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# DESIGN OF DIGITAL TECHNOLOGIES FOR CHILDREN

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## 1 INTRODUCTION

At the time of writing this chapter there were in excess of 1.9 billion children in the world, making up over 25% of the world's population. Large numbers of these children will either be using technology now or will most certainly be using technology in the future. In many developed countries, smartphone ownership among children is not at all unusual and it is well known that children as young as 2 and 3 are interacting with tablets, smartphone, smart toys and other technology-enabled products. Technologies that were remarkable at their introduction for their impact on society such as the internet, smartphones, and social media are to them an integral part of the world they live in, just as electricity, television, and cars have been for earlier generations. It is against this backdrop that we offer this chapter, to explore what is known about designing digital technologies for children from a uniquely HCI perspective. Our focus is primarily on children aged around 5–11 insofar as this is the population most able to extract value from digital content while also being intrinsically different from older children in terms of their design needs; but we also touch on interaction for younger children (pre-school) and older children (adolescent). Space also limits our opportunities to discuss designing for children with special needs and children who are in developing countries, but we do acknowledge a great deal of work in these areas and point the reader to literature that can be constructive in these situations.

### 1.1 Children as Users of Digital Technologies

Although the availability of digital technology and digital infrastructure varies widely for children in different parts of the world and in different socio-economical contexts (Livingstone, Lim, Nandi, & Pham, 2019; UNICEF, 2017), it holds overall that children's encounters with technology are growing rapidly in frequency, intensity, and depth, and that children spend increasing portions of their day interacting with digital technologies. In Mourlam et al.'s (2019) study of pre-schoolers aged 3–5, it was found that the children were 50% more proficient at using iPads than their teachers assumed they would be. This example points to the increasing competence of children with digital technologies. Iivari et al. (2020) describe how, in 2020, faced with online learning and lack of physical social interaction, children have become masters of a raft of technologies. In a study funded by the BBC, Read et al. (2018) showed that while children are becoming expert, parents face many difficulties in mediating children's technology use, and are looking to designers to better deal with issues of accessibility, of parental control and of quality content design. It can be tempting to think that children use technology too much—for example, a 2016 study found that infants and toddlers use digital devices for almost 14 hours per week (Ofcom, 2016), and some schools have digital technology entirely integrated into the learning but that is not necessarily bad; in one study of iPad use in a school in the UK, children were found to be able to put the iPads down and self-regulate their use while also using the affordances of the technology for creative activities (Mann, Hinrichs, Read, & Quigley, 2016). Given that children use digital technologies for almost any activity they engage in, be it for learning, playing, socializing or for health-related reasons, etc., it becomes increasingly important for the creators of digital technologies to address children in their design process, paying close attention to their needs and capabilities while being mindful that these will change and evolve as they grow up and as their technological context changes.

## 1.2 Why Children Need Different Tools and Methods

The need for technology designers to understand their intended users is well established in the field of human computer interaction and ergonomics. Gould and Lewis (1985) argued for an early focus on users and their tasks so as not to stereotype. "Know thy user, and you are not thy user" is a core tenet for the field of human–computer interaction and ergonomics more generally (Lund, 1997). Mainstream HCI methodology leaves it up to the designer of new technologies to understand user needs as part of their design process and consistently expects designers to "do their own investigating." Tools have been developed to assist HCI designers in this effort but many of these are poorly suited for use when the users are children.

Consider a designer attempting to apply Nielsen's (1994) widely used heuristics to a children's user interface. While the principles underpinning the heuristics may appear sensible, the designer may be hard pressed to resolve issues like presenting feedback (which concerns heuristic#1 for the visibility of system status), or deciding what is the children's language (in order to apply #2 heuristic concerning the match between the system and the real world). These questions can be resolved by methods for understanding user needs, such as task analysis, interviews, and participatory design approaches but adjustments need to be made. How should a designer interview or observe children? How should the design process be adapted when prototyping and testing? How should designers frame questions and how should they interpret the answers?

While mainstream HCI methodology is generic and widely applicable, it is also agnostic to the specificities of different user groups and difficult to apply in practice. For this reason, we gather here knowledge, as well as methods and tools that have been developed to assist designers to create technologies for children.

## 1.3 Challenges Specific to Designing Digital Technology for Children

Children think and act very differently than adults. Their abilities and needs change as they grow up, which means that designers cannot treat them as a homogeneous group for whom a standard set of guidelines applies. Child development psychologists have extensively studied children's cognitive and social development and there are many well-respected texts—interested readers can consult some of these including (Berk, 2000) and (Keenan, Evans, & Crowley, 2016). For those with limited time, in the following sections we offer a very basic understanding of child development to illustrate how interaction design has to accommodate children's skills, attitudes, and behaviors.

### 1.3.1 Children's Developing Perceptual and Motor Skills

Children's visual perception is not fully developed until they are about 10, which means young children may have difficulty distinguishing details of objects, and especially distinguishing moving objects from a background. Designers may need to take this into account in deciding on the complexity and detail of a display (Hourcade, 2015). Motor skills and motor-perception coordination are also not fully developed until a similar age, which means that interactive controls and manipulations of interactive objects should not put high demands on precision and speed. Physical manipulatives are more suitable than digital manipulatives for young children, although research shows that children can perform simple interactions with tablets from as early as age 2 (Neumann & Neumann, 2014).

### 1.3.2 Children's Developing Cognition

Infants learn by physical exploration and manipulation, directing their attention to what is within their focus. Most children develop sequential logical thought by around the age of 7, and if younger than that, are not able to relate different concepts to each other, though they can enjoy exploration and exposure to new concepts. By late childhood they can think logically and are able to experiment with physical objects; by the early teens, abstract thinking is possible for most children. This points to a need to keep navigation simple on interfaces as well as simple instructions.

### 1.3.3 Children's Developing Language Ability

Language and reading abilities, and the ability to abstract and keep focused attention, vary substantially between different ages, meaning the use of text in interactive applications needs careful consideration. For young children, symbols and animations are generally preferred over language and text. A child's spoken vocabulary develops from about 50 words for a toddler to several hundred words by the age of 2 (Berk, 2000), so by then they will be able to describe things with words which can help interaction as they can remember images as words. By the end of early childhood (age 5–7), children start learning to read and to write, starting from single characters and words, but generally don't develop a reasonably large vocabulary until around 10, and for many, only then can they deal with multiple meanings of words and sentences. While text entry is complicated for young children, the alternatives, such as spoken entry, do not fare well with children's voices as they are typically developed primarily for adults and deal badly with emergent writers (Shivakumar & Georgiou, 2020).

### 1.3.4 Children's Developing Interests

As they grow, children's interests and needs change and evolve. At infancy they seek to explore and discover the world around them. They enjoy individual play and repetitive sensorimotor actions and like to experiment with making sounds. Interactive products for this age should support active exploration helping the child practice fine motor skills, hand-eye coordination, and develop language. At kindergarten and at the first grades of primary school, children enjoy fantasy and magic and need stimulation (Acuff & Reiher, 1997). Digital technologies for this age are often placed in the context of a fantasy world, maybe with animals or fairies, in which the children have to locate and gather items. Toward late childhood (around ages 9–11), children's interest gradually shifts from fantasy to reality so that by adolescence they relate most strongly with more realistic characters and prefer realistic settings over a fantasy world.

#### 1.3.5 Children's Developing Social Skills and Needs

In early childhood, children appear self-centered, and with others they typically engage in parallel play. As they enter school, they start to play together and develop the ability to turn-take and become better at sharing. Towards late childhood (around ages 9–12), children become more interested in competition, success, and acceptance by peers. There is a shift from a main influence of parents and school to a bigger influence from peers and friends. Adolescents (13 and older) focus mostly on needs of identity and sexuality (Acuff & Reiher, 1997), as they become increasingly independent of peers and their parents. In the age range of 13–15, activities become both more socially and more goal-oriented, such as sports, school clubs, and social activities with friends; during this time, they learn to deal with more than one point of view which means digital products can be more open-ended.

### 1.4 The Field of Child–Computer Interaction

Child–Computer Interaction (CCI) is the area of scientific investigation that concerns the phenomena surrounding the interaction between children and computational and communication technologies (Read & Markopoulos, 2013). As an area of enquiry, and community of scholars, CCI emerged around the millennium, when the democratization of home computing and the increasing availability of devices and digital content targeting children, attracted the interests of researchers and developers seeking to provide appropriate products and services; namely those that can enhance the well-being of, and support the development of children (Markopoulos, Read, MacFarlane, & Hoÿsniemi, 2008).

