech prototypes with a focus on the user interface. It entails children's interaction with prototypes to identify interface issues.	4 - Prototype evaluation
Bonded Design (BD) [7] (method)	In school settings during the lunch break	To draw children and adults together to collaboratively explore solutions for educational interactive technology. Various activities supported children's participation in multiple sessions aimed at creating a web portal; these are a questionnaire survey about the internet usage, critical discussions on existing web portals for collecting ideas before commencing the design process, brainstorming sessions for critical discussions on the context and features of different web portals, drawing activities, and designing a low-tech web portal prototype.	1 - Research on the users' needs and the context of use, 2 - Design exploration, 3 - Prototype building and 4 - Prototype evaluation
Bluebells [8] (method)	-	To balance child-centred design with expert design to facilitate an equal partnership.	2 - Design exploration
Bluebells [8] Stage 1 - Before play: only with researchers	Adults or researchers only	To identify key requirements and technology specifications; this stage is only for designers/researchers.	1 - Research on the users' needs and the context of use
Bluebells [8] Stage 2a - I-Spy (Play stage with children)(technique)	In Museum	To collect contextual information by observing children while they explore the context and the environment. It uses on-site observations (e.g., children visiting museums, children doing worksheet activities, children collecting images of artefacts and audio memories by using their different technologies).	2 - Design exploration
Bluebells [8] Stage 2b - Hide and Seek (Play stage with children)(technique)	School settings	To collect information about product/application content. It includes two parts: a brainstorming session to produce a list of words associated with the application, and design sessions using stationery material to allow children drawing their ideas for interactive products after having been shown particular examples.	2 - Design exploration

Methods, Techniques and Tools	Settings	Purpose	Design Stages: 1st Research on the users' needs and the context of use, 2nd Design exploration, 3rd Prototype building and 4th Prototype evaluation
Bluebells [8] Stage 2c – Tig (Play stage with children)(technique)	School settings	To gather information concerning how children navigate, interact with, and control user interfaces.	2 - Design exploration
Bluebells [8] Stage 2d - Blind Man's Bluff (Play stage with children) (technique)	School settings	To collect data on the user interface. It consists of a game to be played in pairs where both children have been familiarised with the interface and context of use of a technology; one child is required to imagine the interface with closed eyes, and the other to draw the interface.	2 - Design exploration
Bluebells [8] Stage 3 - After play: only with researchers	Adults or researchers only	To use the data collected from the 'play stage' and to create prototypes based on the collected information/suggestions/feedback/designs by children. This stage is only for designers/researchers.	3 - Prototype building
Mad Evaluation Sessions with Schoolchildren (MESS) [9] (method)	Lab settings	To collect data by organising co-design and testing activities with children. Usually used to evaluate software through experiments with small groups of children.	2 - Design exploration and 4 - Prototype evaluation
MESS - Obstructed Theatre [43] (technique)	School and laboratory settings	To generate and elicit various ideas for mobile devices. It comprises three stages: in stage 1, the researcher writes a script explaining the essential aspects of the product (e.g., a mobile device); in stage 2, two children describe some of the functionality of an interactive technology that he/she has, and the children are filmed; and stage 3 uses the video clips as input to a design session aimed at developing designs for a portable device.	2 - Design exploration
Storyboarding [44, 45, 46] (method)	-	To engage children in creating various scenarios describing realistic contexts, challenges, and issues for telling stories that help to express their emotional needs or during the brainstorming process for eliciting design ideas.	2 - Design exploration and 4 - Prototype evaluation
Storyboarding - Electronic [44] (technique)	School settings	To generate child-centred scenarios and emphatic characters exploring bullying issues in a classroom and to evaluate storyboards with users to gather feedback. In this case, storyboards were generated by using a storyboarding software package (Immersive Education's Kar2ouche) from children in the UK and were evaluated by children in Germany by using a questionnaire.	2 - Design exploration and 4 - Prototype evaluation
Storyboarding - Comicboarding [45] (technique)	NA	To run brainstorming sessions with children to generate ideas gradually.	2 - Design exploration
Storyboarding - Magicboarding [45] (technique)	NA	To support children in the brainstorming sessions to communicate their ideas. It uses the Wizard of Oz and drawings.	2 - Design exploration
Storyboarding - Emotional [46] (technique)	Lab settings	Face-to-face crowdsourcing approach to design with children using emotional-storyboarding for self-expression. It encourages children to express their feelings and generate meaningful content. In this case, researchers asked children to draw four different emotions using pumpkin-shaped images in four different colours and then to tell the story, 'The Tale of a Pumpkin', for each pumpkin in the order of the emotion sequences.	2 - Design exploration
Cultural/Design Probes [10, 11, 38] (technique)	-	To generate, elicit, and collect self-documentation data from children about their personal interests, daily lives, activities, and environment.	1 - Research on the users' needs and the context of use and 2 - Design exploration
Cultural/Design Probes - Educationally-Focused [10] (tool)	Home settings	To discover children's personal interests and their ideas within an educational context. In this case, the probe pack contained nine activities: Fun Technology Collage, Subject Ratings, Classroom Architect, Technology Gadget Design, Brainstorming Bubbles, Excursion Day Plan, Science Toy, When I Grow Up… and My Journal.	1 - Research on the users' needs and the context of use

