A Systematic Survey on Embodied Cognition: 11 Years of Research in Child-Computer Interaction

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Abstract

Embodied cognition is a concept that has been extensively explored by scholars within the Child-Computer Interaction community. However, there is a lack of a synthesis of this research to clarify the field's benefits and drawbacks. This paper presents a survey of articles published between 2010 and 2020 in the Interaction Design and Children (IDC) conference and the International Journal of Child-Computer Interaction (IJCCI). We retrieved 158 papers using the keyword "embodied cognition" and its derivatives. Further screening narrowed these down to 43. The purpose of this review is to provide an overview of the current landscape of 'embodied' research by reporting the most common subject areas of application, forms, and modes of embodiment, and the role of children and adults. Our contribution is twofold: we highlight the main trends around these themes within the field, and we provide eight critical areas of future research. By illustrating new challenges and opportunities, we aim to support the growth of this area of research within the CCI community.

Keywords: Embodied Cognition; Children, Child-Computer Interaction; Systematic Literature Review, Embodied Interaction

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1. Introduction

Embodied cognition is a concept that suggests that we learn primarily with our bodies and not just with our brains. It is based on the premise that the brain is tied heavily to the body in cognitive processes. It has its background in philosophy but is extended to several fields like psychology, cognitive science, and neuroscience. The specific focus of embodied cognition revolves around embodied abstract metaphors, offloading cognitive processes externally, and the use of physical constraints across different cognitive development stages. While there was a declining interest in embodied cognition within the Child-Computer Interaction community between 2012 and 2017, there has been a growing exploration of this topic in the last three years. Giannakos et al. in their literature review “Mapping child–computer interaction research through co-word analysis” discuss an initial interest in embodied cognition within the Child-Computer Interaction (CCI) community between 2003 and 2012 [1]. They suggested that the diminishment afterward could result from the isolation of embodied cognition from other themes like coding and interactive surfaces, and the inability to tie it back to external fields.

However, Dourish [2], in his book “Where the Action Is: The Foundations of Embodied Interaction”, presents an argument for the importance of ‘embodied’ styles of interactions. He explains that embodied interactions are next in designing everyday interactions apart from technologies involving text, symbols, and graphics. It can be argued that, with the growth of pervasive multi-sensory technologies and the advent of a global pandemic – which has necessitated the reduction of face-to-face interactions – the place of embodied technologies is more critical now than ever. Embodied interactions can be combined and integrated with other interactive technologies that involve external real-time stimuli like augmented, mixed, and virtual reality (AMVR) and tactile, spatial, and multi-sensory interfaces. These technologies range from single and multi-sensor devices to entire classrooms constructed into embedded learning environments [3].

Several authors have defined and explored these embodied interactions in different ways based on the context of application. Abrahamson and Trninic describe embodied interactions as “hands in” technological activities that enable some degree of physical immersion in a “microworld”, involving movements of various parts or even the whole body, which become part of the “perceptuomotor structures" learned [4]. The focus on such perceptuomotor structures within this context as avenues of embodiment and cognition is heavily focused on how specific movements are tied to seeing. These "microworlds" serve as constraints and could either be imaginary [3], tangible [5, 6] or virtual [7]. Embodied movements in interactions can also provide unique opportunities to explore conceptual ideas. This can be applied in creating social and play companions and agents within these microworlds. However, it has been found that although children are initially excited about playing with such robotic toys, their interest and engagement withdraw over time [8]. Having multiple embodiments of agents and migrating between them solves the problem of disengagement and encourages interaction flows [9] and the ubiquity of such agents.

Aside from having types or modes of embodiment, other factors play a role in affecting children's engagement with embodied technology. Antle et al. [10] explain the role cognitive load theory plays in the design of tangible and embodied systems; since the capacity of the working memory is limited and temporary [11], we naturally seek to offload or extend our cognition externally. An integral part of embodied cognition is the offloading of cognition outside the brain, either to the body or by extending our minds to other objects. These modes of offloading cognition can differ across different stages of cognitive development. According to Piaget, there are four stages of Cognitive Development [12]: the Sensorimotor – Birth to ages 18-24 months; Preoperational – Toddlerhood (18-24 months) through to early childhood (age 7); Concrete Operational – Ages 7 to 11 years; and Formal Operational – Adolescence to Adulthood. A dynamic trajectory of development considers how these different stages of development might embodied knowledge.

Though there have been arguments as to the consistency of the Piagetian stages [13] and their implied psychological behaviours [14], they can be an especially useful categorisation when taking a constructivist point of view [15]. Piaget's research on the role of sensorimotor activity in everyday cognition as well as his constructivist theory show the importance of the body in the process of cognition [16, 17]. While cognition differs across levels of development, the sensorimotor stage has been found to be the perfect template for how humans embody cognition because children in this age group are constantly absorbing information through experiential movements and sensations as well as environmental influences. Antle argues [18] that applying embodied cognition in designing interactive systems for intelligence development is concentrating on the different "development trajectory" and considering children's future abilities and thoughts rather than making assumptions on their current capabilities.

The consideration of these abilities and skills, as well as other factors which influence the design of embodied interactions, can be advantageous when designing for children with special educational needs using touchless technologies like the Microsoft Kinect [19]. According to the Cattell–Horn–Carroll Integrated Model [20], there is a range of skills that children with Special Educational Needs (SEN) can benefit from. These skills can also be applied to child-computer interactions in general and are broken down into different domains: Cognitive skills, Motor and Sensory skills, and Academic skills. Cognitive skills are further broken down into short-term memory, visual processing, and crystallised knowledge. Motor and sensory skills accommodate both Kinesthetic skills and psychomotor speed, and the academic skills focus on operations and computation, and cognitive processing speed.

Looking at these different themes, it is beneficial for the community to examine the patterns across the years, looking for gaps in exploration and the contextualisation of embodied interactions especially given the past year of remote interaction. This systematic survey aims to provide an in-depth analysis of the different layers and concepts surrounding embodied cognition in the CCI community's main venues: Interaction Design and Children (IDC) conference, and the International Journal of Child-Computer Interaction (IJCCI). By narrowing the review to these two main venues, we can focus more intensely on specific concepts and themes while getting a general overview of the field. The aim is to look at the current climate within the CCI community specifically, as there is yet to be a thorough review summary that serves as a reference point for the two main venues. This survey aims to act as an initial exploratory summary giving researchers a stepping stone for future work based on what already exists. The restriction to these two venues was also pragmatic, in order to help keep a workable amount of papers. While work from other related venues and publication genres (like education, psychology, neuroscience, or robotics) are referenced to give a general background of what exists outwith the sample, the survey is not directly comparing the community with other fields but creating an in-depth summary within the community. Further work will build on this reference point in various directions, for example, by making extended comparisons with other relevant areas.

Our objective is to provide a detailed overview of the past 11 years of embodied cognition in CCI research and, more importantly, to develop a deeper understanding of the role of embodied cognition in future investigations and discussions around the designing of technology with and for children. The structure of the paper starts with a discourse on embodied cognition and related areas. Then we discuss our methodology for the systematic literature review, including how the research papers were selected and analysed. This is followed by a presentation of the results and, finally, a discussion on the main findings and suggestions of eight main areas for future research within the CCI community.

2. Background

While embodied cognition had it initial roots in fields like philosophy [21, 22, 22], cognitive psychology [23], robotics [24] and so forth, it has over the years become more concrete and is now seen as a stand-alone field [25]. Whilst our introduction explores embodied cognition within CCI, it is also being surveyed and applied across multiple fields beyond as well [26].

Johnson argues that embodied cognition has its roots in two main pillars of philosophy; naturalism and phenomenology [27, 28]. Naturalism implies the “natural emergence” [29] of all things while phenomenology implies subjective “experimential meaning”[30]. Leitan and Chaffey [31] explain in their review of embodied cognition and its applications, that both phenomenological and naturalistic explanations argue that the body (whether through biological constitution or subjective experiences) and the world are important components of cognition. Their review is summarised in four main themes of embodied cognition;

- The body, environment/tools, social history, and internal representations make up the embodied mind
- The embodied mind distributes memory across body, environment, and tools, and this is enciphered on a situational basis.
- This “situated embodied action” helps us understand and interpret language and abstract concepts.
- Perception and action are “inseparable”.

Cognition is hence understood as situated in the body in relation to the external world. The body is said to have an active, direct role in cognition rather than simply ‘serving’ the mind. Leitan and Chaffey go on to explain Shapiro’s argument that there are three main accounts of embodiment [32]; replacement (replacing traditional methods and understanding of cognition with alternatives), conceptualisation (how the body affects the way we conceptualise experiences and ground cognition), and constitution (what is considered to be cognition). These accounts offer insight into the questions often posed when considering the embodied mind.