The origins of this field though go back to the 1960s and to the pioneering work of Seymour Papert, who envisioned making programming accessible for children, while still in the era of mainframe computers (predating the introduction of home computers by two decades). Papert developed constructionism as a theory of learning which emphasized the importance of constructing personally meaningful artefacts as a way of learning. Papert's research explored how children could benefit from computing and it resulted in game-changing tools such as the Logo programming language (Harvey, 1997) and Lego Mindstorms (Papert, 1980). A core tenet of constructionism, that has been sustained in the CCI community, is to position children as authors and creators rather than as passive recipients of content.

The CCI research literature is populated with examples of technologies, devices, and applications targeting children, but also with methods and theories that can guide the design and evaluation of digital technologies. Tracking the historical development of the broader field of human–computer interaction (Bødker, 2006), CCI similarly focused early on cognitivist considerations of children and on their interaction with technology. It considered how best to match the child's abilities with the user interface toward a broader consideration of the overall experience of learning and playing, in a variety of user contexts.

Methodologically, research in CCI has adopted a participatory approach from the very beginning, considering the involvement of children in the design process as key. In doing so, the field recognizes the inherent difficulties of adult designers trying to understand children. CCI expands on mainstream user-centered and participatory approaches to address the special challenges involved in working with children and sees child participation as a right in accordance with the United Nations Convention on the Rights of the Child (UNCRC), which asserts that children and young people have the right to freely express their views and be heard regarding matters affecting their lives (UNICEF, 2004).

## 2 INVOLVING CHILDREN IN DESIGNING DIGITAL TECHNOLOGIES

In HCI research, the participation of users is considered a valuable and worthwhile activity. This participation has traditionally been positioned with a focus on democratization and end user involvement in the design processes in line with the Scandinavian traditions of PD (Bødker, Kensing, & Simonsen, 2004; Ehn, 2017; Iversen & Smith, 2012). Participation is noted across all contexts of design including ubicomp (Hornecker et al., 2006), and games design (Sim et al., 2015), and with different populations, including the elderly (Lindsay et al., 2012) and the displaced (Fisher, Yefimova, & Yafi, 2016). In its broadest sense, participation can be described as "the social process of taking part (voluntarily) in formal or informal activities, programs and/or discussions to bring about a planned change or improvement in community life, services and/or resources" (Bracht, 1990).

Children can be involved in design at all stages. In a traditional design lifecycle, the maximum benefit from interaction with children will be at the early stages (for ideation) and during iterations of design where feedback is crucial. In the following sections we look at how children can contribute in the early phases of design. Children can also be essential as testers and evaluators of products; and this is described later in this chapter.

### 2.1 Designing with Children

Historically, children did not actively contribute to the design of interactive technology targeting child users. The practice of involving children as co-designers is a relatively new idea with its roots in the early work of Scaife et al. (1997) and Druin et al. (1997). Over time there have been many papers that have explored children's participation in design; some have described methods, methodologies, and tools (Frauenberger et al., 2015; Sim et al., 2015; Walsh et al., 2010; Yip et al., 2013) and others describe how children actually contributed to the ideation or creation of a product or system by narrating how ideas come from children during design (Guha et al., 2004), and (Read, Fitton, & Horton, 2014).

#### 2.1.1 Three Participatory Design Methods

Methods for engaging with children in design are primarily concerned with asking children for ideas for new interactive products (Druin et al., 1997). This generally takes the form of children engaging in one or more "design sessions" that are structured in order to generate design contributions towards an interactive product or system. Methods vary across a range of axes; one is the balance between adult and child in terms of contribution as shown in Read et al. (2002) (see Figure 1); another is in regard to the fidelity of the designs being created in a continuum from ideation through to specified for build. Some methods suit multi-sessions, some suit multiple groups, some suit large groups.

Co-operative inquiry (often simply referred to as co-design in CCI) is a method that suits small groups in multiple sessions and

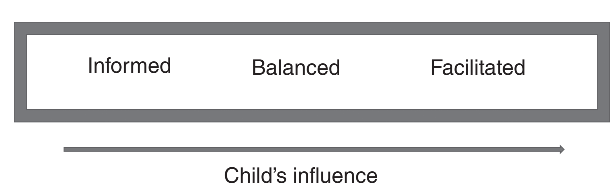


**Figure 1** Informed, facilitated, and balanced.

is positioned toward the middle of Figure 1. It is closer toward technology specification than ideation as shown in products that have been developed like the Children's Digital Library (Druin et al., 2001). Co-operative inquiry is very commonly used in the US where it has been developed over time to include mobile (McNally et al., 2018) and marginalized groups (Walsh, Donahue, & Pease, 2016). In a typical project, the research team recruit a small(ish) group of children to work with a team of adults over a period of several sessions, often over several weeks, to co-examine design requirements for a product. The model promotes an equal partnership between members of an intergenerational team with the aim of delivering design ideas that have been iterated over multiple sessions. The team converge toward one solution over the period of engagement. Many co-design projects in US universities involve teams of children recruited out of school groups (often referred to as KidsTeams; Walsh & Foss, 2015) who work with the researchers over several different projects, thus gaining their own expertise in the techniques and philosophy. Sessions are planned to be fun with snack times and prototyping, as described by Yip et al. (2013). Variations have included Distributed Co-Design (Walsh, 2010), Distributed Participatory Design (Constantin et al., 2020) and techniques like layered elaboration (Walsh et al., 2010) that enhance the experience of the children.

Workshop approaches typically involve more children and fewer adults in such a way that the children are left more "unattended," toward the facilitated end of Figure 1, one might say, in their exploration of designs. Often in workshop methods, there may only be a single design session and the outcome is more likely to be toward ideation than development. Children may feel more empowered than in co-operative inquiry insofar as the adults have less input, which carries some risk that the event may go off track. An example of a workshop approach is the BRIDGE Method described by Iversen and Brodersen (2008). Here a sequence of workshops uses imaginative techniques to explore a design space. BRIDGE describes a process where children contribute as a community of practice at their own level, their input is considered meaningful, and the techniques used with the children must be meaningful to them. Iversen and Brodersen, (2008) describe three techniques that they used in that philosophy but stress that each implementation of the method might require bespoke techniques. Video prototyping was one technique used with school pupils to visualize an event that had meaning for them. A second technique was Technology Immersion in which children were observed using technology—The KidReporter technique of Bekker et al., (2002) is one example that could be used. The third technique introduced in the BRIDGE method was Fictional Inquiry, encapsulated in the Mission from Mars protocol (Dindler et al., 2005) where children describe a design to a Martian. The main point in all these techniques is that they suit the children's contexts and are not simply adult design techniques adapted for children.

Bluebells (Kelly, Mazzone, Horton, & Read, 2006) is a method that is positioned firmly toward the child as informant (Figure 1) and which is focused toward technology build. It can be used with many children, but the assumption is that they would normally only attend a single session each. Bluebells sandwiches researcher activity with children's activity and is described in three stages with four techniques mentioned.

- The first stage is carried out solely by adults and results in a list of requirements, a technology specification, and a notion of how the end product may look. The outputs at this stage include sketches and a technical specification.
- In stage two, adults go to the children to fill in details. Four activities are suggested that can be used by design teams with children to collect design ideas: *I-Spy*, *Hide and Seek*, *Tig*, and *Blind Man's Bluff*, each named after a children's playground game. I-Spy is observational where the design team watch children doing activities that fit the context of the design aims, for example—if designing a chat app, they would see how children chat with one another. Hide and Seek is where children are given wire frame prototypes—and first generate words that they associate with the product and then get a chance to position these on the wireframes, Tig is about navigation and wayfinding and Blind Man's Bluff furnishes the interface look and feel.
- In stage three, the design team then collates and examines the outputs from the activity sessions and incorporates them into design documentation.
- The important aspect of Bluebells is not in the detailed specification of the ways to work with children but in the philosophy and shape of it—the philosophy is that a design goes back and forth to the children—and the shape of it is that children work on different aspects in different ways—separating the graphics from the navigation and the information. This makes it relatively easy for young children and children without design backgrounds to participate.

### 2.2 Working Ethically in Design Sessions with Children

In their five provocations for ethical HCI research, Brown et al. (2016) argue that the more vulnerable a group is, the stronger the case has to be made for their participation in research. When children participate in CCI research, it is very important to be clear about their inclusion and the meaning of their contributions (Iversen, Smith, & Dindler, 2017). From an ethical position it is not appropriate to work with children and then to discard, without justification, their contributions. A constant tension in design work with children is to ensure that they understand how their contributions will contribute to the eventual designs (Guha et al., 2004). Read et al. (2016) developed a tool to account for ideas as they pass from the children to the design team which goes some way toward acknowledging the need for good practice when working with children in this way. We return to the ethics of working with children later in this chapter.