Methods, Techniques and Tools	**Settings**	**Purpose**	**Design Stages: 1st Research on the users' needs and the context of use, 2nd Design exploration, 3rd Prototype building and 4th Prototype evaluation**
Cultural/Design Probes - Digital [11] (tool)	Different settings	To gain basic knowledge of children's learning process outside the typical school environment. It used a mobile phone Nokia 7650 with camera and dictaphone functions for collecting pictures and audio-clips of children.	1 - Research on the users' needs and the context of use
Cultural/Design Probes - For Child-Personas [38] (tool)	Design probes in school settings Use the probe materials in home settings	To understand the type of users and create child personas. Children are involved in the design of probe materials by using the W-question approach (Who? When? What? and Where?). This helps to choose the context of the qualitative (e.g., postcards, collage, and maps) and quantitative (e.g., a pre-structured diary) probe materials and to design them. The same children who were involved in the design of the probes worked with the probe materials.	2 - Design exploration
Child-Personas [47] (technique)	Different settings	To guide design in scenarios, test prototypes, and develop persona-centric usability studies. It is used to overcome the lack of access and work with children as design partners or informants. It includes contextual observation of children in different settings, work with groups of children, interviews made by a 15-year-old individual, observations of children in public spaces, analysis of children's artefacts and activities, and sticky notes to cluster pattern of behaviour.	1 - Research on the users' needs and the context of use and 2 - Design exploration
Curriculum-Focused Design [12] (method)	School settings	To perform UCD/LCD in learning settings. Design activities are integrated into the English National Curriculum. It includes: think-aloud sessions, ethnography, written questionnaires, and verbal feedback.	2 - Design exploration and 4 - Prototype evaluation of low-fidelity artefacts
CARSS [13] (method)	School settings	To collaboratively develop educational software design. It includes focus group interviews and questionnaires, group discussions, and pen and paper design tasks.	1 - Research on the users' needs and the context of use, 2 - Design exploration, 3 - Prototype building and 4 - Prototype evaluation
Cooperative Inquiry (CI) [14] (method)	-	To involve children in the design process as design partners.	1 - Research on the users' needs and the context of use, 3 - Prototype building and 4 - Prototype evaluation
Cooperative Inquiry (CI) - Bags of Stuff [48] (technique)	Lab settings	To use stationery material to suggest ideas or build prototypes.	2 - Design exploration and 3 - Prototype building
Cooperative Inquiry (CI) - Technology Immersion [14] (technique)	Different settings	To observe children's interaction with various technologies and identify roles and patterns at the beginning of the project. It uses different types of technologies.	1 - Research on the users' needs and the context of use
Cooperative Inquiry (CI) - Mixing of Ideas [49] (technique)	Lab settings	To design innovative new technology and engage children in a collaborative design process by using three stages. In stage one, each child generates ideas by working one-on-one with an adult; in stage two, all ideas generated by the children who worked in one group are combined; and in stage three, multiple groups' ideas are combined into one big idea.	2 - Design exploration
Cooperative Inquiry (CI) - Sticky Noting [48] (technique)	Lab settings	To generate design requirements. It uses sticky notes in different colours to identify categories of likes, dislikes, and design ideas while children examine an existing technology or prototype. All sticky notes are placed on the whiteboard and organised into groupings of similar themes, and the generated data are used by designers for formulating design requirements.	1 - Research on the users' needs and the context of use
Cooperative Inquiry (CI) -	Lab settings	To add and to expand ideas asynchronously without destroying the original resource. It uses markers on	3 - Prototype building

Methods, Techniques and Tools	Settings	Purpose	Design Stages: 1st Research on the users' needs and the context of use, 2nd Design exploration, 3rd Prototype building and 4th Prototype evaluation
Layered Elaboration [50] (technique)		transparent sheets over the original paper-based prototype to allow the children and designer to draw new elements or comment on existing ones.	
Cooperative Inquiry (CI) - Pictorial Flowcharts [14] (technique)	NA	To write short text descriptions while observing other children. A note-taking technique that contains a combination of small amounts of text and pictures.	1 - Research on the users' needs and the context of use
Cooperative Inquiry (CI) - Telling Stories [51] (technique)	Lab settings	To support collaborative storytelling with children in brainstorming sessions. It uses a magic plate and idea cards that give children hints for telling stories.	2 - Design exploration
Cooperative Inquiry (CI) - Journals [22] (technique)	Different settings	To write down individual ideas related to the design of new technology, to take some notes on sessions, to draw sketches, etc. It supports reflections on the design sessions; children can draw/write their own design ideas, or criticise the technology.	1 - Research on the users' needs and the context of use, 2 - Design exploration, 3 - Prototype building and 4 - Prototype evaluation
Cooperative Inquiry (CI) - DisCo [52] (tool)	Lab settings Different settings	To enable asynchronous and intergenerational co-design with children. Each design group can elaborate on requirements and can annotate and offer a critique of the designs by adding different layers to create and evaluate multiple solutions. It uses open-ended interviews with the children, observations, group discussions, and co-design sessions.	3 - Prototype building and 4 - Prototype evaluation
BRIDGE [39] (method)	-	To involve children in the design process as "authentic stakeholders".	1 - Research on the users' needs and the context of use, 2 - Design exploration, 3 - Prototype building and 4 - Prototype evaluation
BRIDGE - Video Prototyping [39] (technique)	School settings	To stimulate, generate, and visualise ideas about technologies and their use in the future. It starts with brainstorming then uses cardboard to produce props that are subsequently used to produce storyboards for video recording (video prototypes).	2 - Design exploration and 3 - Prototype building
BRIDGE - Probing Practice [39] (technique)	School settings	To find out how children in the school settings would appropriate the mobile technology and to explore the potential of mobile phones in educational contexts. It uses a video camera to document the discussion on various topics used for the news websites, which are then used for video analysis.	1 - Research on the users' needs and the context of use and 2 - Design exploration
BRIDGE - Fictional Inquiry & Mission from Mars [39] (technique)	School settings Different locations near to the school	To collect data on children's present practices and everyday life through role-playing. Data are then used to generate user requirements. In this case, the Wizard of Oz technique was applied to encourage children to communicate with aliens on Mars, creating a narrative shared space. The Martians would ask questions to learn about the children's lives, which helped to gather user requirements and understand the culture and knowledge within a practice. It uses a video camera, a monitor, speakers, and equipment connecting the three.	1 - Research on the users' needs and the context of use