The body heavily affects how we perceive and interpret information, especially in children [18]. The perception of visual characteristics like color [33, 34], spatial information [35] and understanding/ interpretation of metaphors [36, 37] is dependent of physical embodiment of the entities. Experiments within linguistics found that children’s cultures, especially native spoken languages, influence their creation of “cognitive pathways” and “mental models” [38]. Our everyday experiences with social history also affect how we understand metaphors [39, 40]. Metaphors are often referred to as the basis of embodiment and operationalised both consciously (at the language level) and unconsciously (through different abstract concepts). George Lakoff and Mark Johnson [41] in “Metaphors we live by” explain how universal metaphors exist in everyday interactions: “our metaphors will reflect our commonplace experiences in the world. Inevitably, many primary metaphors are universal because everybody has the same kinds of bodies and brains and lives in basically the same kinds of environments”.

Using these insights, we can pose the following questions when designing embodied technologies for children:

- How can we replace input-processing-output technologies for language and abstract concepts with more dynamically embodied systems?
- How can we tailor technologies to reflect and respond to different social histories, groups, and stages of human development, (e.g. cognitive-developmental phases, gender, etc.) and conceptualisation of information?
- What is the border between environment/technology and the mind, and how much of cognitive process can be offloaded to everyday technological interactions in natural contexts?

Embodied cognition has numerous applications, including health, marketing, sport, social media, education, robotics, linguistics, and so on. The understanding of these themes of embodied cognition has also been useful in the design of robots that are more responsive and adaptive to their environments; by streamlining physical attributes, movements, and sensors [42], for example, female robot crickets can identify and locate the male robot cricket’s sounds [43]. The understanding of embodiment and the extension of the mind beyond its body also has trans-humanistic implications [44]. Embodiment as a whole has been advantageous when designing and studying human-centered educational technologies [45] especially with subjects like mathematics [46]. Abrahamson et al. explain that the embodiment movement has done this by combining and interweaving knowledge from various related concepts like genetic epistemology, enactivisim, phenomenology, pragmatism, and pedagogy literature [25].

Within the HCI community, Abrahamson [47] encourages the spread of an

‘Embodied design’ approach when designing for STEM learning and has explored this through gesture-based technologies [48, 46, 49, 50, 51] and gamification [52]. While not explored as much within the community, embodied cognition has the potential for numerous possible applications outside of STEM (e.g. linguistics, cultural studies, art, literature) [53]. One of the main theories of embodied cognition proposes that knowledge is situated in sensorimotor activity. Putnam [54] explains the “disembodied mind” as having activities that do not focus on the brain and body but are based on functionalism. While it is arguable that no interaction can be fully disembodied [55, 56], the way information, knowledge, content, agent, or technology is presented can be disembodied or have low levels of embodiment [57, 45]. Studies that focus mainly on embodied knowledge do not simply investigate “the extracted verbal or formal description of a situation, but rather the perceptual interpretations and motoric interactions” [58].

Johnson-Glenberg et al. [57] explain that for any content to be considered ‘minimally embodied’, three concepts need to be in place; (a) sensorimotoric engagement, (b) gestural congruency, and (c) a sense of immersion; otherwise the content would simply be referred to a simulation. Lee et al. [55] defined embodied robots as having both physical shape and embedded sensors and motors. Hence, taking these definitions of embodiments, this review intends to survey publications assumed to be minimally embodied, focusing not just on embodied learning but also embodied cognition within the two main venues for the CCI community.

2.1. Existing reviews

Antle [18] breaks down the theoretical implication of current work and highlights key areas for further exploration. Understanding and designing to support children’s dynamic trajectory, offloading cognition to technical products, and supporting ”movement-based simulations” or replicating “motor-perceptual states” that augment children’s cognition. Our survey takes this a step further, looking at how these areas have been addressed in the past decade and the existing gaps. The survey takes a more quantitative and systematic exploration of the field. One review on embodied cognition that also summarises developments and trends is Lee-Cultura and Giannakos's [59] study, which examined 36 peer-reviewed papers over 10 years from 2008 to 2018. However, although related to embodied cognition, their review focuses mainly on the intersection of embodied interactions and spatial skills rather than a comprehensive overview of the topic.

Though these reviews are both focused on embodied interactions, they are somewhat limited in scope and do not present a comprehensive overview as a starting point for researchers. Given the current technological landscape and the expansion of the field over the past 2 years, there is a need to further explore the different aspects and themes within the embodied interactions design-space in CCI. Hence the reason for this review as it collates themes that span various studies over the past decade. The main areas covered in this paper are the most common **subject areas of application and skills, forms and mode of embodiment**, and **roles of children and adults within studies.**

2.2. Subject areas of application and skills

Looking at types of technologies used, Falcão and Price[60] in their study on designing tangible interactions for children with learning difficulties, explain that there is a focus on visual and particularly text engagement in creating educational technologies. However, this does not make for a holistic general learning experience as this mostly focuses on disembodied information and ignores other body parts engaged when learning. Children are generally creative and, due to their extrapolation of the world, the perfect example of embodied cognition. While there is a growing focus on children as co-designers as a result, according to Hemmert et al. [61] there is little personalisation of the co-designing process for children. This might be because of the perception that it is more challenging for children to understand such complex systems; however, collaborative learning types like role-play or participatory simulations [6] can simplify such interactions and encourage multi-sensory stimulation for children.

It is essential to create opportunities for healthy competition and interactions in designing such embodied scenarios, depending on the skills or applications being engaged. Some systems eliminate competition [5, 62], while others encourage competition [6] depending on the learning goal. This might lead to a higher level of unpredictability, especially when running studies with younger children, but this can allow for more innovative and diverse results and design methods. An example of such a scenario is the initial study of the *Aquaroom* [3], some activities became competitive – contrary to the initial aim of having cooperative activities. However, this was addressed by using a map and the elimination of duplicate results. Similarly, in the *BeeSims* experiment [6], the children were initially focused on succeeding. That shifted focus from the design objective of increasing the appreciation of the bees' pollination dance and nectar collection system.

2.3. Roles of children and adults within studies

However, unlike the *BeeSims* experiment [6], most studies relating to embodied cognition, co-designing, and participatory interactions have been predominantly focused on older children, teens, and adults, especially [61, 6]. This might be due to the normalisation of such interactions during children's "playtime", with children setting up their own play rules for such interaction; hence, it might be perceived as more challenging to determine such boundaries with younger children. However, the natural occurrence of this in children should indicate the possibilities research-wise and the need to integrate embodiment into all forms of children's technologies. Adults playing different roles [63] as users, proxies, experts or facilitators could help facilitate these boundaries by making sure not to influence the natural exploration of children within their mini-worlds. In the *BeeSims* experiment [6], for example, the adults playing the role of facilitators/researchers addressed a shift in design objectives by changing the tools used for collection, as well as limiting the collection time to be similar to the constraints faced by actual bees.

2.4. Forms and mode of embodiment

The forms of embodiment within different contexts also differ depending on the body parts being engaged and the learning methods and technologies used. Kynigos et al. [64], in their research into collaborative full-body games, elicit the importance of body movements, "gesture, language, and static and dynamic semantic representations" in the design of games and comprehension of mathematical or scientific concepts for the child. Embodied interactions can help augment otherwise "mundane" reproductions of learning materials. This includes the learning of concepts like nectar collection [6], which use indicators like light sensors and a history of hunting strategies using gestures [5]. However, there is a gap in more art and design-related learning interactions, which help in the teaching and learning of abstract 2D concepts [65] by leveraging embodied technologies (such as embedded and wearable computing, projectors, gesture recognition techniques, and so forth).

3. Methodology

A systematic literature review was conducted to understand the different forms of embodiment and the extent, context, and technologies in which they have been explored in CCI research for the past 11 years. This review's scope is limited to IDC and IJCCI as these are the most extensive and commonly used repositories for the CCI community. The review protocol includes the research questions, data extraction and selection, inclusion and exclusion criteria, and data analysis.

The methodology was crafted around the main objective of this paper: *to examine the current trends and themes within the CCI community and use the resulting analyses to suggest and inform potential areas of future research.* The review aims to answer **three main research questions** based on the examined literature:

1. What different subject areas of application and skills are prominent?
2. What forms of embodiment can we infer?

SEARCH TERM 1	SEARCH TERM 2
Child	Embodied Cognition
Children	Embodied learning
	Embodied interaction
	Embodied metaphors
	Embodiment

Table 1: Search terms using AND between them

3. What are the roles of children and adults in this research?

The rest of this section examines the methods used for each process and breaks these research questions down further into different categories.