## 3 INTERACTIVE DIGITAL TECHNOLOGIES FOR CHILDREN

In many cases it is not practical to work directly with children at the design stage. There may be constraints of time and money as well as accessibility. Employing a user-centered approach can be supported by using other methods including proxies and personas. Teachers and parents can bring very useful insights to designers (Chen et al., 2019) and personas of children can be used to steer design (Antle, 2006) but also children have been able to design for personas that are not the same as themselves, thus opening up for more inclusive design practice (Metatla, Read, & Horton, 2020).

There is also considerable knowledge that has been gathered from research and practice on practical design for children. We bring a subset of this knowledge together in the following sections.

### 3.1 Interaction and Children

User interface designers need to take into account children's diverse and developing abilities to perceive information presented on the interface and to operate input devices. Here we summarize some generic guidelines that can guide the user interface designer. A more comprehensive treatment is provided by Hourcade (2015), in his book on child–computer interaction:

- *Instructions, affordances and labeling*. User interfaces should be primarily visual with limited text. The younger the child, the less text should be on an interface. Audio feedback can be helpful provided that the child does not have to convert spoken words into written form to complete an interaction.
- *Mouse skill*. In graphical user interfaces target sizes should be adjusted to children's pointing skills. Hourcade (2015) found that for young children target sizes might need to be up to four times larger than those needed for young adults. Hourcade et al. (2004) studied children's pointing skills using a mouse and reported a 90% accuracy on pointing tasks for 4-year-olds with target sizes of 23.7 mm on the screen and 3.6 mm on the physical mouse space. Interestingly, Hourcade (2006) has shown that automatically reducing the speed of the pointer as it approaches a target can help 4-year olds achieve pointing performance comparable to that of young adults. Using a stylus to point may be helpful to develop fine control, and it showed no performance issues when compared to finger interaction (Cassidy, Read, & MacKenzie, 2019).
- *Inputting text*. Text-based input and output, which can be challenging for adults as well, is only feasible once children become fluent in reading and writing. Typing on a keyboard is the most effective way for inputting text but is difficult for children who at younger ages at least "hunt and peck." For a study of how children type on keyboards, see Kano and Read (2009), whose work showed not only that children made different errors than adults but also that recovery and identification of errors were more difficult as they were often not aware of errors being made. This can create mode errors and can put children into loops of poor interaction, as also noted in speech input with children and even when using handwriting recognition (Read et al., 2004).

### 3.1.1 Touchscreens

In recent years, touchscreens have become very popular for children who are avid users of smartphones and tablets and who, from pre-kindergarten age, are able to perform a range of gestures on touchscreens (tap, drag, one-finger rotation and two-finger scale up and scale down) while some other harder gestures (double-tap and long-pressed) may be feasible provided precision and cognitive limitations are considered (Nacher et al., 2015). Based on a series of six studies conducted over a period of five years, Anthony (2019) suggests that children after the age of 10 exhibit similar usage patterns to adults, while for children aged 5–10, she proposes a range of design guidelines for touchscreen interaction as follows:

- Unintended input events may be caused due to the dynamics of the interaction, e.g., not releasing the touchscreen after selecting a target, by hovering over targets without the intention to select them, by holding the screen or touching it without the intention of selecting a target. Suggested remedies include clearer feedback for the selection of targets and implementing a time threshold before which new input events will be ignored.
- Children may be inaccurate in selecting a target when it is small, or when it is far from them (on a large screen) or when it is close to the edges. The suggested remedies include clearly marking interactive areas and ensuring there are easy ways back if an error is made. Another fix is to increase the active area for interface widgets to allow slightly out-of-bounds touches to register and to avoid small targets at the screen edges, placing interactive elements closer to the child.
- For gesture-based interaction on touchscreens children younger than 10 may not be able to correctly execute gestures. Gesture sets should be intuitive and familiar, the interface should provide fine-grained visual feedback for the gestures to support the child performing them. The gesture recognizers should be trained for specific age groups and be adaptive to learn from an individual child's gestures.

Read et al. (2018), carried out an at-home study of children playing touchscreen games using iPads and other tablets. There were significant accessibility problems for several of the children ranging from children not having the physical hand control needed to touch a single object on the screen through to mode errors causing windows to close. For children without sight, touchscreens are very problematic so it is important to consider all the users who might meet technologies when designing.

### 3.1.2 Augmented Reality (AR)

In augmented reality, digital imagery and interactive elements are superimposed on the physical world, e.g., with projection, or by mapping the digital elements on the image registered through the camera of a mobile device as in mobile AR. Contrary to the touchscreen interactions discussed above, an AR target is a 3D virtual object that is anchored to a physical object instead of on the screen. Therefore, the target's on-screen size and position change in response to the child's distance and orientation to the physical surface.

A comparative study of AR selection mechanisms for children (Radu MacIntyre, & Lourenco, 2016) found significant effects of age on performance, and suggested that selection should not be constrained by the child's orientation toward the physical surface viewed and that "finger selection" (where the user's finger can tap on targets shown anywhere on the screen) is to be preferred over "cross-hair selection" (where a cross-hair on a fixed position on the display has to be centered on a target by moving and reorienting the handheld device, and then selection is made by buttons at fixed positions). Innovations like the Merge Cube that place AR into the hands of children may circumvent some of these limitations (Ntuli, 2019).

Touchless gesture-based interaction has been shown to be feasible for children as young as 2 (Rubegni et al., 2019); however, while children's performance in interaction tasks in that study was found to improve with age, older children aged 8–10 tended to expect touch-based interaction on the screen and did not enjoy the interaction as much as 6-year-olds.

### 3.1.3 Tangibles

In tangible user interfaces, physical artefacts are used to register user input, either through sensors attached to them or through an external tracking system. These artefacts are physical representations of digital information and functionality to control a digital system by physical manipulations. The motivation for doing so is that users can transfer their real-world skills for manipulating physical objects to the user interface, which can lead to more natural and easier to use interfaces. Researchers have typically expected that tangible user interfaces would be more usable for children and would result in improved learning compared to traditional user interfaces as well as improved collaboration in multi-user applications.

The potential of tangible user interfaces to support CCI has been widely recognized, and there has been extensive exploration on the topic. A survey of more than a decade of related research (Zaman et al., 2012) showed clear evidence for the potential benefits of this approach. For children learning letters and other early skills, tangible interfaces have shown considerable promise, tapping as they do into the physical affordances of play (Fan & Antle, 2015).

#### 3.1.4 Full-Body Interaction

In full-body interaction, users perform body movements and physical actions as mediators of the interactive experience using technologies such as computer vision or sensors to register their movements, e.g., their posture or limb movement, or their gestures. Related applications strive to achieve body-synchronicity, a term introduced by Papert (1980) to emphasize the "resonance" between abstract concepts and what people know about their own body. There are emerging guidelines for designing such applications (Malinverni, Schaper, & Pares, 2019) and research so far has demonstrated substantial learning benefits for children when compared to traditional screen-based interfaces (Malinverni et al., 2012).

#### 3.1.5 Social Robots

Social robots are robots that are specifically designed to interact and communicate with people in ways that resemble in various ways human–human or sometimes human–animal interactions. Social robots can potentially be cast in the role of an instructor, a coach, a companion, or a pet with the ambition to support a range of purposes such as learning, therapy and companionship (Lambert, Norouzi, Bruder, & Welch, 2020). This technology is developing fast and increasingly researchers are experimenting with deploying it in laboratory and classroom setting. Social robots have been studied extensively for their potential to support language learning (van den Berghe et al., 2019). So far, results are very mixed regarding their efficacy (both first and second language) but the results are quite positive regarding their impact upon learning-related emotions (Kory-Westlund & Breazeal, 2019). While in principle robots can move and interact with children in their real world, technology is not yet sufficiently mature to allow especially useful applications, although they have been shown to share gaze attention and they can make recognizable gestures (van den Berghe et al., 2019).

Learning gains with robots in classrooms have been demonstrated in the domain of geometric thinking and metacognition (Keren & Fridin, 2014), mathematics (Baxter et al., 2017) and in physical geography (Jones & Castellano, 2018), however, in all these cases, the social interaction with the robot was auxiliary to screen-based interaction supported by a tablet interface. To have robots with capabilities to understand and interact with children as well as carry out various roles, such as be teachers, play games, or be peers is a challenging task; and more work is needed to understand how children interact with robots and to equip robots with cognitive abilities that enable smooth child–robot interaction.

### 3.2 Learning and Children

One of the main application areas of digital technologies for children is learning and education. Learning is not always an easy process and is associated with many aspects of interaction and cognition (e.g., hard mental operations, cognitive friction) that differ across the different developmental phases of a child. In addition, learning takes place in and across diverse contexts (e.g., online, classrooms, labs, maker spaces) and the content-area (e.g., maths, language, art) plays an important role in the mental models generated from children during learning. In the context of learning and education, many age-appropriate technologies have been proposed and implemented, either to support activities such as making and coding or to facilitate children's learning directly. Those two strands represent two traditions that have strong roots in CCI research. The former focuses on allowing children to think about powerful ideas (Papert, 1993) and the latter is connected with the broad vision for the use of computers to facilitate learning (DiSessa, 2001; Kay & Goldberg, 1977).