4.4. Methods, techniques and tools: benefits and challenges

Based on the information provided by the researchers who developed and used the various methods, techniques, and tools, we created an additional third colour coded table showing the reported benefits (second column) and challenges (third column, showing disadvantages and limitations reported by the authors of the papers we reviewed). We offer this third table to facilitate our discussion in the next section as well as to better support designers in the selection of co-design activities for working with children.

Table 3. **Table illustrating the benefits and challenges described for each co-deign activity**

Methods, Techniques and Tools	Benefits	Challenges
User eXperience - Contextual Laddering [5] (technique)	• Investigates meaningful differences between products through comparison • Designers can measure the individual experiences of children using different technologies • Probes into the judgments • Supports attribute-elicitation measurement • Helps to compensate young children's cognitive limitations	• Laddering is feasible, but only with the older pre-schoolers aged almost five years and older
User eXperience - This-or-That [40] (tool)	• Measures the likeability of tangible interactions	• Children may feel embarrassed to criticise technology characteristics
User eXperience - Smileyometer [41] (tool)	• Helps to compensate young children's cognitive limitations • Can be used before and after the child experiences with the considered technology	• Not suitable for young children
User eXperience - Funometer [64] (tool)	• Supports work with very young children	NA
User eXperience - Fun Sorter [41] (tool)	• Measures both ergonomic and hedonic qualities of application or software • Helps to rank items	• Understanding of the meaning of the tool is required
User eXperience - Again-Again table [41] (tool)	• Measures the attractiveness of the software defined by the child	• Not usable to evaluate a single product or technology
Usability Evaluation - Co-Discovery [6] (technique)	• Allows working in pairs • Supports co-operation during tasks performance	• Children need to share a goal • The slow real-time collaboration between children may influence collection of data • Prompt is needed to encourage co-operation
Usability Evaluation - Peer Tutoring [6] (technique)	• Supports role-playing during the evaluation process • Allows usability evaluation of a perceptual user interface	• Tutors may take over the tasks
Usability Evaluation - Thinking Aloud [6] (technique)	• Helps to collect useful comments from children	• Depends on individual characteristics, i.e., open to discuss vs shy to share opinion
Usability Evaluation - Active Intervention [6] (technique)	• Collects high data on children's comments by asking questions during performing tasks in the evaluation process	• Depends on individual characteristics, i.e., open to discuss vs shy to share opinion
Usability Evaluation - Retrospection [6] (technique)	• Allows children could reflect on their actions	• Time-consuming • Children may get tired or bored
Usability Evaluation - PIPC [42] (technique)	• Helps to express usability and fun problems while children are playing a computer game • The combination of the traditional thinking-aloud method with picture cards helps children express and detect more problems than only verbalising them • Picture cards help to identify and explain different types of problems, and therefore may increase the collection of valuable data	• May not be suitable for the assessment of other interactive technologies different from adventure games • Testing time: between 30 min and one hour as children have short attention spans • Training of the participants is required on how to use the picture cards • Shifting children's attention from the computer screen to the box with cards when selecting an appropriate card to evaluate design (divide attention) • Restriction: one test per child per week
Informant Design (ID) [15] (method) - Phase one - Phase two - Phase three - Phase four	• Supports the participation of children only in phase one (Define domain & problems), three (Design low-tech materials & test) and four (Design and test hi-tech materials) • Children discussed different aspects of the same problem that differs from their teachers' opinion • Help to design an interactive environment for educational software • Supports reflection on suggested ideas by other children • Elaborates various design ideas and builds low-tech prototypes	• Not all children are able/willing to be creative and designers • Not all ideas are applicable • Difficulties for facilitator to keep discussion on the topic • Needs a careful selection of activities at each stage to save time and maximise the value of the process