3.1. Data extraction & selection

3.1.1. Data collection & search query

Focusing on the two major publication avenues for the CCI community (IDC and IJCCI), a search was conducted within the Association for Computing Machinery Digital Library (ACM), and in the Science Direct online repository to collect high-quality data. The period examined for ACM was from 2010 to 2020, and we also included all articles published in IJCCI from the start of the journal in 2013 until December 2020. The key search terms used are shown in Table 1. The word "embodied" when used exclusively (unrelated to other relevant keywords) was ignored as a search term, given it could be used in contexts other than those relating specifically to the subject matter. This also was in the interest of increasing the quality and relevance of papers identified. The search pattern for IDC and IJCCI differed as IJCCI focuses primarily on research with children, hence the first search terms were ignored, and only the second search terms were used from Table 1. This was the first step in the selection process and resulted in 158 papers after duplicates were removed.

3.1.2. Exclusion and inclusion criteria

The next stage of this review process was removal of papers which were not relevant, the following exclusion criteria was applied to the initial selection of 158 papers:

- Papers which do not include children or students in the design, data gathering or testing process

- Papers which do not focus on technologies created for children or students from the age 0 to 18. This was decided by using an age-based definition of "child", as adopted by the "Convention on the Rights of the Child" [66].

- Papers which do not involve the use any clear form of embodiment

- Dissertations and theses; as these are considered as grey literature

- Credibility: Short-papers, posters, workshop proposals and position papers, abstracts, work-in progress studies, panels, doctoral consortium, Demos, tutorials, editorials and papers which are not peer-reviewed. This is because either primary research and design reports are not included in these formats, or less mature work is presented.

- Relevance: Papers that mention *embodied* as well as derivatives of the term exclusively in the keywords and references as they do not provide enough information of what type of embodiment was involved in the research design.

In terms of inclusion, we considered peer-reviewed papers backed by empirical evidence, which includes both quantitative and qualitative studies. The research design had to be appropriate for addressing the aim of the research, with there being a clear statement of the aim, objectives, data collection, analysis, and findings.

We also focused on papers which seem centered around some form of sensorimotor change/simulation (sensory inputs and motor outputs) [67, 57] rather than only non-sensory input using the eyes and ears [68]. Sensory inputs are stimuli which are recognised by the body and evoke a perceptual, motor or affective state or inference (for example, smelling an object, feeling the shape of a robot etc.), while non-sensory inputs rely primarily on the brain's interpretation of information, rather than physical sensing (for example, reading options from a menu display) [68]. This is because one of the theories of embodied cognition proposes that when embodied knowledge is simulated through perceptual and sensory systems (sensorimotor activity), the same "visual stimuli, motor movement, and tactile sensations" can be reenacted partially or unconsciously without the initial action [26, 68, 57]. Hence experiments that show no distinct use of sensorimotor change, (e.g. an animation on a screen with no interactivity [57]), often rely on the brain's interpretation of the content via vision and sound to add context rather than using the body's perception.

Most of the definitions of the categories around embodied cognition such as metaphors were coded and operationalised based off Lakoff's "Explaining embodied cognition results" [69]. Other categories were decided upon using the authors' expertise based on how the studies were structured (e.g. age group, type of study etc). These studies were conducted in both formal and informal environments and focused on both hard and soft skills like collaboration. Given these criteria, 43 papers met the final inclusion criteria. The first author conducted the data extraction and selection process; however the second and third authors defined some of the criteria for the process.

3.1.3. Data analysis

Based on Robson and McCartan's [70] template approach for qualitative analysis, the papers were analysed using areas derived from our research questions. The categories were refined over three iterations and formed the templates for the data analysis.

The final template was as follows:

- The subject areas that are focused on in the studies (e.g. Maths, Music, Coding, Collaboration);
- What skills and abilities are being engaged (e.g. cognitive skills, Motor and sensory skills – Learning communication, play, problem solving, etc.);
- What kinds of learning/teaching methods are used (storytelling, creativity, prototyping etc.);

- Which body parts are being engaged (hands, eyes, ears etc.);
- What sort of stimulus/sense is being used (light, sound, smell etc.);
- What behaviours were observed (Facial expressions, Response latency etc);
- What methodologies are used to understand cognitive-affective state (direct observations, psychological markers etc.);
- What were the physical or environmental context/constraints (physical, spatial, social etc.);
- What abstract metaphors and concepts can be seen;
- What cognitive process is being offloaded on to an artefact (memory, perception, balance etc.);
- What forms of external representations are used (symbols, pictures, movement etc.);
- What kinds of technologies are they based upon;
- What tangible materials are used;
- What digital materials are used;
- What is the role of the children in these pieces of research (social actors, designers, users etc.);
- The age group of the children participants;
- What cognitive developmental phase is covered (sensorimotor, preoperational etc.)
- The role of adults in the design process (users, proxies, expert etc.);

We also created a general template about the studies, including title, authors, conference, year, instrument, study type, data analysis, sample size, location, and duration.

The authors selected and extracted each attribute of the different papers based on the defined categories. The final results were then discussed to ensure consistency. All 43 studies were analysed in detail following the template, extracted, and coded into an Excel sheet to give a structural overview of the papers. This enabled the authors to see patterns across the different categories and better answer the initial research questions. The details of the coding are shown in Appendices H1–H3.

3.2. Limitations

While this study focuses on embodied cognition, the search term only includes papers that explicitly use the term 'embodied', its derivatives (e.g. embodied interaction), and 'embodiment'. It can be said that not all papers which address embodied cognition use those terms explicitly but may use related terms like "Sensory", "Tangible", "Enactivist" or "Embedded", however, we are focused on addressing embodied cognition related to CCI specifically, which led to the selected search terms. Also, we discovered that some of the related terms have negligible results (e.g. using the search term "Child" and "Enactivism," and its derivatives returned no results within IDC and IJCCI.

Another limitation for the search terms is the use of 'child' and 'children' and the age group referenced by that topic. The age range for children considered in this survey is between 0 and 18 because ages above that could be considered adulthood depending on the cultural context of development [71]. This can be a grey area, as the marker for where adolescence ends is not strictly defined; and ages between 18 and 24 can be considered as "late adolescence" or "extended adolescence" [72, 73]. While the terms used to refer to the participants might also differ, narrowing the search to the IDC and IJCCI assumes that most papers would include the term "child" or "children" either within the experiments, or the related literature. It is possible that some literature may not have the word "child" in it, however, we assume this is a minimal number based on the venues of focus.

This paper encompasses papers published in the IDC and IJCCI, though there is a likelihood of relevant works in venues apart from these (e.g. TEI, CHI). The scope was limited to these two leading venues of CCI research publications to ensure a workable number of papers but still allow the summarised findings to give a starting point for future exploration. Hence while there are likely highly related publications in other venues, not just within computer science, the initial literature background tries to highlight some of the key findings across these fields briefly. This gives researchers within the community a starting point from which they can then make comparisons with other venues. Given the initial contextualisation that this review intends to offer, subsequent literature surveys in comparison to other venues would yield additional insights.

Due to the scope of this review, literature in other fields such as cognitive sciences, applied psychology, body-mind philosophy, experimental psychology, neuroscience, were also omitted. This creates the opportunity for expansion and interdisciplinary collaboration in future research, interweaving the research findings within HCI with its social science and theoretical roots.

Dissertations and theses were not included as they are not published by the venues referenced for this review. It can be argued that grey literature can help reduce publication bias in some cases [74], however, Ferguson and Brannick [75] found that there is not much evidence to support how effective unpublished works are in reducing publication bias, and that they could even increase bias if the sample is not full or representative.

Though a few works could be missed, some research shows that the inclusion of grey literature (like dissertations and theses) has a negligible or minor impact on the results and conclusions of systematic reviews [76], and included grey literature can often lead to an overestimation of current results.

Some of the sections used in the data analysis, such as ‘abstract metaphors’, may not be explicitly stated by authors but were assumed based on the research context. This allowed for a more flexible analysis whilst ensuring consistency when interpreting the result.

Year	**Number of publications**	**%**	**References**
2010	4	9.3	[64, 61, 6, 5]
2011	4	9.3	[3, 4, 10, 65]
2012	3	6.98	[77, 78, 79]
2013	2	4.65	[80, 81]
2014	2	4.65	[82, 17]
2015	**3**	6.98	
IJCCI	1		[83]
IDC	2		[84, 85]
2016	4	9.3	[86, 87, 88, 62]
2017	**3**	6.98	
IJCCI	2		[19, 89]
IDC	1		[90]
2018	**3**	6.98	
IJCCI	1		[91]
IDC	2		[92, 93]
2019	**6**	13.95	
IJCCI	2		[94, 95]
IDC	4		[96, 97, 98, 99]
2020	**9**	20.93	
IJCCI	3		[100, 101, 102]
IDC	6		[103, 104, 105, 106, 107, 108]

Table 2: Overview of the 43 papers according to the years, venue and percentage of total papers included. 2010-2014 and 2016 are solely from IDC

4. Research findings

In this section, we break down the results of the analysis of the 43 main reports and use that to answer the main research questions. An overview of all the included papers is given in Table 2.