The need to understand and improve how learning occurs, in ever-increasingly open, distributed, subject-specific and ubiquitous learning spaces and scenarios, requires expertise from several research areas including psychology, the learning sciences, and computer-supported collaborative work. In order to portray the complete picture of children's learning experience, and, thus, to be able to inform the design and evaluation of the digital learning technology, we need a selection of methods and techniques. Recent research has considered the use of technology to support children's learning in formal domains (e.g., eye-trackers in classrooms to measure engagement; Giannakos, Papavlasopoulou, & Sharma, 2020), informal domains (e.g., science centers and out in nature; Arici et al., 2019), and digital domains (e.g., online Scratch; Dasgupta & Hill, 2018). Research often focuses on diverse perspectives on what learning is, who is involved, where it occurs, and how it is studied (Gillen & Kucirkova, 2018; Xie et al., 2019).

Previous studies have employed several practices to evaluate and inform the design and development of children's learning experiences. A common practice is to collect evidence produced from child–environment interaction (context). A more qualitative way of assessing children's learning is to conduct interaction analysis (Jordan & Henderson, 1995; Serholt, 2018). Interaction analysis techniques investigate children's activities, such as talk, nonverbal interaction, and the use of artefacts and technologies, identifying routine practices and problems, and so providing useful insights for the design of the technology and the process. Another qualitative way of assessing children's learning is to use a think-aloud approach that allows us to reveal the authentic cognitive process, but this sometimes creates distractions from the core task. A very common and upcoming practice is the collection of evidence produced through various analytics (called Learning Analytics). Such analytics can be mainstream data produced from the technology (e.g., clickstreams, standardized surveys, and tests) but also more sophisticated analytics coming from various technologies, and human-observed or sensor-produced data (Cukurova et al., 2020; Lee-Cultura et al., 2020). Such evidence allows us to portray children's learning trajectories but also augment our understanding (e.g., as researchers, teachers, or parents) and support the design and development of both the digital technologies for learning, as well as the respective processes (e.g., instruction, learning design).

### 3.3 Gamification and Children

Gamification has been defined as "the use of game design elements in non-game contexts" (Deterding, Dixon, Khaled, & Nacke, 2011) and during the last few years we have seen its application in various contexts, such as learning, behavior change, healthcare and well-being (Høiseth et al., 2013; Johnson et al., 2016; Read, Sim, et al., 2013). The underlying idea of gamification is to use specific motivational affordances stemming from the fields of entertainment and games in other systems and processes to make engagement with these more motivating (Dele-Ajayi et al., 2016). Examples of such motivational affordances are points, leader boards, badges, levels, stories, rewards, to mention but a few (Hamari, Koivisto, & Sarsa, 2014; Schwarz et al., 2020).

Since its emergence around 2010, gamification has been at the epicenter of HCI as well as the Child-Computer Interaction, both in the industry and academia (Giannakos, Papavlasopoulou, & Sharma, 2020). In particular, we have seen gamification practices applied to increase motivation and engagement (e.g., in learning, health, and well-being, but also seen gamification applied to support research methods and tactics (e.g., Cultural Probes for children; Samso et al., 2017); motivating participation and increasing the completion rates (Brewer et al., 2013).

Considering how young children approach, and play with, age-appropriate applications, gamification needs to consider children's needs and capacities throughout the different developmental stages. For example, a game for toddlers will be about "making things happen" such as tapping an object that responds with a sound (Lieberman, Fisk, & Biely, 2009), while older children might need more sophisticated gamification techniques. To consider the similarities and differences between applications for young children, the following taxonomy has been proposed: (1) gameplay/mechanics or activity; (2) characters; (3) narrative (as defined by the game and experienced by the child); and (4) curriculum (both implicit and explicit) (Cohen, Hadley, & Frank, 2011), with gameplay referring to a range of challenges, actions, and reactions leading to skill acquisition and achievement; characters referring to the various roles and avatars; narrative to the story, and curriculum is the content area.

Given the natural connection of gamification with children's fun, it's important to highlight works that have been employed in developing and evaluating gamification for children. Zaman and Abeele (2007) offer the Likeability Framework for designing applications for children; the framework connects basic needs, contextual and societal factors, and individual needs to five gratification areas that children seek in terms of fun in products: (1) challenge and control; (2) social experiences; (3) fantasy; (4) creative and constructive expressions; and (5) body and senses. In the same vein, Lieberman et al. (2009) focus on gamification for pre-schoolers, providing a list of strategies, named: demonstrations, stories, role-models, interactive questioning, challenges, repetition and rehearsal of skills, social interaction, personalization and fun, humor, fantasy, and entertainment. The respective "requirements" underpinned from the aforementioned related works in the area of gamification and play for children, depict important elements that need to be considered during the design, development, and evaluation of technologies that focus on children and utilize gamification. This allows the gamification capacities to be age-appropriate but also consider children's values and characteristics.

### 3.4 Sociable Technologies for Children

The sociability of technologies has been discussed in CSCW, HCI and IS literature, especially after surrounding the notion of the "Media Equation" (Reeves & Nass, 1996) which suggests that people interact with technology in ways that demonstrate existing sociability. According to Preece (2001), good sociability comes from practices that support the community's purpose and are understandable, socially acceptable, and practical. Technological designs that typically reinforce sociability have good usability, high levels of trust and security, and follow good governance (in social communities) (Lazar & Preece, 2002). To strengthen sociability and participation, Preece and Shneiderman (2009) describe three critical design concerns: (1) reading (motivation to access, visit/revisit); (2) contributing (motivation to post, change or comment content); and (3) collaborating (motivation to react to/interact with other users and engage in shared resources). Moreover, researchers (Bouman et al., 2007), argue for design interactions that mimic "real" interactions and help building an identity, fulfilling a n a gency, a nd e nable a social practice that exists.

For children, the most important question for this section is "What would make technologies sociable for children?". Although there is a vast amount of research on designing and scaffolding sociable technologies (e.g., social media) to support children's play and learning (Kawas et al., 2019), the response to this question cannot be one-size-fits-all. This question is sensitive to the context (e.g., healthcare, learning) and the settings (e.g., formal, informal) but also needs to consider children's needs and abilities (e.g., age-appropriateness). Therefore, it is important to capture data that is highly infused with in-situ and contextual aspects and which will allow the designer and developer to reveal and understand critical insights that are needed to designing sociable technologies that can make the experience more understandable and pleasurable for the children concerned.

### 3.5 Collaborative Technologies for Children

Social relationships play a very important role in children's lives and having a good social life and friendships prevents depression and reduces speech, language and communication difficulties (Cappadocia, Weiss, & Pepler, 2012). Assessing the collaboration capacities of the various technologies for children is challenging and the CCI community needs to further work on developing theoretical frameworks and design tools to support collaborative technologies for children (Baykal, Van Mechelen, & Eriksson, 2020). Nevertheless, engaging children in activities in which they can exercise and sharpen their collaboration skills allow them to overcome certain difficulties and get a sense of togetherness (the product of successful interaction rituals). According to Collins, togetherness creates a "feeling of confidence, e lation, s trength, e nthusiasm, a nd i nitiative i n taking action" (2014, p. 49). Therefore, collaboration is particularly useful for children due to its capacity to help them develop bonds between one other and thus reinforce their skills development (Baykal et al., 2020), Borrowing the concept of interaction rituals from Erving Goffman (1961), Collins states four necessary elements or conditions for achieving interaction rituals for collaboration:

- *Co-location*. Letting them directly or indirectly notice each other's bodily presence.
- *Awareness of participation*. Noticing distinctions between those participating and those not participating.
- *Collective awareness*. Users involved focus their attention on the same object or activity.
- *Shared emotion*. Participants share a common emotion or mood related to the activity.

In the context of CCI, there is a recognition of the value of collaborative activities and in most of the cases all the four aforementioned elements are incorporated (Eriksson et al., 2019). Examples, such as playing collaborative games using interactive surfaces and multi-touch technology, or social robots using avatars Boyd et al. (2015) have successfully used to build applications to train social and emotional skills as well as to assist children with special abilities (e.g., ASD; Hourcade, Bullock-Rest, & Hansen, 2012). Technologies that reinforce the aforementioned elements (e.g., shared interactive surfaces that enhance the sense of co-location and 3D expressive avatars that share the sense of shared emotion) are particularly compelling as platforms for developing collaborative applications for children (Cheng & Ye, 2010), especially for children with special abilities (e.g., ASD) where the improvement of social interactions and understanding of social interactions need additional support.