Methods, Techniques and Tools	Benefits	Challenges
	• Discusses user interface and interactive elements • Help to tests high-tech prototypes	
Bonded design (BD) [7] (method)	• Plans sessions thematically • Allows work in teams (of 6 or 8 children and 3 adults) • Allows brainstorming ideas for selecting an appropriate team name • T-shirt with the team name helps create cohesion of the group • Pilot studies with children between 10 and 12 years of age • Drawings seemed a valuable design tool, which helped to illustrate the evolution of the design ideas • Brainstorming with young users aged 11-12 years is more successful in large groups than in smaller ones • Selects appropriate design activities based on the children's age to improve their active participation and contribution during sessions	• Scheduling the number and time of the design activities by considering the school timetable • Drawings: 1) lack of time to complete their work, 2) difficulties in focusing on one feature rather than an entire technology (a web portal) and 3) impossibility of linking drawings of individual technology components to represent the portal • Brainstorming is more problematic with younger children (age 8-9) because of the interpretation of things at a literal level. This is a result of child development, i.e., thinking and solving problems in a logical fashion but not abstractly • Two sessions per week required
Bluebells [8] (method) Stage 2a - I-Spy (Play stage with children) (technique) Stage 2b - Hide and Seek (Play stage with children)(technique) Stage 2c - Tig (Play stage with children) (technique) Stage 2d - Blind Man's Bluff (Play stage with children)(technique)	• Helps to collect children's perceptions on the context of a particular technology • Selects technology that has particular characteristics for use in museum • Helps to deal with the constraints of real-world product development	• Further exploration of the method in different real-world context is needed
MESS [9] (method)	• In a single session, children take part in many different activities • Researchers can collect rich data	• Good planning is essential: schedule a day, time and location, transport, adults/teachers/designers to look after children, room arrangement, select design activities and technological equipment
MESS - Obstructed Theatre [43] (technique)	• Helpful for gathering requirements and identifying specification of device • Provides participants with the same information by using videos to introduce design sessions in a series of different events	• Requires scenario for recording the movie • Less effective for conveying more complex interactive ideas
Storyboarding - Electronic [44] (technique)	• Supports the generation and evaluation of scenarios virtually • Helps to enhance the design of scenarios • Helps to create believable and engaging characters • Supports exploration of empathy	NA
Storyboarding - Comicboarding [45] (technique)	• Helps to reduce the barriers to conduct successful participatory approach • Scaffolds the brainstorming process by using comics • Supports one-to-one participation • Keeps the child engaged with the process: an artist helps the child translate his/her idea into drawings • Elicits ideas on functionality and interaction • Elicits high-level context	• The context and theme are predetermined; the scope of the generated ideas is limited
Storyboarding - Magicboarding [45] (technique)	• Helps to empower feeling of creating a comic book independently: replaces physical presence of the artist by using Wizard of Oz component	NA
Storyboarding - Emotional [46] (technique)	• Helps children express their feelings and emotions • Helps children engage with the storytelling • Supports one-on-one interaction for open conversation to exchange ideas safely	• More facilitators are needed to support one-to one communication

Methods, Techniques and Tools	Benefits	Challenges
Cultural/Design Probes - Educationally-Focused [10] (tool)	• Helps to explore children's personal interests, what they like or dislike, and their opinion on the world in general • Supports children's participation in design	• The number of activities influences the completion rate • Difficult activities should be avoided • Activities have to be well formulated, not too open-ended • The tool should not help to identify specific learning preferences • Materials required to complete the activities
Cultural/Design Probes - Digital [11] (tool)	• Helps to generate and collect rich data, i.e., photos and audio clips • Helps to gain data on children's everyday lives • Supports spontaneous use by children	NA
Cultural/Design Probes - For Child-Personas [38] (tool)	• Designing probe materials with children motivates them to participate in the probes recruitment process and their work with the activities in the pack • Helps collect qualitative and quantitative data which is important for creating child personas • Helps in investigating and enriching data on the gaming behaviour and gathering user requirements from children	Improving children's engagement of with activities: • Finding the balance between the levels of details and short and clear instructions • Use of sub-tasks in instructions
Child-Personas [47] (technique)	• Develops different types of archetypes of children	• Complex theories from psychology need to be simplified to build concepts supporting interaction design
Curriculum-Focused Design [12] (method)	• Supports evaluation of low-tech prototypes in a classroom setting	• Work with children in school settings involves curriculum constraints • Good planning and control over the physical environment and resources are required to fit all activities within the school curriculum • Experience of working in a classroom environment required • Evaluating high technology prototypes can be challenging • Children may feel uncomfortable to offer criticism of presented lessons of their teachers
CARSS [13] (method)	• Supports design in learning environments – lesson-driven environment • Helps to determine appropriate degree of children's involvement in design • Offers activities for each stage of the design process	• Team members require a set of core skills and attitudes
Cooperative Inquiry (CI) - Bags of Stuff [48] (technique)	• Supports visualisation and testing of ideas • Helps to build prototypes quickly	NA
Cooperative Inquiry (CI) - Technology Immersion [14] (technique)	• Helps to explore the children's interaction with many different types of technology	• Requires planning and resources for building technology-rich environment
Cooperative Inquiry (CI) - Mixing of Ideas [49] (technique)	• Combines different ideas to create one big idea • Each child can develop his/her own idea • Drawings support discussions for suggesting one big idea	• Each child needs to work one-on-one with an adult • Physically cutting and mixing ideas requires adult assistance and is time-consuming • Needs space to place all paper ideas • For some children, drawing/sketching ideas is challenging • Young children need more structure to support their collaboration
Cooperative Inquiry (CI) - Sticky Noting [48] (technique)	• Identifies set of categories under, e.g., like, dislike, surprise, design ideas, etc. • Visualisation of different categories and ideas • Supports discussions and documentation • Supports bottom-up fashion • Could be adapted and used by teenagers	• Help is needed for arranging notes • Space needed to rearrange, group, and display a large number of notes
Cooperative Inquiry (CI) - Layered Elaboration [50] (technique)	• Supports reflection on ideas without damaging the original artefact • Supports collaboration and elaboration between different groups of	• Permanent markers required