In the analysis we broke down categories for the review based on the three research questions:

1. What different subject areas of application and skills are prominent?
2. What forms of embodiment can we infer?
3. What are the roles of children and adults in these research?

The different subject areas of application and skills that are prominent include: the subject areas that are focused on in the studies, what skills and abilities are being engaged, and what kinds of learning/teaching methods are used. 'The forms of embodiment' is the largest category and is further broken down into the body parts engaged, the stimuli used, the behaviours observed, the methodologies, environmental context/constraint, abstract metaphors, cognitive process offloaded, and forms of external representation used. The final category is the involvement of children and adults in the research, including their roles, age groups, cognitive development phase, and the role of adults in the study.

Out of the papers retrieved, the percentage of screened papers included in the final report is 28.1% (43 out of 158 papers). We can see that the percentage of papers reduced from 2012 to 2018, though 2016 had more included papers within that year range. From 2019 to 2020, there was an increase in papers, accounting for 34.88% of the total papers. In terms of venues, 20.93% (9) are from IJCCI, and 79.07% (34) are from IDC.

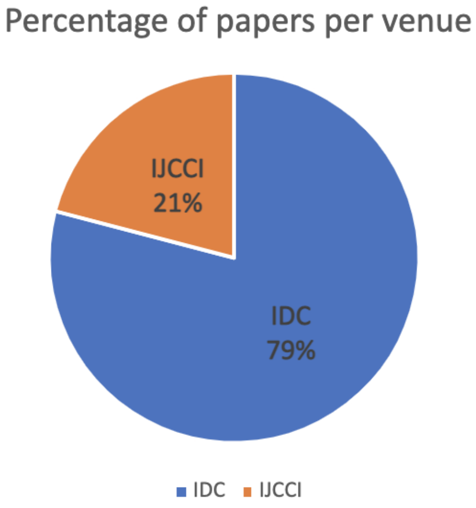


Figure 1: Percentage of papers per venue

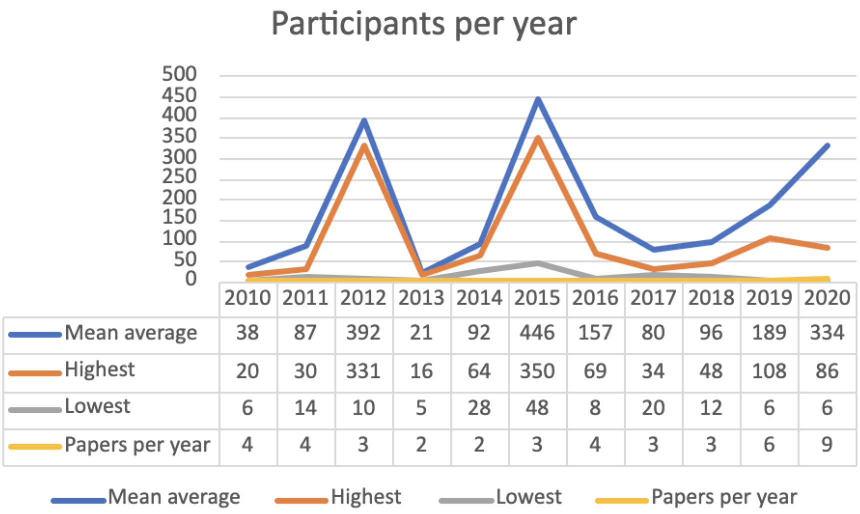
4.1. Research Overview

There were a wide variety of papers by different authors; however, three authors had the most papers attached to their names. Narcís Parés had seven co-authored papers [5, 62, 77, 17, 84, 89, 93], followed by Laura Malinverni with four main-authored papers [77, 84, 93, 100] and Joan Mora-Guiard who had three main-authored papers [17, 62, 89].

The 'type of study' refers to whether the methodologies used were qualitative, quantitative, or mixed. Based on this categorisation, the majority of the papers were qualitative. Out of 43, 44.19% (19) of the papers were qualitative, 30.23% (13) were quantitative, and 25.58% (11) made use of mixed methods. We also made the distinction as to whether the experiments were carried out within groups (19), between groups (1), individually (1), or using pre-test (1) and post-test (5). We also saw combinations of different experimental designs like pre-test and post-test (5), individually and within groups (9), and one study combining individually, within groups, and a post-test. However, there was no combination of within and between groups. All studies that involved a post-test made use of control conditions, and one of the studies made use of the Solomon four-group design.

The average sample size was between 10–50. With five (11.63%) studies having less than 10 participants, 18 (41.86%) studies being having 10–30 participants, and five (11.63%) having between 30–50 participants. Among the studies with participant numbers over 50, four had less than 100, one had 108, and two had over 300, with one of them taking place at a major fair (over 350). Among these participants, there was a range of skills and abilities, with five (11.63%) out of 43 studies involving children with special educational needs (SEN), having a total of 87 children participants altogether. However though not all studies made mention of the gender percentage, 13 studies had more male participants than female participants, three were equal balance, and 11 had more females.

The most prominent location for these experiments was the classroom (18), followed by the lab (10), some taking place in both, some in museums (3), and a few experiments taking place outside these two venues like home (1), gaming



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mean average	38	87	392	21	92	446	157	80	96	189	334
Highest	20	30	331	16	64	350	69	34	48	108	86
Lowest	6	14	10	5	28	48	8	20	12	6	6
Papers per year	4	4	3	2	2	3	4	3	3	6	9

Figure 2: Participant per year

centres (1), a park/field (4) and a fair (1). One of the studies did not have a specific location but allowed the students to take the technology into their everyday context. Most experiments were conducted within a day (20) to less than a week (5). However, some lasted more from up to three weeks (4) to 6 months (8), and only a few studies (2) were more than six months (one being for two years and another for two terms).

Most studies reported using digital artefacts like tablets (8), desktops computers (3), laptops (3), cameras (5), RFID tags (3), projectors (8), and some form of sensor technology (6). Some (33) used different tangible materials depending on the study design, while some did not. Though there was a variety of tech in the individual studies, Arduino (6), Making/tool kits (4), Kinect (3), and the UCube (2) were the most used. We also had robot agents (5) like *PhyPleo, Jibo, mBot, Cellulo Robot*, and Clementoni's *Doc robot*.

The rest of this section takes each research question as a heading and addresses them based on the survey results.

4.2. RQ1, what different subject areas of application and skills are prominent?

The subject areas involved are important as they determine what forms of embodiment can be explored and how. We split these areas into more concrete subjects like mathematics and science and more social/cognitive skills like problem-solving. There could also be 'learning communication' which refers to a specific concept rather than a whole subject area. Learning communication (15) was the largest single area of focus with topics like bees, group hunting strategies, sustainability, buoyancy, and nanoscale. Problem-solving (13) was the second-largest area of focus, followed by mathematics (7), science (6), programming (5), and design (5).

The exploration of cognitive skills like learning-communication (15), language development (3), behavioural-cognitive skills (3), collaboration (2), verbal ability (1), however, outweighed academic skills like computational thinking (1) problem-solving (13), abstract thinking (1), and motor-sensory skills like play (6), social interaction (3) and geometry/handwriting (1). There was also a higher focus on soft skills (31) as opposed to more concrete skills (24). We had one study on concrete skills that focused on an art-related study outside of STEM (23) which was music. Examining the papers, we see that although there is a combination of learning methods with some doubling as subject areas, more than half of the papers featured play (29) with six papers being open-ended (6), and collaboration (24) with two articles specifying "Encouraged collaboration" (2). Other popular methods were gamification (16), creativity (15), learning (12), role-playing (8), problem-based prototyping/making (4), and designing (4). We also saw singular occurrences of methods like situated learning and learning by teaching.

4.3. RQ2, What forms of embodiment can we infer?

This addresses the forms of embodied behaviours the studies were based on as well as what body parts were involved. The body parts involved were categorised based on the five senses and the embodied stimulus. Though most studies involve some level of visual perception, this was ignored in studies that do not employ visual cues in a purely embodied manner but rely on the brain only to process the visual information in a top-down manner. The most engagement of different body parts by studies in order of highest to lowest; hands (24), eyes (18), ears (6), fingers (1), head (1), leg (1), and face (1). While most of the studies combined multiple body parts, we had studies involving full-body interactions (21), including touchless interaction (1). However, none of the studies was concentrated on interacting with the nose/tongue or intentional use of olfactory and taste stimuli. While stimuli seemed fairly distributed across studies, the use of visual stimulus (27) was still the most prominent, breaking down into specifics like imagery (4), light (7), and colour (2). Other stimuli used were touch (18), movement (23), gesture (15), auditory (13), and one study involving all types of stimulus.