## 4 EVALUATING DIGITAL TECHNOLOGIES FOR CHILDREN

Evaluation is a key aspect of designing digital technologies. It is typically carried out midway through a design process, (formative) where it can help designers identify flaws that have to be corrected, but can also be carried out at the end of a design process (summative) where it can help make concrete statements regarding the quality of a system or service,

Evaluations can provide feedback for different aspects including usability, user experience, safety, and the efficacy of the technology for its designated purpose. For an educational technology, efficacy might concern how well it supports learnability, while for a messaging application, how well it supports co-operation or social interaction between children (i.e., communication). Much more than when evaluating technologies for adults, evaluators also need to examine whether children enjoy using the product, system or service evaluated, even when entertainment is not their primary purpose. For example, an educational application that is austere and repetitive is not likely to motivate children to engage with it for long, and a technology to support a health-related behavior change intervention, which is tedious or stressful, is likely to be abandoned before any beneficial changes have been achieved.

### 4.1 Challenges in Evaluating Children's Digital Technologies

As with design, evaluations of digital technologies might ideally be done with children, but time and situation do not always make this possible or even desirable. For non-child-based evaluations there are the usual HCI methods available but, as pointed out earlier in the chapter, these are often a poor fit. Given the diversity of children and their needs, generic rules that can be applied during an "expert" evaluation are hard to come by and some expertise regarding children may be necessary. One method designed to assist in this is SEEM (Baauw, Bekker, & Barendregt, 2005), which is a structured expert evaluation method. where an expert scrutinizes the interaction, with the system answering targeted questions at each step that aim to predict what aspects of the technology evaluated compromise its usability and the fun children experience with it.

Empirical methods for evaluating children's digital technologies are similar to those used for adults, e.g., usability testing, using questionnaires to assess attitudes and experiences, interviews, etc. However, carrying out any of these processes needs adjustments when the participants are children. Each presents several challenges that are specific to children which we discuss briefly in the following sections.

#### 4.1.1 Children's Ability to Perform Procedures

Children may lack the cognitive and social skills required to carry out the evaluation procedures. Understanding what the evaluator asks them to do, the questions they put to them and formulating suitable answers all entail cognitive challenges relating to children's ability to read, to verbalize, to follow plans. For younger children many of the methods that are customary in evaluating products for adults are too challenging, e.g., answering questionnaires, thinking aloud, in-depth interviews, etc. Careful design of evaluation procedures, and piloting, will make sure instructions are easy and possible to follow for children and that the context in which the data collection takes place is friendly and supportive to help them overcome any difficulties. It is important to realize that children may get tired, distracted, and not carry out instructions as intended. The evaluator should temper the requirements put upon children participants, and be sensitive to signs of the children disengaging, not putting effort into the evaluation and choosing the path of least effort while providing data that is perhaps misleading for the technology designers.

#### 4.1.2 Biases

Particular biases inherent in empirical research are commonplace when working with children. These are:

- *Acquiescence bias*. Children may be more likely to provide positive rather than critical feedback on technology in order to be perceived as friendly. For example, in an evaluation of an e-book application for children the responses of four of the thirty-two participants were removed because they tended to answer consistently positively (Colombo & Landoni, 2014). Temperament as well as age may cause acquiescence, in an evaluation of a digital platform for health promotion and management addressing teenagers, researchers noted how shyer children tended to agree with the points of view of the opinion leaders in the group (Lang et al., 2016).
- *Selection bias*. Often in an evaluation, the children who are chosen will be from the more compliant, or the more mobile areas, and thus may bring a skewed result as to how suitable, enjoyable and acceptable a technology will be for a broader selection of children. This may be because only some children have the time and opportunity to attend evaluation sessions, they may be in the social network of the technology developers, or when working with a school they may even be selected by a teacher who wishes to make a good impression for their class. Another variant of this bias, that is very specific to children, has to do with the selective presentation of qualitative results with the cutest, brightest or funniest children making it to video excerpts of the test sessions, leaving perhaps a false impression for how the majority of test participants experience a digital technology.
- *Halo effect*. Children generally enjoy working with researchers and enjoy technology, in this situation children might provide positive evaluations and demonstrate enthusiastic behavior, because they appreciate the overall experience of participating in the evaluation, e.g., because they get a lot of personal attention by adults, they have a day out of school or they visit exciting installations and infrastructure of a company. An example of an evaluation plagued by this problem is discussed in Metaxas et al. (2005), where children were so excited to take part in the study and so impressed by the lab, and so energetic after snacks and refreshments, that whatever interaction design option they tried, they would respond equally enthusiastically.

#### 4.1.3 Evaluator Effects

For their sake, it may be best for the evaluator to stay with the child during the test to put the child at ease and provide help when this is needed. The evaluator can then watch closely if the child is engaged, needs some encouragement to stay on task or has lost motivation for completing the test. However, the presence of the evaluator can also induce a bias on the results. Their presence may make children feel more uncertain about trying out things, as they feel that there is an adult who knows the "right way" to interact with the technology under test or feel the pressure of parental expectations or other social pressure "to perform." For example, children might guess the right way to go but hesitate to try it out because they seek confirmation from the adult sitting next to them (Markopoulos et al., 2008). In these cases, it helps to have prepared a "help protocol," by which help and encouragement can be offered in order to minimize the biases thus introduced into the test results.

#### 4.1.4 Access, Consent, and Assent

For many researchers, the main barrier to empirical work with children is one of access. Workarounds can include engaging with children during a STEM-style event, as described in Horton et al. (2012), another can be to set up a KidsTeam (Walsh & Foss, 2015) and recruit a group of children to the lab to work on evaluation (as well as design) work. Consent typically has to be given from parents or teachers and this can be facilitated by building relationships with schools; one challenge is then also to enable the children to be able to assent to take part, an issue that we will further elaborate in the ethics section. Evaluators may adapt methods originally developed for adults to the capabilities and needs of children, or use methods specially developed to enable the participation of children. Below we consider a range of options, distinguishing them by the way data is collected: observed data and self-reported data.

### 4.2 Observation Methods

Observing, for the purposes of evaluation, can take place in a laboratory setting or in the field, it can be part of a usability test, where it may be highly structured, or it might be a naturalistic (unstructured) observation or even an ethnographic study. The data collected might include the things children say and observations made by the observer. The child may be working alone, with a teacher or parent, or in a group. These different configurations create different conditions for working with children.

#### 4.2.1 Usability Testing with Children in the Laboratory

Usability testing in the laboratory has been carried out with children since the 1990s, and enables the evaluator to perform rigorous and controlled testing; it makes it easier to collect performance data and other sequential data (e.g., video footage, audio recordings, logs) when compared to a field test. However, developments in supporting technologies such as portable usability labs make it possible to capture such data also in the field. With adults, lab-based usability testing has been criticized because it filters out contextual factors that impact greatly upon the eventual usability of a product, e.g., the interruption-driven nature of work, the physical and social context of work.

Different but similar problems characterize usability testing for children. Children will use software in contexts such as at home or in the classroom, that are physically and socially very different than a usability laboratory. They will interact with products in the context of play or classroom learning that is hard to stage within a usability lab (e.g., consider a game to be played outdoors by groups of children). In addition, bringing children into a laboratory can be difficult, they may need to adjust to unfamiliar, perhaps unfriendly, surroundings, might be distracted by the paraphernalia of a test-laboratory, recording equipment has to be adjusted to their physical characteristics, etc. Table 1 summarizes some of the advice by Hanna et al. (1997), pertaining to the usability testing laboratory itself. One potential solution is to furnish a special purpose usability testing laboratory.

The use of video cameras has been a contentious issue, both in the context of usability test and in the context of general requirements gathering activities (Druin, 1999); current practice suggests that video can be used so long as relevant consents have been gathered; the distracting effect of a video camera can be reduced by positioning several around a room—even if only one is being used.

**Table 1 Recommendations by Hanna, Risden, and Alexander Regarding the Set-Up of a Usability Lab**

| | |
|---|---|
| Environment | Colourful posters, appropriate furniture. Avoid childish objects |
| Microphones | Small microphones placed close to the children |
| Video camera | Avoid pointing camera straight into their faces |
| One-way mirror | Children should not face the mirror |

#### 4.2.2 Testing with Children in the Field

Testing products in the field, i.e., in the intended context of use by children, has the advantage of ecological validity (as for adult users), and puts fewer demands on the children to adapt to new environments. This can be particularly important for young children. Practical reasons also make field-testing attractive. It can be much less effort to meet children in their classroom for a test session than bring them to a lab. In the latter case, the co-operation of the teacher can be valuable for practical issues like getting informed consent from parents, making time available, e.g., during extra-curricular activities, helping with the selection of the children, finding a location in the school, etc. Further, teachers are useful informants for explaining the researcher's observations and impressions of the children, as they are aware of the children's capabilities, characters, and social behavior, so they can place the observed behaviors in a wider context (Horton et al., 2012). As well as observing use of a product in a single session, access to schools can allow for longitudinal studies and multi-session studies which can be very useful to explore the attraction of a product over time, as in the one-year-long iPad usage study described in Mann et al. (2016).