Methods, Techniques and Tools	Benefits	Challenges
	participants • Allows visualisation of the new ideas by overlapping the transparent sheets • Small and portable • Used asynchronously	
Cooperative Inquiry (CI) - Pictorial Flowcharts [14] (technique)	• Allows children to gather data effectively • Compares data taken from children and adults	NA
Cooperative Inquiry (CI) - Telling Stories [51] (technique)	• The same story props can help to produce different stories • The same story props can help to produce one story with many different orders to it • The different story props can help to produce the same story • The different story props can help to inspire the development of many different stories	NA
Cooperative Inquiry (CI) - Journals [22] (technique)	• Supports individual work at home • Helps to write/draw to present design ideas • Used for discussion/reflection	• Small in size with hard covers and unlined paper
Cooperative Inquiry (CI) - DisCo [52] (tool)	• Facilitates asynchronous co-design with children • Shares messaging between design partners • Keeps data for critique iterations	• Requires internet connection • Needs access to computers to run and use the software
BRIDGE - Video Prototyping [39] (technique)	• Helps envision future technologies	NA
BRIDGE - Probing Practice [39] (technique)	• Supports children experiment in using new technology in a school environment • Uses technology to get access to children's existing practice	NA
BRIDGE - Fictional Inquiry & Mission from Mars [39] (technique)	• Shares narrative space and props	• The need for equipment

By reviewing the co-design methods, techniques, and tools enabling different roles to be carried out in the UCD, LCD, and PD process, we mean to offer both an overview of the most recent developments in research on methodological aspects of CCI, and a map or guide of available methods, techniques, and tools for researchers and designers. In this sense, our three tables are meant to help in planning a co-design process involving children as well as to offer a better sense of the areas that have received varying degrees of attention in the literature and so to ask better questions about the directions of future research. Also, the data provided in these tables is used to analyse the reviewed co-design activities and to discuss our findings.

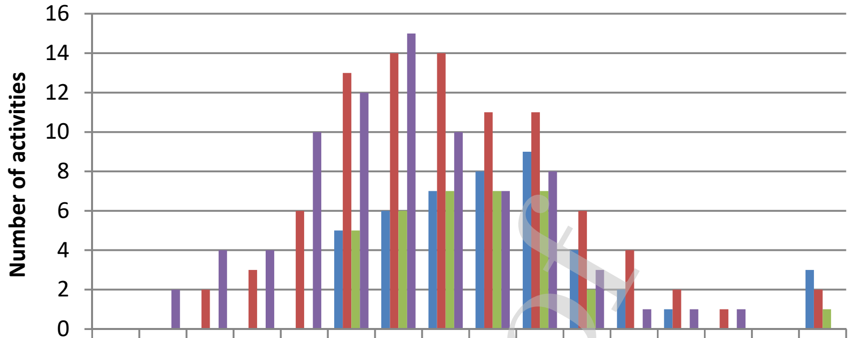
5. Selection of design intervention: an analysis

In this section, we suggest an analysis of all the reviewed co-design interventions developed for or adapted to design technologies with a more general child population. Following the results of the findings, we discuss several main factors that should help and guide the selection and adaptation of methods, techniques, and tools for working with young individuals. These factors are specifically related to a) the age and number of young participants involved in the design process, b) the levels of their participation and particularly the roles they should play in the different phases of the technology development, and c) the settings and design context of the co-design activity to afford collaborative work with children. As a result of our work, we offer researchers and designers a set of requirements to be followed when planning and designing research projects to explore children's participation in design and when publishing their findings in scientific papers.

The children’s age and the physical settings within which the design is carried out seem to be important elements to be considered when planning a co-design intervention. Information about the age of the young participants and about the settings of the co-design interventions is also typically reported in the literature. This enables us to offer a series of considerations.

5.1. Children’s age: a criterion for participation

We use the information given on the target age of the participants (Table 1, column five) and on the design stages within which children were involved (Table 2, column four) to create Fig. 3. We worked with the data to illustrate the aggregated number of co-design methods, techniques, and tools that have been adapted/designed for each of the four design stages (background research on users’ needs, design explorations, prototyping, and testing) for children at different ages.



Age of participants	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15	Age 16	No info
Research on the users' needs and the context of use						5	6	7	8	9	4	2	1			3
Design exploration			2	3	6	13	14	14	11	11	6	4	2	1		2
Prototype building						5	6	7	7	7	2					1
Prototype evaluation		2	4	4	10	12	15	10	7	8	3	1	1	1		

Fig. 3. **The number of co-design activities designed /adapted to facilitate the participation of children of different ages in four stages of technological development: Research on the users' needs and the context of use, Design exploration, Prototype building and Prototype evaluation**

Fig. 3 shows a prevalence of attention on the 7 to 12 range to act as evaluators, informants, and design partners, with a high number of reported methods, techniques, and tools supporting design explorations and evaluation of prototypes (with a maximum of 15 different reported methods, techniques, or tools for evaluation with 8-year-old children). Prototyping methods, techniques, and tools are less present in the literature either because such activities might be too difficult to execute in participation with children, or because participation at this stage is less explored, and if this is the case, it requires more attention.