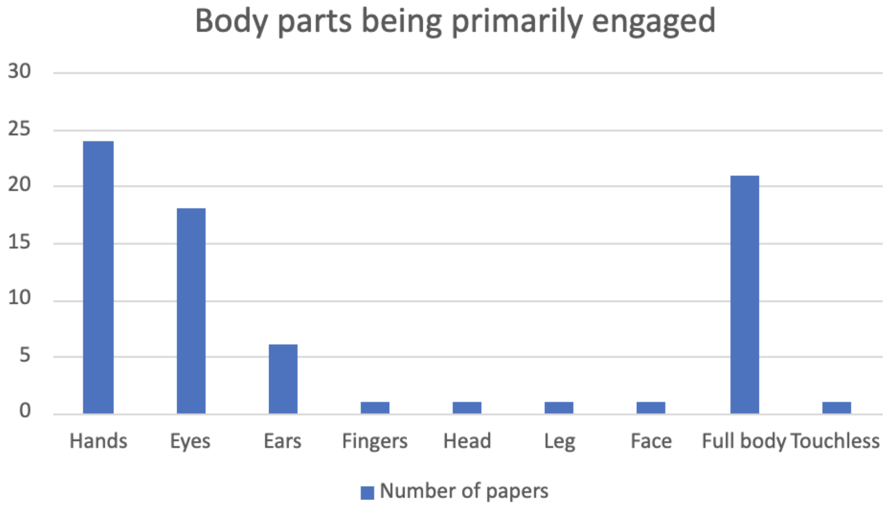


Figure 3: Body parts being primarily engaged

Due to how context-dependent observable behaviours in experiments are, they depended solely on the researcher and the study type, but behaviours frequently focused on were; understanding of the concept (8), engagement (5), task completion (3), and motivation to play (2). When reporting these behaviours, a variety of methodologies were used, such as direct observation (29), indirect observation (11), artefacts (8), self-reporting (18), semi-structured interviews (15), tests or questionnaires (19), Wizard of OZ (3), and focus groups (2).

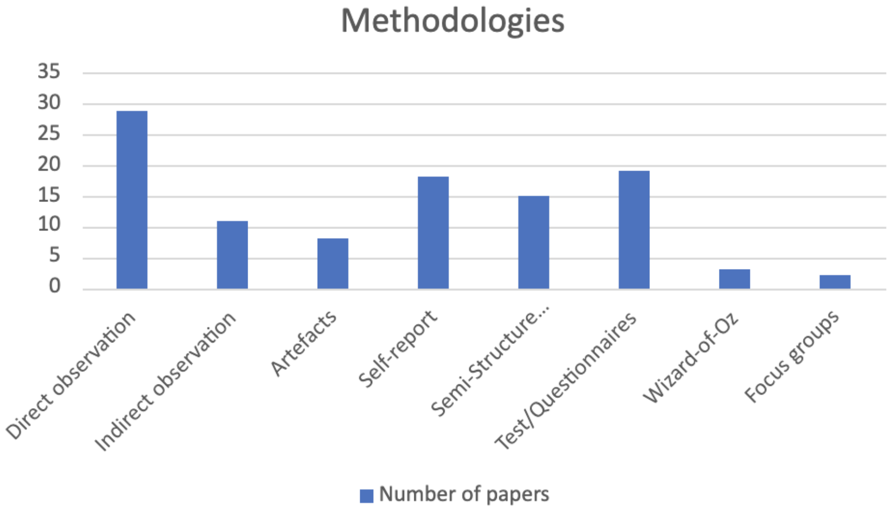


Figure 4: Methodologies

Some abstract metaphors and concepts are not always explicitly stated in the research papers but can be assumed from the experimental design. For example, walking forwards to show progress or using height to represent distance. For example, they may also be embedded in concepts like portraying nectar collection by acting as a honey bee, or role-playing as hunters or town members. Some metaphors and concepts appear multiple times across different studies like balance (4), building blocks (5), and modelling (4), possibly due to the simplicity of the metaphors. These and other abstract metaphors and external representations occurred with 2D (9), 3D (20), and physical (24) constraints and are to help offload a part of the child's cognition of artefacts. Offloading perception (38) and conceptual processing (32) of a particular topic was the most cognitive process being offloaded/embodied through the body. Apart from this, we observed other cognitive processes like memory (3), language processing (4), computation (4), balance (5), and problem-solving (3) being offloaded to artefacts.

4.4. RQ3, what are the roles of children and adults in these pieces of research?

This section of the analysis breaks down the role of children and adults in the 43 main reports. Based on our research, we decided on five major roles children play in research and four roles that adults can play, especially relating to CCI research. Examining the roles of children in papers, out of the 43 studies, portrayed children as social actors (5), designers (13), users (28), testers (23), and as informants (4). Looking at this, we see a gap for more studies exploring children's involvement as social agents and informants. Adult roles, however, are slightly different; facilitator (40) is the most common role, followed by expert (22), proxy (13), and in one study, teachers were also users (1).

As embodied cognition differs across cognitive developmental stages (see Table 3 and Figure 5), we looked at the ages specified in the studies and categorised them accordingly based on the Piagetian stages. Though not rigid, this allows for a more cohesive analysis. The average age in most studies was 7–11 years, which is the concrete operational stage of development (35). This is often combined with children from the formal operational (21) or preoperational (12) stage. Though the general age range for the formal operational had a high frequency, most of the studies were combined with other groups and often fell within 12 and 14 years. Only two studies focused on the formal operational stage; one focusing on ages 12 to 14, and the other on ages 14 to 17. The sensorimotor stage is not involved in any of the studies, possibly due to ethical concerns. Some studies (22) combine two or more phases of development while some only focus only one (19), and others have a dynamic trajectory of development (2).

Sensorimotor	**Pre-operational**	**Concrete**	**Formal operational**
(Birth—18-24m)	(18-24m—7 years)	(7—11 years)	(Adolescence—adulthood)
0	12	35	21

Table 3: Number of studies which focus on the different stages of cognitive development

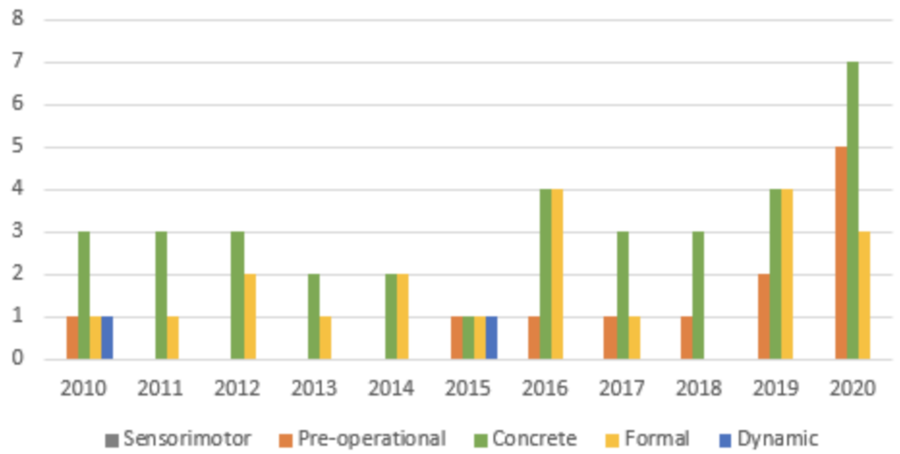


Figure 5: Number of stages over the years

5. Discussion

After surveying the initial 153 papers, we can see that embodied cognition remains a relatively new theme within the CCI community, however, there has been an increase in its exploration over the past few years, with the peak of research contributions being in 2020, as seen in Table 2. This review focused on the trends of ‘embodied’ research concepts in recent years and the most common subject areas of application and skills, forms and mode of embodiment, technologies, and the role of children and adults in the study. Our inclusion and exclusion criteria helped streamline the most relevant papers based on our initial research questions. Finally, 43 peer-reviewed reports were selected through various categories and applications (both educational and non-educational). This section further discusses more qualitative observations and trends from the reviewed papers.

Due to the nature of embodied cognition and the involvement of children in studies, ethics is a highly relevant issue to consider for researchers. As emerged from the survey, ethics pervades topics such as personalisation, special needs, diversity, inclusion, and children’s ages and stages of development. Researchers need to consider it in all the aspects that concern their research, for example, conceiving fieldwork, designing a prototype, or writing a protocol. Ethical concerns often affect how and if specific experiments are carried out and what age groups are involved, this could be why certain trends are more pervasive than others, such as studies involving the concrete operational stage instead of the sensorimotor stage.