#### 4.2.3 Think-Aloud

Watching children interact with technology can inform the observer of what is happening (e.g., click-stream) but it cannot provide access to their thought processes. Asking children after they have used a product is often a poor substitute for getting feedback during use. Children will not remember their mental processes after completing a task and are likely to satisfice (Simon, 1959), in their responses. Verbalization methods can bridge the gap by creating a context in which users verbalize some of their thinking processes. They are most applicable as methods for formative evaluation, in order to identify aspects of the interaction design that should be improved. As such, the efficiency of these methods is typically assessed by the number of problems they help uncover, given a certain number of test participants (Donker & Markopoulos, 2002; Markopoulos, et al., 2008).

Think-aloud is a verbalization technique originally developed by cognitive scientists to study human problem-solving mental processes. The technique requires people to verbalize their thoughts rather than reflect upon them (Ericsson & Simon, 1984). For usability testing the user is typically required to provide a running commentary on their actions (concurrent verbalization) while the observer is expected not to intervene, only providing minimal reminders to the participants to keep verbalizing their thoughts. This "non-intervention" as well as the need to "keep talking," can be problematic for children, especially young ones who struggle to find the cognitive resources to figure out how to use a technology and talk about it, and who find the behavior of an adult who does not engage with them confusing. In addition, even if we stress to the child that it is the technology we are testing and not them, it is very easy for them to feel that their performance is being evaluated.

Several research efforts have been made to establish whether children can think aloud for the purposes of evaluating products, at what age this becomes feasible and which setup of the method is most appropriate for children. Donker and Markopoulos (2002) have shown that children aged 9–12 are able to provide a running commentary during interaction and that such a commentary helps identify more usability problems than simply interviewing children or asking them to fill in questionnaires. An adaptation that was suggested from this work was for the evaluator to specifically remind the children to describe the difficulties they experienced (rather than just the encouragement to keep talking about the interaction) as well as sometimes encouraging them to go on. Overall, due to the distractions from the core task and young child's limited cognitive resources, a think-aloud protocol is not advisable for younger children.

An alternative to think-aloud for younger children is a short post-task interview that could probe particular issues interesting the evaluator after the children complete a small chunk of interaction, e.g., lasting about 2–3 minutes. For example, when the evaluator is interested to find out how usable a particular product is, they may ask questions such as:

- Did you need help to do this?
- What, if anything, happened that you did not expect or want?

In general, more open questions can be used and a dialogical style for asking them can help uncover issues the evaluator does not expect. While several children are comfortable in verbalizing their thoughts in a more relaxed setting as described above, the experience can still be daunting for some. For this, alternative verbalization methods have been proposed for testing digital technologies with children participants. Common to these methods is that they aim to provide a more natural setting and make the interaction less intimidating for younger and shyer children.

### 4.2.4 Co-Discovery Learning and Peer Tutoring

The aforementioned problems of think-aloud have led researchers to hypothesize that usability testing techniques involving more than one child, e.g., co-discovery, where children discover together how to use a product, would provide a more natural context for the child to verbalize. Co-discovery came from adult usability studies where the ability of adults to co-operate is assumed (Kennedy, 1989). Given that children are quite different, the CCI community has looked to adapt methods that might help children verbalize in team settings. Johanna Höysniemi et al. (2003) developed the peer tutoring approach, aiming to evaluate full body interaction in interactive computer games for children. In this method children teach each other how to use the technology under test and their verbal exchanges constitute the verbal protocol that will portray the mental model they form of the interactions and the challenges they face in comprehending it. The evaluator can directly assess whether children are able and willing to teach each other how to play the game and can also see, in their communications, what aspects they may not fully understand. The method can be used in different ways; in two-on-one tutoring two children teach one tutee, another format is each-one-teach-one, where each tutee acts as a tutor for the next child.

Peer tutoring process usually consists of four phases:

- the introduction of the test setup and of the tutor-tutee roles to evaluators;
- the training of the tutors;
- tutors teaching the tutees;
- final interview.

During the tutoring session Höysniemi et al. (2003) suggested that the researchers do not teach or instruct tutees but ask questions of the tutors if the teaching situation requires adult intervention. For this reason, a question-asking protocol needs to be prepared for interviewing the tutor and providing help for the tutor in the teaching situation.

The question-asking protocol involves two kinds of questions:

- questions that help tutors to teach a tutee and carry out specific tasks, such as "Could you explain to Paul how to send an email?"
- comment-related questions (example dialogue: first tutor says: "It is very tricky," an adult then asks: "What is tricky?", and then the tutor replies: "It's very difficult to find a button where to send the email").

When answering a question, the tutor provides product-related information based on the tutor's own experiences and observations using language similar to the tutee's. Peer tutoring provides us with information about the learnability and teach-ability of the system and what kind of instructions children use when teaching one another. Since the test situation is not completely adult-free, it is important to make sure that the researchers behave informally and make space for the children to interact with each other.

### 4.2.5 Observing Non-Verbal Behavior

Whether in the lab or in a natural setting, we often have to observe children's behavior as part of the evaluation. This may be important for the designer for a couple of reasons:

- The behavior can help assess how engaging an interactive technology is. This can be crucial for a game or for an educational activity alike.
- The child's behavior can reveal challenges the child faces with interacting with the product.

These observations, whether carried out live or whether applied to earlier captured video footage, require interpretation and coding; both problematic when observing children given that their actions may not make sense to us. For the specific case of evaluating the usability of interactive games, Barendregt and Bekker (2006) have proposed a coding scheme for detecting usability and fun problems in computer games for young children testers' behaviors during a usability test.

Observation can be particularly useful to evaluate interactions with digital technology in naturalistic settings particularly when the technology aims to promote a specific kind of behavior. For example, Head-Up-Games is a class of digital technologies developed to encourage outdoor social play in groups among children (Soute & Markopoulos, 2007; Soute, Markopoulos, & Magielse, 2010). In these games, physical activity, face-to-face social interaction, and engagement with the game are desirable behaviors. In evaluating these games, the team developed an observation scheme that can be used to evaluate Head-Up Games and, more generally, outdoor pervasive games intended for children (called OPOS).

This observational protocol points to the need for an evaluator to focus carefully, when carrying out an evaluation, on what it is that is of interest. As an example, Xu et al. (2007) noted that capturing the magic of tangible interaction needed a new protocol, and Petric et al. (2018) created POMDP to code child–robot interaction.

### 4.3 Survey Methods

A survey method is any method that relies on a question-answer approach. The important steps in the question answer process for the one completing the survey are:

1. Understanding the question.
2. Retrieving relevant information from memory and "computing" an answer.
3. Formatting the answer (choosing the appropriate response category—as in a Likert scale).
4. Evaluation of the answer (may result in editing due to social desirability or peer pressure).
5. Communicating the final answer.

With child respondents, there is an increased chance for error in any of the five stages outlined above and so care has to be taken. In particular, children younger than 12 years (i.e., during middle childhood, or the stage of concrete operations in Piagetian tradition) have not yet developed some of these skills; instead, their thinking processes are based on mental representations that relate to concrete events, objects, or experience. This must be considered to adapt the measurement method to the level of cognitive development of the respondent as a child. Following this line of reasoning, and the related work from child development and psychology (Harter & Pike, 1984), several CCI research methods (e.g., Fun Toolkit) follow visual methods, which we know are more effective compared to verbal ones (Döring et al., 2010). Such visualizations represent specific situations, behavior, and the person to whom the child can easily relate.

Survey methods have to therefore take account of the developmental stage of the children. For young children (aged 3–6) images and spoken responses are preferred to having children need to write words, while for older children more sophisticated surveys can be used. The picture cards method (Barendregt et al., 2008), used images of emotional states for children to "post" during interaction with a technology, this relied on children associating images with feelings, the main attraction of this was the ease with which the children could "respond." In Read and Beale's (2009) study, children with very little language ability completed a "survey" task by drawing objects that they were most fond of and the research team then talked to each child about their drawings and added text to give the data more value. Young children are very literal, so care has to be applied when using words in interviews, for example, in Horton and Read's (2008) study, children reported having mobile phones in school which, on examination referred to the teachers having mobile phones. This age of child is very suggestible, they will want to please the surveyor and will be reluctant to express their own thoughts or feelings. Their attention span is very short, and they easily lose interest. They are more likely to use "satisficing"' responses and approaches when they are not very interested in the activity (Vaillancourt, 1973).