We found no discussions on co-design activities for individuals younger than 3 and older than 15 years of age (Fig. 3). A few studies reported working with small children in the preoperational stage (2 to 6 years) and with adolescents at the ages of 14 and 15. Only two activities [5, 64] support pre-school children aged 3 to play the role of testers when evaluating user experience. A similar scenario is found for children between the ages of 4 and 5, whose participation revolved around evaluation [5, 9, 40, 42, 64], with only three exceptions [9, 46, 49] suggesting participation in the elaboration of design ideas as well. Similar results were also found for individuals around 14/15 to 18 years old; only one method (MESS [9]) has been reported to facilitate their participation in design and evaluation tasks. In this case, 14-year-old adolescents played the role of informants for collecting users' requirements [15] and as design partners during the MESS days [9] or helping with the development of child-personas [38] by working with cultural probes.

This lower amount of attention, which highlights a potential series of lacunae in the field, seems to reflect the results of another review of IDC papers (from 2002 to 2010) by Yarosh et al. [83] who, looking at the various types of contributions to the field (including contributions on understanding the role of the young subjects in the design process), concluded that there seems to be "very little interest at targeting technology or investigating children under the age of two" and "there are a few investigations that include teenagers in the target range" (p. 140).

5.2. Extend of participation and the participants' roles

We then looked at all the co-design methods, techniques, and tools reviewed in Tables 1, 2 and 3 (49[10] in total) to better understand the extent of the participation, and we noticed the following (Fig. 4).

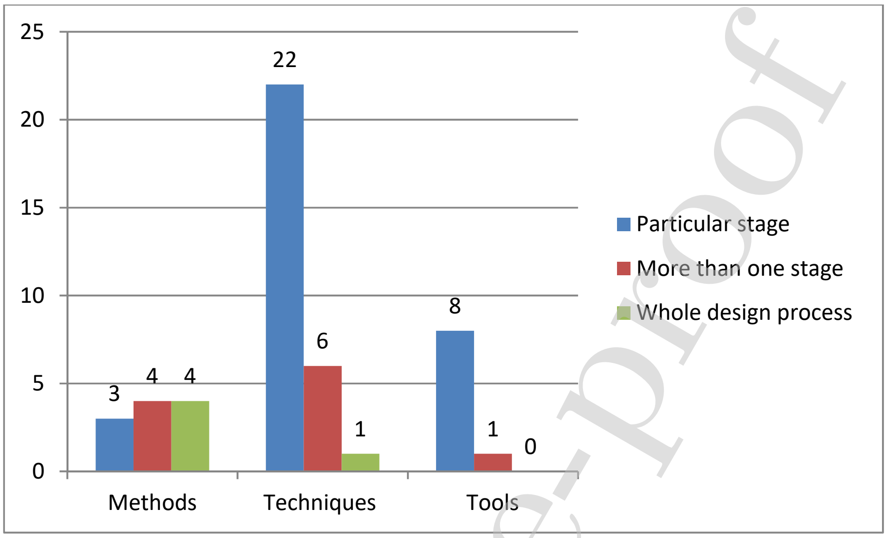


Fig. 4. **The number of co-design activities in different stages**

Out of 11 reviewed methods (Fig. 4), 4 are used throughout the whole design process [7, 13, 14, 39] thus involving users in all stages of a co-design (Research on the users' needs and the context of use, Design exploration, Prototype building, and Prototype evaluation. In this case, the participant role coincides with that of a design partner). In four cases, the methods allow for participation in more than one stage but not in the entire design process[11]. Given the more specific nature of techniques and tools, we identified an opposite trend: most of the techniques (22 out of 29) are specifically devised to support participation during one specific design stage only, thus supporting the participation in one of the four phases. Specifically, 10 out of the 22 techniques (a 35%) are used to support the design phase[12], 4 offer support for the user research[13], 7 for the evaluation[14], and only one for the prototyping stage (Layered Elaboration [50]). The remaining seven techniques are used in more than one stage of the design process[15]. Similar results are found by looking at tools; eight out of the nine are used in one specific stage only and one in more than one stage [52] (Fig. 4). Of the eight used in isolation, five (56%) are used in prototype evaluation[16] while two (22%) are used to support participation in the research phase [10, 11] and one in the design exploration [38].

[10] We do not include those techniques supporting the work of designers/researchers such as Stage 1- Before play and Stage 3- After play part of Bluebells [8] method.
[11] MESS [9], Curriculum-Focused Design [12], Informant Design [15], and Storyboarding [44, 45, 46]
[12] I-Spy [8], Hide and Seek [8], Tig [8], Blind Man's Bluff [8], Obstructed Theatre [43], Comicboarding [45], Magicboarding [45], Emotional [46], Mixing of Ideas [49], and Telling Stories [51]
[13] Technology Immersion [14], Sticky Noting [48], Pictorial Flowcharts [14] and Fictional Inquiry & Mission from Mars [39]
[14] Contextual Laddering [5], Co-Discovery [6], Peer Tutoring [6], Thinking Aloud [6], Active Intervention [6], Retrospection [6], and PIPC [42]
[15] three for research and design - Child-Personas [47], Cultural/Design Probes [10, 11, 38] and Probing Practice [39], two for design and prototyping - Bags of Stuff [48] and Video Prototyping [39], one for design and evaluation - Electronic [44], and only one during the whole process - Journals [22]
[16] This-or-That [40], Smileyometer [41], Funometer [64], Fun Sorter [41], and Again-Again table [41]

From this analysis, we looked at the number of co-design activities[17] that were developed to support children in playing a particular role in the design process. As we discussed, these roles were described in the reviewed articles by the authors/researchers and were used to identify the positions of different methods and techniques in the map (Fig. 2). More than half of all methods and techniques (66%) have been developed to facilitate the role of design partners, as they support participation in multiple phases of the design process, while the rest 24% and 10% respectively support the role of tester and informant. The reason for having such a high number of activities for facilitating the participatory approach with children is because 1) many of these activities support only one stage of technology development [5, 6, 43, 45, 46, 50], 2) some of the participatory methods suggest a collection of techniques [8, 14, 39], and 3) the equal partnership with children was difficult to achieve [7].