Following the analysis, we present the main trends in the field which emerged from the survey:

5.1. Exploration of neurological evidence of body parts being engaged

We understand the place of empirical evidence when carrying out any form of study: when it comes to proving embodiment, this could either be neuroscientific (e.g. associated motor areas [109, 110, 111]) or behavioural (e.g. conceptual understanding [26, 67]). Compared to more psychological and cognitive fields, none of the studies surveyed in this paper used neurological evidence to support claims. While looking at behavioural evidence is valid and points to embodiment, it can be subject to assumptions and biases as to what body parts are being engaged in the interaction and to what extent. Neuro-imaging may be needed in some cases to truly determine what corresponding brain areas are especially activated during the experiments (for example, visual, olfactory, motor, gustatory etc) [112, 68]. There is also the potential for ignoring certain forms of motor and sensory embodiment, which are not apparent using behavioural observation, (e.g. idiom comprehension [110]). We do not think that behavioural evidence is negligible, but it can still be subjective and can lead us to ignore certain sensorimotor information in favour of others because we cannot observe the behaviours directly. The exploration of more neurological evidence can open up more opportunities for collaboration with other fields.

As an intersection exists between embodiment and making, studies involving maker technologies and activities were included. However, there is still some question as to what extent some making technologies are embodied, as not all maker platforms use sensorimotoric engagement (e.g. using physical artifacts). Some mostly use simple screen simulations, which could be argued as not primarily being an embodied approach. Godhe also explains that the term 'maker' has been misappropriated for numerous learning scenarios and activities [113]. Given that some studies relied solely on behavioural evidence, the making studies included [65, 78, 95] were those which explicitly showed some form of body engagement, interaction, or physical embodiment.

5.2. Measuring cognitive-affective state

The results show that although there was mention of methodologies for measuring 'cognitive-affective state' as one of the categories, only one study explicitly addressed the cognitive-affective states of the children, making use of real-time psychological markers [105]. While it seemed hard to explicitly determine if a number of the studies were augmenting pre-existing knowledge or helping children form new knowledge, some studies addressed this. Antle et al., in their "Towards Utopia" study mentioned this 'inability to determine' as a limitation of their study [10]. This questions the direct long-term effects of the studies, but does not discredit the validity of the different studies – instead requiring a specification of such contexts, limitations, and suggestions of future exploration of long-term effects. In Segura et al.'s analysis, the research aim was based on the assumption of the children's first encounter with migration [79]. This led to the postulation that the study was designed to help form new knowledge. They explain that there is the possibility of children showing a deeper understanding of the concept if they get more familiar with it in future studies. In contrast, Malinverni et al. [77] were more explicit with their approach and contacted schools prior to the study to ensure the children had no prior knowledge of the concept of 'buoyancy' (for example), focusing and reinforcing their study as one aimed in the development of new skills. Additionally, Mora et al.'s way of addressing this was slightly different and more empirical, using pre- and post-tests to ascertain the children's level of knowledge before and after the study.

5.3. Embodied versus dis-embodied learning methods

While it is a general assumption that embodied knowledge offers a more robust experience compared to disembodied knowledge, only a handful of studies [61, 79, 77, 17] made empirical comparisons between learning outcomes of embodied as opposed to dis-embodied learning. There was a larger focus on the results of the embodied technologies; however, this does not generate contextual evidence of their effectiveness against dis-embodied methods. In the studies where the learning results were evaluated quantitatively [17, 77], most did not show a statistically significant difference between both approaches. Still, it led to the posing of further research questions. It might be said that although learning outcomes were not statistically different, the children's self-reporting and observation of the learning process showed more engagement and excitement. Some other studies even had children asking to prolong the experiment time so they could "play" more [83].

The lack of a statistical difference could also be as a result of the metrics used and the time frame of these experiments. These studies compared short-term effect of embodied technologies (with the longest study being three weeks [77]). Still, they did not incline the long-term aggregated impact of embodied technologies over disembodied ones. In one of the studies, 'Whom would you like to talk with?' [106] which compared children's perspective of different levels of embodied peers during the creation process, the authors found that there was no influence on children's creative outcome; however, the use of more embodied agents made the process of creating more engaging. One thing to note in carrying out these comparative experiments is ensuring the embodied, and disembodied agents have similar and comparable affordances, though in some experiments like *Pleo* (*PhyPleo* and *ViPleo*) [79] the presentations of those affordances may differ. Roberts et al. [82] took a different route, comparing two different approaches to designing embodied interaction. Studies that rely on self-reporting could have the bias of children having higher expectations for a particular type of technology or embodiment – especially robots – hence rating it lower [108].

One of the studies [107] that saw a difference between how children embodied technologies looked at the difference in the embodiment patterns of the children themselves rather than the technologies. They found that children who were considered as “high gesturers” during the reflective process had a higher understanding of abstract concepts compared to “low gesturers”. Almjally et al. suggest further study of how different gestures affect learning gains over time. Though this study also compares embodied Tangible User Interfaces (TUI) with Graphical User Interfaces (GUI) and found no significant difference between the gestures (interpreted as learning gains), it can be assumed that the children who were high gesturers had higher long-term embodied learning effects. Perhaps this opens up an opportunity to explore how long-term embodied teaching can affect children considered as low gesturers.

5.4. Embodied robot toys companions and social agents

One area not as explored is embodied robot toys, companions, and social agents. One of the studies carried out by Segura et al. [79], compared the migration or “teleportation” from a physical embodiment of the robot *Pleo* and a virtual representation using a tablet. Aside from this, another area that has potential research opportunities is full-bodied interactive technologies which make use of the body as a “referent” [17], focusing on the body as the main element driving the learning experience. In some full body interactions like the *CoCensus* [82] the position of the participants respective to the data system affected how they viewed the data, whether in first-person (Active), or third-person (onlooker).

5.5. Engaging play skills as a form of embodiment

It has been found that the use of play as a method of learning allows active engagement, motivation, and immersion of the players (children) [77]. Participatory games, especially those involving role-playing, give a feeling of personal investment, which makes the activities more meaningful to the children [3, 10, 82]. Role-playing games can also elicit a sense of interdependence and collaboration depending on the context (e.g. as town members [3], as hunters [5], or cops and robbers [80]). Studies have established direct relationships showing that an increase in body movement leads to an increase in engagement, further staging the case for full body technologies. Collaboration also plays a significant role in engagement, as Sylla et al. [83] demonstrate in their storytelling experiment, finding that children who played in groups had a longer mean interaction time – 19.24 min as opposed to 10.3 min.

5.6. Physical/environmental contexts

During the analysis, we found that most studies took place in either a laboratory setting or in a classroom, with only a few studies like Sylla et al. [83, 82] bringing parents into the design studies. Mora et al. [17], carried out experiments both in the lab and the classroom to compare a controlled environment to a less controlled environment. Participatory design is not limited to students alone; teachers are involved in the requirement gathering, whether informally or informally. In Kang et al.'s study [87], a formative pre-design session of 2.5 hours was held with 20 teachers, testing the concepts and prototypes using mock-ups and sketching materials. This helps to better the possible areas for improvement in the current design as the teachers had a better understanding of the field and the children.

In some cases, teachers would serve as proxies as they had a better relationship with the children. Pire et al. involved educators both in the requirement gathering phase and in the analysis of the study [104]. A number of studies involve the informal settings in which the learners interact with objects found naturally in their environment, while some others were in more formal settings but still involved direct play with objects found within their environment [95]. Only one study [99] allowed children to take the technologies individually into their everyday contexts, relying on the children's natural interactions and embodiment in their settings outside of the classroom. Chu et al. also gave the students smartwatches and allowed them to record their objects and locations that led to certain scientific reflections. This not only let children take note of how the knowledge they gathered is embodied in everyday contexts (both imaginary and real) but gave them a playful way to embed smartwatches as educational tools.

5.7. Abstract metaphors/concepts and gaming technologies

Some *Kinem* games like *Farm Walks* [19] allow researchers to change the difficulty of the games by removing or including certain features like obstacles and stop signs, and some studies carried out multiple experiments using multiple games or concepts in terms of experiments. Chu et al. [91] broke down their making-experiments into simulation models which simulate earthquakes and solar energy, concept-process models which require students to program a food chain based on their knowledge over 2 years, and illustrative models which use LED lights to show their understanding of concepts. There was the combination of new concepts with pre-established knowledge, like music and conductivity [85], football and programming [94], and emotions and machine learning [102]. Only one study [102] was centered around emotions; however, it focused on children teaching different emotions to the AI by using their bodily and facial expressions. There was no exploration of how the state of the body can affect children's feelings, especially when relating to technology.

5.8. Children's roles, age and stages of development

Depending on the cognitive-developmental stage of children, certain concepts are easier to introduce. Out of the number of studies reviewed, only a few considered differences across different age groups. Kang et al. [87] broke their session into different groups based on the ages of the children, and while the experiments did not vary by age, the conveying language did. Antle et al. [10] focused their research on children between the ages of 7 to 10 (concrete operational stage). This was influenced by the research of environmental psychologist McKenzie-Mohr who suggested that this age was the best time to help build "ecologically sustainable behaviour" in children [114]. Xiao et al. [88] also focus on children between 7 and 13, as it was mentioned based on Piaget's observation that children between the ages of a toddler and up to 12 years old have not fully developed their abstract symbolic thinking. Still, the latter end of the spectrum had higher stage-like increases in abstract, symbolic understandings, while children at the lower end relied more on sensory-motor thinking.