Older children 8–11 can be surveyed more successfully and can complete simple questionnaires, however, they still tend to be very literal and cannot easily understand negatively constructed questions. Guidelines for adult surveys favor interspersing positive and negative statements when determining attitudes; this is not advisable with children. Short concentration spans or boredom occur and may also result in unanswered questions or satisficing a nswers t o questions. Children with more developed language skills produce better data and research has indicated that low reading ability correlates with the number of unanswered questions. Interestingly, boys are more likely to leave questions unanswered than girls, and the proportion of unanswered questions decreases with age.

#### 4.3.1 Planning a Survey with Children

When planning a survey, the same caveats are needed as for all evaluations, careful planning, and careful design to make sure the protocol is manageable for the children and the results are useful for the design team. Questions to ask include:

- *What is the survey for?* It may be to identify usability problems, or it may be to elicit the children's preferences about and/or attitudes to one or more product.
- *When will it be done?* It can be helpful to carry out a survey before children use a product as well as after it has been used.
- *How will it be administered?* Will it be an interview or a questionnaire? If an interview, will it be one-on-one, or in a group? If a questionnaire, will the children do the questionnaire on their own or in a group, will they have help with the words?
- *What will be collected?* Decisions about how the data is recorded need to be made—will audio- or video-recording be used?; how will children be identified/anonymized?; how will the data be safely stored?

#### 4.3.2 Designing Questions (and Answers)

The key to a good interview or questionnaire is to design the questions very carefully. This is the case whether adult or child users are involved, but with child users it assumes greater importance due to the child having a different understanding of language than the adult. The language that is used needs to be the language used by the children. Practical ways of ensuring that this is the case include carrying out a pilot survey, asking a class teacher, or researching language development. Within a group of children of a similar age there will be significant differences in their individual language skills. For a survey to have validity, it needs to make sense for the least articulate members of the group.

It is often difficult to get children to comment effectively on closely related things. Depending on their age, some children may be unable to differentiate between constructs such as "like" and "find easy." The younger the children are, the more difficult they find it to state preferences for products. Ideas to help children do this can be found in the Fun Toolkit which we describe in the next section. Young children also exhibit a strong acquiescence response bias, that is they tend to say "yes," irrespective of what the question is! This can be in part overcome by asking them "what do you feel about?" rather than questions that those that result in a "yes/no" response.

#### 4.3.3 Interviews

An interview may be one-on-one or may be more of a focus group where there is a group of children and one or more interviewers. Breakwell (2000) identifies a range of hazards associated with interviewing children. He states that difficult people to interview include young children who are unwilling to assert themselves or to contradict the adult. Interestingly he notes that teenager children behave in an opposite way! When children are being interviewed, they have different priorities than adults—they may not realize that in an interview the adult asks and they answer, they might want to ask questions too! Children are likely to hesitate and in these instances the interviewer should avoid jumping in.

Early interviews can be used to inform the design of later interviews. Interviews need to be carefully planned and the room or space that is being used should ideally be quiet and free from distractions while also being safe for both the interviewer and the children. It is useful to record interviews as well as make notes during the session. Note taking while the child is talking needs to be done very carefully. The child needs to feel comfortable and may well ask what you are writing down.

### 4.3.4 Questionnaires

The big problem with questionnaires and children is that the children have to be able to write and read; additionally, as the language has to be simplified to make it understandable, it can be difficult to make the questions clear. It is essential to pilot questionnaires before they are used as they can cause considerable stress if presented inappropriately to children. Class teachers can be helpful in looking over questionnaires to see if they are age-appropriate. In our experience, we believe that questionnaires for children should follow these simple rules:

- Be attractive to look at.
- Have only 5–15 questions.
- Have simple questions at the start to make it easy for the children to get started.
- Be presented on one side and one sheet of paper only.
- Be printed in a child-friendly font and font size.

When questionnaires are administered to a group of children in one place, there will be some collusion going on. This is a disadvantage that has to be outweighed against the advantage of all the children filling in their views at the same time and the time that is saved by doing it this way. There will be some spoiled questionnaires. It is likely that you will be unable to work out what all the words mean as children experiment with their spellings. Some children will choose not to answer all the questions; this may be for any number of reasons. Some of these reasons are identified here:

- They are too tired.
- They cannot read the question.
- They cannot understand the question.
- They don't know the answer.
- They don't know how to write their answer.
- They are bored with answering the questions.

If at all possible, the child should be helped to answer all questions as their comments may be very enlightening. One method is to ask children as they hand in their questionnaires about any missing answers/comments.

### 4.3.5 Measuring User Satisfaction with Child Users

Quite often, the purpose of a survey is to determine user satisfaction. Satisfaction measuring with children is particularly problematic when computer interfaces are being evaluated. The computer has a "bewitching" effect on the child, as demonstrated in Read et al. (2001). Satisfaction itself is a word with very little meaning for children and it was this observation, as well as a shortage of child-friendly user experience survey tools that led to the development of the Fun Toolkit as a suite of metrics to assist in gathering user experience data from children. The Fun Toolkit (Read, 2008), is a set of three tools that can be used independently or together. They have been shown to be useable with children from as young as 4, but also are not considered unacceptable for teenagers. The three tools are briefly described here with suggestions on their use:

- Tool One: The Smileyometer. This is a Likert-style visual analog scale (VAS) that was originally designed with the help of children. During use, children are asked to tick one face. This is a very easy tool for the children, and it includes textual information to improve the validity. The Smileyometer, shown in Figure 2, is commonly scored from 1 to 5 for the different faces; if used in this way, the evaluator needs to be aware that the scale is only a rank ordering as the difference between, say, 3 and 4 may not be the same as the distance between 4 and 5. Commonly the Smileyometer can be used before and after the child uses a technology and in this way it can see if expectations are met (Read, 2008).
- Tool Two: The Fun Sorter. In many evaluation studies, the desire is to rank a series of connected or competing activities or technologies. This can help the evaluator determine which may be more appealing or which may be least fun. Repeated instances of the Smileyometer can be used but the Fun Sorter offers several opportunities to go beyond fun and evaluate other constructs. The Fun-Sorter has one or more constructs and a divided line (or table) that has as many spaces in it as there are activities to be compared. The children either write the activities in the spaces, or for younger children, picture cards can be made and placed on the empty grid. This tool has been evaluated in a number of field trials and it is encouraging to note that, in general, children understand the meanings of the different constructs, and it has the advantage of forcing some discrimination.
- Tool Three: The simplest of the three tools is the "Again–Again" table which can also be used to compare activities/events. This table lists some activities or technologies on the left-hand side, and has three columns headed Yes, Maybe, and No which are used by the children to indicate where they should tick—given that the question is "would you like to do this again?". In the validation of the Fun Toolkit it was observed that this tool was especially useful for distancing the child's intentions form the child's ratings of products. It appears that children find it easier to say they might not want to use a product again than to say something slightly detrimental about a product.

Table 2 shows how to effectively use the three tools in different evaluation situations.

It is important to note here that while the Fun Toolkit is the most used evaluation method in CCI for UX, there are several other methods that are especially useful in different circumstances and as with the discussion about observation, the evaluator has to make a careful study of the tools available ad determine what fits their context. We particularly refer the

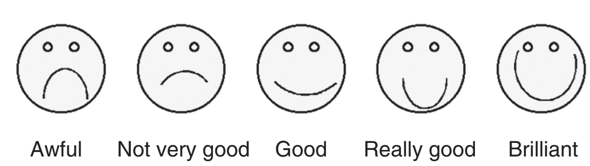


**Figure 2** The Smileyometer.

**Table 2 Choosing Tools from the Fun Toolkit**

| | Comparing two or more alternative products or features | What does it show |
|---|---|---|
| Before seeing the single product/trying the single feature | Smileyometer | The child's expectation of the product/feature |
| After seeing the single product | Smileyometer | The child's experience of the product/feature |
| After seeing all products | Fun Sorter or Again-Again table<br>The Again-Again table can be useful for multiple products; The Fun Sorter is better suited to multiple features. | The comparative experience of the child across the products / features. The Fun Sorter returns a ranking for one or more products or features.<br>The Again-Again table returns a score based on the desirability of the child to use the product/feature again |

reader to survey tools like laddering (Zaman & Abeele, 2010) and the possibilities of surveying long-term user experience as seen in (Vissers, De Bot, & Zaman, 2013).