This further analysis seems to suggest that more research is necessary in order 1) to assist the design/adaptation of new co-design activities for prototyping tasks, and 2) to explore the applicability of the existing ones in more design phases.

5.3. School context vs other settings, adapting settings vs adapting co-design activities

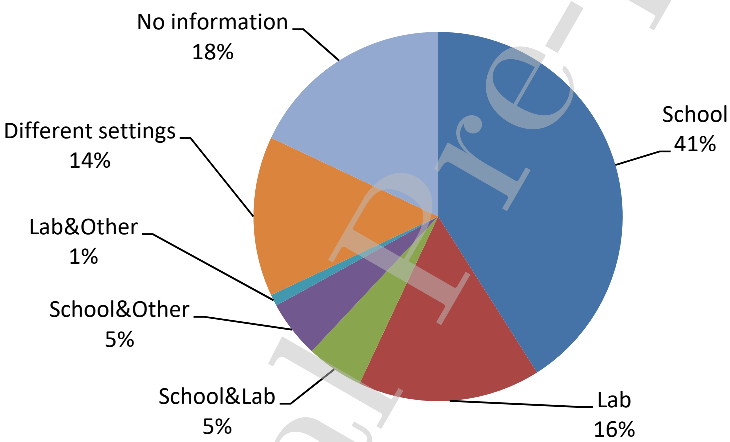


Fig. 5. **Design activities and settings**

Fig. 5 offers an overview of the settings in which the co-design activities were carried out; the data of the settings was taken from Table 2 (second column). The school settings (41%) seem to be the preferred context for co-design activities with children. Laboratories (CI [14] - University of Maryland and MESS [9] - University of Lancaster) are also desirable places (16%) for working and meeting on a regular basis or where children from local schools can pay a visit. The literature also reports activities conducted in more than one setting, such as School&Lab (5%), School&Other (5%) and Lab&Other (1%). Under different settings (14%) are all public spaces, such as science centres, museums [8], public transport, and playgrounds [11, 47], and domestic spaces, such as private homes [10, 22]. Only one tool suggests asynchronous work with geographically distributed children, namely, DisCo [52]; for the rest (18% of the methods, techniques, and tools reviewed, amounting to eight design activities), no information about the setting is given in the article. This shows a certain inconsistency in reporting information about the settings in which co-design activities were carried out and highlights the need

[17] We have included only the methods and techniques because the tools can 'make the children' play different roles depending on the techniques and methods used.

for more research on the influence of the places in which co-design can take place (ranging from school to public spaces, from school to domestic environments).

Despite this lack of comprehensive information, it seems that two main different approaches are in use when selecting locations for co-design with children. In the first, designers adapt the space to make it possible to carry out the planned activities. These spaces can be schools or laboratories and require appropriate equipment (i.e., chairs and tables for children of diverse ages), various apparatus (video camera, camcorder, etc.) to collect data for analysis, and consumable materials (A4 paper, pencils, cards, etc.) or technology (e.g., prototypes of different levels of fidelity) to support different co-design activities. In the second approach, researchers select/adapt design activities to support co-designing with children in a particular setting, i.e., integration of design activities within the class lessons (Curriculum-Focused Design [12]), or for exploring real-world contexts as probes [10, 11], including the Bluebells method [8], Fictional Inquiry & Mission from Mars [39], Child-Personas [47], etc. These settings might be characterised by a series of constraints (i.e., in getting access to work with children, shortage of time to conduct planned work, or overcoming the lack of participants in a study) that need to be considered.

5.4. Lack of details: age, number of participants, settings, and challenges

For the sake of completeness and to better assess the validity of our considerations, Fig. 6 further details the information that is missing in the reviewed articles, including information about the age, number of participants and settings as well as any explicit reflection on the challenges faced by the researchers in carrying out co-design activities. To display the results graphically, we used the information listed in the different columns, i.e., Target age and Number of participants (Table 1), Settings (Table 2) and Challenges (Table 3).