However, other studies did not show the rationale for the selected age groups of their studies. We expected more interventions in the sensorimotor stage, but to our knowledge, none of the research has involved this age group so far. This could be due, for instance, to the difficulty of finding a consistent sample of children who have similar abilities when comparing results. We also expected more experiments with participants who fell into the middle adolescent age (15 to 17) within the formal operational stage, however only one study was found, and others concentrated on participants between the ages of 12 and 14 (early adolescent).

5.9. Subjects focused on in embodied learning studies

On the subject of exploration, we expected more subjects within the arts and humanities, but there was a heavy focus on STEM-related learning concepts. Most areas concerned biology like *SharedPhys* [87], mathematics [19, 98, 64, 65], or programming [107, 104, 102], with few studies exploring the arts, such as music, independent of STEM knowledge – *Andantino* [88] being an excellent example of that. We find that other studies involving design and other arts only used it as a teaching method for a more STEM-related goal rather than as the sole purpose of engagement. For example, Leduc-Mills et al., in their 2012 study, make use of designing as means to help children learn mathematics and geometric shapes, and Petersen et al. [85] extrapolated on musical instruments to help children conceptualise intangible conductivity. While it is encouraged to interplay different subjects to help draw on metaphors, the focus on STEM subjects, especially programming, could be because they fall naturally within our domain as researchers. This isolates and ignores other interests children might have and how embodied technologies can help them learn better.

5.10. Personalisation, special needs, diversity and inclusion

Personalisation goes beyond age and cognitive development stage and also includes abilities. It can make the experience better or complicate the experience when it involves a large-scale of users. This can be an especially intricate subject when relating to children with neurologically diverse needs [81, 89, 19, 92]. Some or all types of stimuli may be hard to process: this is where embodied full-body touchless technologies with "focused, predictable and replicable" stimuli maybe be of high advantage [81]. However, most studies often only focus on particular abilities rather than designing inclusively and accommodating different abilities. One study that executes that well is Neto et al.'s paper "Using tabletop robots to promote inclusive classroom experiences" [103], which includes both students with and without visual impairments in the experimental design. There still seems to be a gap for studies that look at different levels of knowledge, cognitive development, race, gender, and skills. When it comes to gender, the participants were predominantly boys, and although studies relating to special needs like Autism had a rationale as the ratio of males to females within the autism spectrum is 5-to-1 [89], other studies did not. There was also a lack of studies that looked outside binary gender definitions. One surprising result of our study was the expectation of more studies that address and account for gender biases, differences, and gaps, especially in more STEM-related subjects; however, none of the studies we reviewed focused on gender issues. Besides gender, we also did not find any studies addressing the differences in perceiving embodied interactions racially as most of the research seemed to involve children from ethnic 'majorities'.

6. Directions for future research

Considering the survey results critically, we believe it paramount that the community commits to a more thorough discourse of the fundamental philosophical concepts before making the link to technological embodiment. Following this, we propose eight key areas of exploration that could be leveraged by the community.

1. **Using technologies within natural contexts:** Most of the technologies are only available in specific contexts like labs [61, 6, 4, 78], schools

[3, 83, 90, 19, 103, 104, 105], or museums [10, 82, 17]. It would be interesting to have more studies and research into how these systems can function in public and natural contexts [99] such as children's homes [82, 102], or parks [95]. This will also allow us to embed embodied technologies into everyday child-interactions and open our research to other forms of technology, like IoT (Internet of Things), as well as reflect upon the most suitable methods to collect data in such contexts.

2. **Long-term studies:** Most of the studies [103, 104, 105, 107, 108, 98] took place over shorter periods (less than a month). There is the need to account for carrying experiments over more extended periods (more than 6 months) [92, 91] and consider other metrics other than static output, such as maintenance of attention span and long-term learning retention. Shorter studies allow us to test hypotheses more quickly, however, these could be further validated over a longer study phase. A longer experimental period will help account for aggregated output over time and better understand the impact of the initial experiment outcomes [8]. A more prolonged engagement can also reduce the innovation effect in children using a technology for the first time. Despite the apparent benefits however, long-term studies are not always possible, and several contexts do not allow them.
3. **Personalisation using multiple trajectories:** There needs to be more consideration of multiple and dynamic cognitive development trajectories and embodiment, allowing children learners to regulate their learning themselves. This includes deeper investigation into different learning paths [18], levels of difficulty [103], and knowledge, and abstracting them to augment inclusive embodied interactions. Personalisation should not only be considered when designing for children with special educational needs [103]. There also needs to be more personalisation based on different stages of development, especially more experiments within the sensorimotor stage, and ages that fall outside early adolescence. Due to the grey areas on what is considered a child, especially when it comes to ages above

15, it can be easy to categorise them as adults. However, older adolescents have different developmental/psychosocial characteristics, behaviours, and relationships with technology to fully developed adults, and that needs to be investigated further [72, 115, 73]. Understanding how these groups' individual technological and psychological needs are embodied, given current cultural nuances and shifts, will encourage better design.

4. **Cross-field research and topics:** In the study by Spitale et al. [106], the researchers worked with a linguistic specialist in designing and carrying out experiments. Wilson et al. [92] worked with a speech therapist in their study; this helped better understand the needs of the children as well as other nuances and psychological cues. An increase in interdisciplinary collaborations with researchers as proxies and experts (e.g., in psychological, neurological, and philosophical fields) could improve the robustness of outputs. It could also encourage looking at the phenomenon from different or less familiar perspectives. For instance, using neuroimaging and psychological markers can provide further evidence to determine true embodiment. Additionally, there seems to be a focus primarily on STEM-related research, and embodied design has the potential to influence and be applied to other areas of learning by collaborating with researchers within those fields, such as the arts, history, language cultural studies, writing, and so on [53, 88, 116].
5. **Use of embodied memory:** One of the potential areas which did not see much focus was the exploration of more embodied designs and experiments that encourage reflection on everyday interactions and the use of ordinary daily objects as memory palaces by offloading cognition [117]. The only study we found to use was Chu et al. [99] which allowed children to test their embodied technology in their everyday contexts. More research could be conducted on how spatial locations and metaphors affect memory, and there is also a need to explore how we can store and retrieve information by using the whole body (e.g. olfactory stimulus as a memory trigger, the use of physical motion to encode memories like in sign language [118], and

spoken word patterns [119, 120]).

6. **Movement, perception and action:** Most of the work we looked at centered around embodiment, including that outside of the CCI community, and seems to focus primarily on learning as an outcome. One of the main themes of embodied cognition explored outside of the wider HCI community is the direct influence, and “inseparability” of perception from action [121]. More research into emotions [88], bodily movements [90], and psychological perceptions should be conducted. To our knowledge, just a few works addressed these topics and these focused on specific body parts. When considering movements that embody abstract metaphors, the only studies we found which used full-body movements to elicit embodied metaphors were short experimental papers hence these were not included in the detailed review [122, 123]. Most of the studies involved children offloading or outsourcing some form of physical perception onto objects, however, only one study [79] was found to explicitly explore how different forms of embodiment (virtual and physical) of a robot affect how children perceive and behave towards it. There is still space to explore how specific physical characteristics (such as color [124], size perception, etc.) of embodied agents embody different metaphors and actions for children in different contexts (natural and controlled). So more empirical investigation needs to be done to understand how bodily states and physical properties bias or affect emotional and psychological perspective/action and vice versa.
7. **Diversity, Inclusion and Cognitive Biases:** Following the point on psychological perception and personalisation, although these ideas have been explored in adults, none of the studies we found addressed how gender and ethnicity may affect how children perceive embodied information. For example, some abstract metaphors like colors [125, 126] might have different meanings based on the cultural background, and there might be biases attached to specific physical properties relating to race[127], and gender portrayals [128, 129]. Moreover, there is a need to explore how

embodied interactions might differ across genders, including those outside the binary. These points pose a gap for more research into how embodied technologies can be used to educate children on biases as well as inform how better embodied interactions can be designed.

8. **Multi-sensory embodied cognition:** As mentioned in the review analysis, there were no studies involving smell and taste as the main stimuli for embodiment. This could be due to how contextual those stimuli are and how they are affected by individual perceptions, increasing their variability. Another limitation might be a lack of resources and expertise around these types of stimuli. However, if we centre more studies around the perceptual states, collaborate with researchers in other fields [106], and have longer-term studies [92, 91], this might provide a work-around for such experiments.

While this systematic literature review focuses extensively on the two primary venues for child-computer interaction publications; this is not an all-encompassing review for the field of embodied cognition and its associated technologies: other works of interest will exist outside of these venues. Though the background section gives a broad span of embodied cognition literature that is not currently represented in IDC/IJCCI, further work will involve extending this review beyond the two main CCI venues and investigating what differences and similarities may exist. Overall we recommend addressing under-explored areas of research such as stimuli like smell and taste, art-related subjects [88], and dynamic cognitive stages of development [85, 5]. This could be an opportunity for collaboration with other fields, especially the native fields responsible for philosophical concepts.