## 4.4 Sensing Technologies in Evaluation

In recent years, the CCI community has engaged in discussions regarding the promised benefits and ethical impositions of sensing and logging technologies in evaluating technologies for children (Hourcade et al., 2018). These technologies include tracking of movements and keystrokes, the capture of facial movements and eye tracking data as well as the use of biomarkers and quantified data. Despite the challenges of sensing technologies as an evaluation method for children's technologies, previous works advocate the use of such technologies to capture complex interactions exchanged between children and the interactive systems they engage with (Kourakli et al., 2017; Papavlasopoulou, Sharma, & Giannakos, 2018).

This line of research is collectively driven by multimodal data capacities to capture and inform the researcher with regards to temporal and sometimes unique qualities of children's experience and behavior (Crescenzi-Lanna, 2020). For instance, eye-tracking allows us to capture children's attention and get insights into their cognitive effort when engaging with a system (Papavlasopoulou et al., 2018). Electrodermal Activity (EDA) and temperature can be used to infer engagement and stress (Di Lascio, Gashi, & Santini, 2018), while facial videos are capable, to a limited extent, of informing on the emotions displayed by children throughout the different events of the interaction (Amos, Ludwiczuk, & Satyanarayanan, 2016). Wristbands have been used, with app technology, with children and parents to track changes in emotions (Betancourt et al., 2017).

Leveraging sensing technologies to explore children's experience while interacting with systems (see Figure 3) is a valuable evaluation method (Lee-Cultura et al., 2020), but, rather like an observation without dialogue, the data is enhanced in terms of its usefulness when the evaluation triangulates with other methods including mainstream analytics, observations, interviews, survey, and verbalization methods. From a practical standpoint, preparations of studies using such technologies will also need additional time and special attention to the ethics of data collection. Most of the children (and maybe parents) will be new to some of the technologies, therefore, when planning to use sensing devices in your research, it is not enough to describe the details in the consent form. Rather, it is extremely important to engage in discussion with the children and parents to explain the rationale and added value of such data collections.

Measuring children's experience via sensing technologies involves inference, and inference involving complex psycho-physiological constructs, involves a degree of error.

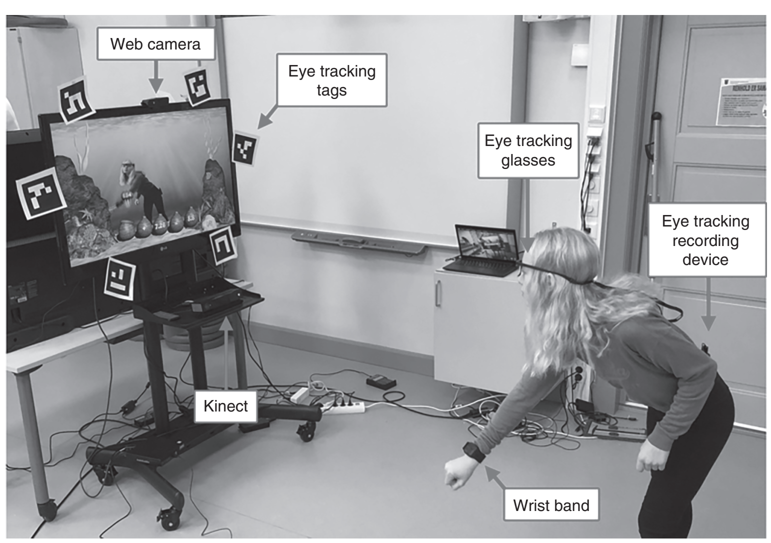


**Figure 3** A child is playing a motion-based game, while sensing technologies are used to evaluate their experience.(*Source*: Lee-Cultura et al., 2020.)

Other challenges are connected with the fact that wearable sensing devices (e.g., wristbands, glasses and other wearables) are mainly designed for adults (e.g., size, weight, tolerance), and some of them might not be appropriate for very young children or the researchers might need to make some adjustments. In addition, wearable sensing might affect the ecology of the study, for instance, device calibration might be needed (e.g., if the child feels tired and removes the equipment for a while). Nevertheless, sensing technologies are becoming more and more prevalent in CCI research due to their inherent benefits (e.g., automatic, pervasive, temporal measures) and their ability to complement the other methods (Lee-Cultura et al., 2020).

### 4.5 Working Ethically in Evaluations with Children

Just as with design work, there is a need to take into account the needs and feelings of children when doing evaluation work. As there is generally data gathered from children, it is important to be clear why the data is being gathered and why those children are the ones who are giving this data up. A useful provocation toward ethical work with children is found in Read, Horton, et al. (2013) ,where two checklists are provided to be used before carrying out an evaluation or design activity. The first a sks four questions:

1. What are we aiming to discover?
2. Why (this question)?
3. Why are we using these methods?
4. Why are we using these children?

The intention is that the respondent tries to both think of an excuse as well as an honest answer, in this way surfacing the tensions that are inherent in much HCI work where we may claim to be doing research both to change the word but also to get a published paper. The second set of questions is used as a preparation for the introductory session with the children and asks four main questions -with a practical requirement associated with each:

1. Why are we doing this research?
   a. What do we tell (the children)?
2. Who is funding the research?
   a. What do we tell (the children)?
3. What might happen in the long term?
   a. What do we tell (the children)?
4. What might we publish?
   a. What do we tell (the children)?

While this is not a substitute for an institutional or company IRB/Ethics application, it puts communication with the children at the center and steers the research/evaluation team toward an honest conversation with the children. Associated with these approaches, the children need, in all cases to be empowered to not take part, to be able to not submit their data and to withdraw their data if at all possible after they know what they have agreed to.

## 5 CONCLUSION

As a handbook contribution, this chapter has focused on what is known, on explicit knowledge. The world is changing at a rapid pace and much of the technology landscape that is found in other sections of this book will directly apply to children's lives, in this one chapter we have had to make decisions on what is included. We acknowledge that some groups of children, especially those who have disabilities or live in conflict zones or areas of poverty, have not been given the space they may deserve. We are also aware that issues around data privacy, AI, social media and media sharing have not been given extensive coverage in the preceding sections. We bring out some of the challenges around these environments in the following paragraphs.

Already, children in medium- to high-income countries have access to several ubiquitous technologies such as tablets, smartphones, and wearables. These technologies, thanks to their various affordances (e.g., multitouch technology, motion-based technology) are becoming accessible to very young children. Due to their ubiquitous nature, those technologies are accessible to younger children anytime, anywhere. Technologies such as voice agents (e.g., Amazon's Alexa and Google Assistant) allow children to perform more complex interactions, such as searching for information, while they are learning how to speak a language and sometimes even before they have learned how to read and write (Beneteau et al., 2020; Lovato & Piper, 2015). At the same time some voice agents, robots, and other automated systems are designed specifically f or c hildren, w ith examples already available through toys that are capable of sensing and processing data during child's interaction (McReynolds et al., 2017).

As those ubiquitous automated systems, and their respective intelligence that is fueled by sophisticated AI techniques, evolve and are used daily, several novel techno-social realities encompassed with novel ethical and social concerns also appear (Charisi et al., 2020; Frauenberger et al., 2019). Examples are related to children's social and physical development, the rights of children in regard to privacy and surveillance, the reproduction of gender hierarchies, and the protection of vulnerable children (Charisi et al., 2020; Harvey, 1997).. These innovations remind us that when designing interactive products for and with children, despite the powerful designs and affordances of AI and user-data enabled devices, it's also important to consider the various ethical issues and dilemmas and proceed with care and responsibility around the potential ethical implications of our research designs, methods and practices, and resulting technologies.

Data is a part of the habitat for children and as such has a different meaning for them than it does for adults (Hourcade et al., 2017); moreover, their dispositions over the use of their personal data (e.g., voice and biometric recognition) might be different compared to the previous generations. Our understanding of the way children comprehend the function of such technology and the inferences that can be drawn on their behavior remain under-explored (Antle et al., 2020). Therefore, it is important that children and their parents should be educated (Hourcade et al., 2018), in ways they can understand and personally relate to. For example, children and parents need to be jointly informed as to how personal data can be used and misused and need to jointly be informed about the role each can play in regard to their data while following different guidelines and regulations e.g., the European Union's General Data Protection Regulation (GDPR). Making aspects and potential consequences of AI-powered devices and data-driven interactions visible to children and guardians in ways they can understand (e.g., empowering children to understand their own data and create agency about the uses of data in their lives) is critical.

Returning to the reality of children across the globe who may be much more concerned with food on their plate than with photos on their WhatsApp, we conclude this chapter by returning to the overarching aim of Child- Computer Interaction, as described in Section 1.4, which is to provide appropriate products and services; namely those that can enhance the well-being of and support the development of children (Markopoulos et al., 2008). Lessons learned in the mainstream and in the developed world have to actively bring advantage to, and reduce inequality between, children from across the world.

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