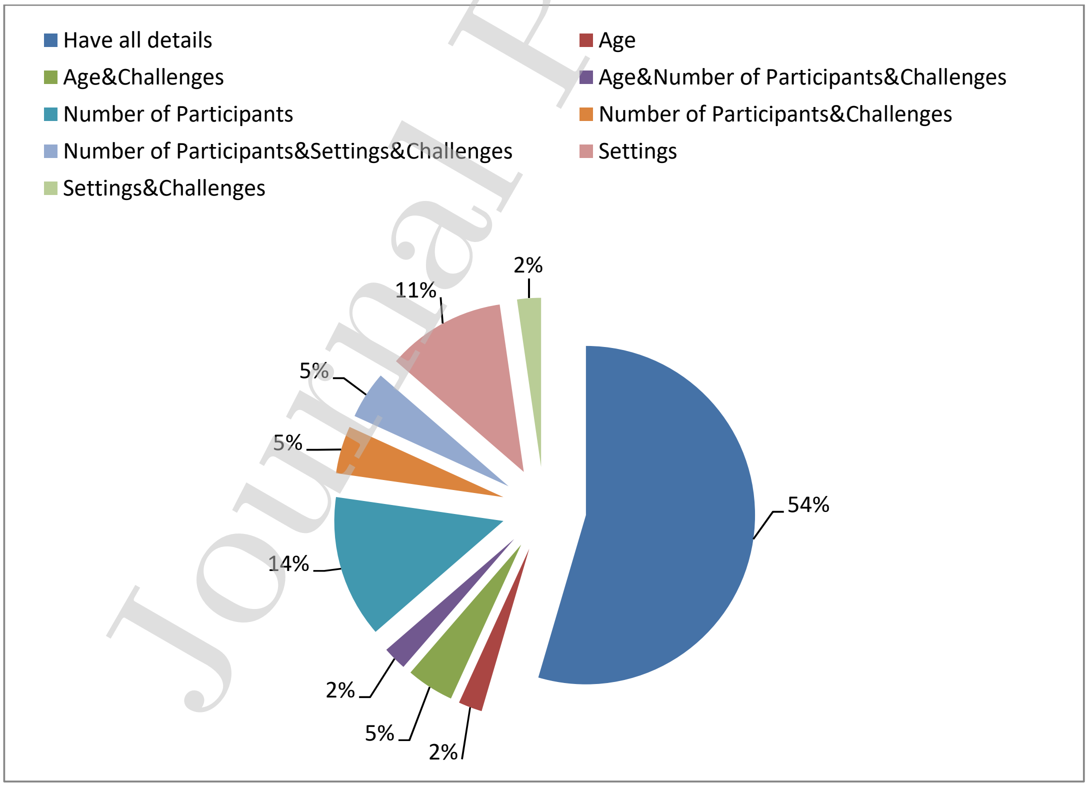


Fig. 6. **Lack of details**

Full information was given on 24 of the methods, techniques and tools (54%). The majority of missing data is concerning the number of participants (14%) followed by information on the settings (11%) in which the studies were carried out. In a few papers, common omissions were detected: some did not discuss the age or number of participants, the settings, and the challenges. These gaps are represented in different variations and may include one to three variables (Fig. 6). Inconsistencies such as these are potentially problematic for the purpose of generalising findings, but they should not be seen as obstacles for further exploring the various methods, techniques, and tools in different contexts and with different young participants. Further explorations facilitating rich reflections, clarifications, and articulation will help to synthesise and complement the knowledge currently available in CCI.

6. Conclusion

In this work, we have reviewed a series of contributions to the field of CCI that have focused on the active involvement and participation of children in the design process with a focus on the roles that they could play and on the methods, techniques, and tools that enable them to carry out these roles. With a focus on a series of design approaches which entail different forms of collaboration (UCD, LCD, and PD), our intention was to review available descriptions and reflections not only to establish the most recent developments in collaborative methodologies in CCI but also to guide less experienced researchers in the understanding and the selection of specific methods, techniques, and tools to support different forms of children's participation in the design process. In this sense, this work can also be seen as contributing to the Intermediate-Level Knowledge [84, 85], which is useful for many in the field of CCI.

There are some limitations to this work. For instance, we limit our review to papers published over two decades, specifically, 1996 – 2015. As the field of CCI is quickly evolving, investigations discussing new design interventions after that period, such as editorial special issues on children's role in design [86], GLID [87], and GaCoCo [88] methods, as well as studies examining co-design with developmentally diverse children and those with special educational needs, are beyond the scope of this paper, so they also are not included.

To support our discussion and findings, we offer a map visualisation where we have positioned a series of methods and techniques showing children's potential roles in the design process, and a series of tables summing up the methods, techniques, and tools; the age and number of participants; the context of the design process; the phase of a design; and the perceived benefits and challenges of the co-design activities. We then offer discussions of a series of elements that are key in the selection of appropriate methods, techniques, and tools, such as the children's age and the settings within which the design process occurs. Based on our findings and discussions, we list some suggestions for future work with children, as follows:

- to develop activities to facilitate a higher level of involvement of children in the preoperational stage (2-6-year-olds) and adolescents (14-15-year-olds) in technology development, especially in relation to background research and prototyping, which are less explored in a collaborative fashion
- to design/adapt co-design activities supporting prototyping work with participants and/or to explore the existing ones for their feasibility in more stages of the design process
- to extend the examination of children's quotidian experiences in diverse settings, such as public places (for example, urban plazas, parks, playgrounds, libraries, green zones, sidewalks, etc.) and domestic environments in order to open up new design spaces and develop new interactive technologies to support domestic and outdoor activities

- to establish good practices of improving the levels of specificity and details in academic publications around co-design methods, techniques, and tools by including the number and the age of participants, the settings, the perceived benefits, and the challenges faced

Most of the papers made explicit statements on their work with children. The roles of informant and design partner suggested the need for more discussions and a critical analysis of all methods, indicating that careful consideration for the selection of an appropriate design approach is essential. Focusing on the CCI theory, and particularly on the various developed/adapted methods, techniques, and tools, this article could be very beneficial as an inspiration to future designers/researchers when they need to plan co-design activities with/for young individuals for various technology design.

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AUTHORSHIP

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication.

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Section I

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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