7. Conclusion

This work surveys 43 peer-reviewed articles selected from the search of a wide variety of papers on embodied cognition over the past 11 years. The aim of the paper was to give an in-depth analysis of the different layers and concepts of embodied cognition in the CCI community – hence focusing on the two leading venues, IDC and IJCCI – and use that to make suggestions for future research.

The main reports were analysed based on categories that address the research questions and better show the direction of embodied research in recent years. Our research addressed the areas of application and skills, forms and mode of embodiment, technologies used, and the role of children and adults, focusing on advantages and opportunities for future research. Given the recent events in which children have interacted and learned remotely for the past year, the role of embodied cognition and interactions is more important than ever.

The summary of the discourse is eight key areas showing future research directions in the field of embodied cognition in Child-Computer Interaction, offering guidance to the community by illustrating new challenges and opportunities for researchers who aim to investigate this field. Our work demonstrates the comparative lack of investigations that use neurological evidence, memory palaces, the under-exploration of research with children within the sensorimotor and pre-operational stage, and the need for a deeper understanding and application of embodied metaphors and cognitive-affective states.

Future work would be a comparative exploration of embodied cognition and other related concepts such as enactivisim, situated cognition, context-aware computing, not just within the CCI community, but within other venues and literature repositories. We aim to create a conceptual, theoretical, and methodological basis for a new field of embodied cognition and Child-Computer Interaction in the near future.

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8. Appendix

Definition of some coding terms

- Cognitive skills- This involve skills which help us understand information such as memory, problem solving, reasoning, thinking,and learning
- Behavioural-cognitive skills - These are cognitive skills which combine both cognition and behaviour such as understanding and recognising emotional responses
- Concrete skills - This refers to more more physical and tangible skills rather than abstract learning outcomes e.g. Writing, Playing an instrument, building an artefact
- Wizard of Oz method - This is when participants interact with a prototype which appears to be autonomous but is controlled by a unseen human

- Conceptual processing - This is the ability of participants to assimilate certain new or existing ideas and concepts like buoyancy
- Proxy - An external person who is authorise to act on behalf of or as a go-between for the participants
- Body storming - This is a method of brainstorming which makes use of the body of the researcher or participants acting within or without a simulated scenario
- Perception - Information gotten through the main senses
- Learning communication - This is the process of imparting a new knowledge to participants.

Table 4: AppendixH1

No	Authors	What body parts	Stimuli	Behaviours observed	What methodologies are used	Abstract metaphors/ concept used	Cognitive process being offloaded	external representation	Physical constraints/ context
1	Hemmert et al. [61]	Hands, eyes	Touch, Movement, gesture	Interpretation of sketches, novelty and applicability	Body storming, Direct observation, Self-report of ideas and Prototyping artefacts	Physical sketching, Body storming	Conceptual processing, Visualisation	Pictures, gestures,	2D drawings of environments
2	Peppler et al. [6]	Hands, Body and eyes	Light, Touch, Movement,	Number of nectars collected, return time, Similarity of interaction with bees	Direct Observation and artefacts	Honeybee nectar collection	Conceptual processing, Perception of nectar depletion and collection ()	Lights, symbols, movements	3D flower, bee nectar stomach, social interactions
3	Kourakis et al. [5]	Fingers, hands, body, eyes	Touch, movement, gestures	Reaction time, independent action	Direct Observation and artefacts	Hunters and Hunting, Pushing and thrusting, flocking and fleeing	Conceptual processing (hunting, animal behaviour), Perception of animal behaviour	Gesture, Symbols Movement	Visual 2D representation of animals using cave paintings
4	Kynigos et al.[64]	Whole body	Movement, Gesture	identifying concepts and rules, task completion	Direct observation, Self-report (Post task Interviews)	Falling, Sorting, Balancing weights (heavy vs light), Friction Moving board game pieces	Conceptual processing, Balance, Perception (forces, weight, location and direction)	Movement, gesture	Virtual 3D shadow screen, Virtual floorboard size, friction of virtual balls
5	Leduc-Mills et al. [65]	Hands, eyes	Touch, light	Task completion, problem solving techniques	Direct observation, Self-report (Think out loud)	Modelling, Construction, building blocks	Conceptual processing (3D space), Perception (distance)	Shapes, Gestures, lights	3D constraints of shapes
6	Novellis et al. [3]	Hands, eyes	Colour, movement, Touch, gesture	Location, Number of dye insertions, Samples extracted, Participation rate, Perception of artefacts	Direct Observation, Self-report, open post-study surveys and interview, activity logs from artefacts	Room as a town, Flow of water, dye tracing, drilling process and units	Conceptual processing of Dye tracing practices and artefacts, Perception (location)	Symbols, Movements, Gestures	Physical constraints of a physical classroom Generated town map

7	Antle et al. [10]	Hands, eyes, ears	Auditory, Visual images	Level of understanding pre and post-test, quantity, location, and type of each instance of a stamp, cumulative effect of land use activity on the environment.	Direct observation, Clinical Interview, Dual tasks (Open question administered orally), Self-report	tabletop as community, Erasing and Impacting activities, Stamping and building by placing things, Land use	Conceptual processing (resources, development need, spatial allocation, environmental impact), Spatial perception (location, distance, quantity)	Pictures, Symbols, Movements, Gestures	2D Topographic map of local river basin
8	Abrahamson et al.[4]	Body, Hands	Colour, movement, gesture	Learning Trajectory, Task completion	Direct observation, Semi-structured clinical interviews	Positions as magnitudes, Height as distance, moving position by increasing hand heights, hand motion speed as unit speed, Green, red and yellow as levels correctness	Computation and problem solving, Perception (distance, magnitude, proportions), Conceptual processing (multiplication, ratios)	Gestures, Colour	Vertical distance of their hand, Size of display motion
9	Leduc-Mills et al. [78]	Hands, Eyes	Light, Touch	Completion time	Direct observation	Modelling, Matching, building blocks	Memory, conceptual processing (spatial cognition and reasoning)	Shapes, Gestures, lights	3D constraints of shapes
10	Segura et al. [79]	body	Touch, Visual, Gesture	Emotional reactions to migration, Type of migration and fear, Type of embodiment and fear, Responsiveness, Understanding and relationship with Pleo, perceived number of dinosaurs	Direct observation, Post-study closed questionnaire (5-point scale), Open semi-structured interview	Having a pet (preservation and affiliation needs), Touching to pet, feeding, Teleporting between bodies	Conceptual processing (Multiple embodiment of robotic pets), Perception of a pet	Gestures and bodily reactions, Symbols	Mental model; Shape and behaviours of the physical body, virtual body and expressions
11	Malinverni et al. [77]	Full body	Movement, Visual	educational effectiveness of the application, problem solving skills, transfer ability	Pre and post-test questionnaire, Self-report	Balance, sliding down as gravity, dragging down into water, Landscape having water and characters,	Conceptual processing (buoyancy), Perception (Mass, density, gravity)	Pictures, Symbols, body movements.	2D projected environment or play area, physical behaviours of objects and characters

12	Bartoli et al. [81]	Full body movement, head, arms, legs, eyes	Visual, movement	Movements (direct or indirect), Posture, Accuracy (Total number of target items identified in maximum time), speed (number of target items identified in the first 30), behavioural variables	Standardized therapeutic tests, Direct observation	Marking targets, avatars as self, lives as extra rounds, time, vertical and horizontal hand,movements, kicking a ball, throwing a ball, hitting a target	Perception (size, orientation, balance, coordination)	Images, Shapes, gesture	Type of stimuli, Nature of game virtual environment
13	Soute et al. [80]	Full body interactive	auditory, visual, tactile movements	Engagement when playing the games, Ranking of the games	Direct observation, Post study ranking and Group interviews	Chasing, collecting and tagging as farmer, Trading items, Animal sounds, animal sizes as steps, spinning a wheel, Red as robbers and Blue as cops,	Conceptual processing of value, Perception (size, vision)	Colour, Symbols, audio	Types of game, Physical constraints of play area, Speed of players running
14	Mora-Guiard et al. [17]	Full body interactive	Visual, Tactile and spatial movements	Memorability, Card sorting performance	Pre and post-test questionnaire	Sliding to throw, Touching and pushing, falling to show heaviness, Body to show scale and proportion, zooming to grow/shrink	conceptual processing(nanoscale), Perception (size, scale, proportion, location of body parts,, motion)	Images, gestures,	3D Objects, Play arena
15	Roberts et al. [82]	Full body interactive	Visual, Tactile and spatial movements	Perception of control, enjoyment of display,	Closed and Open Questionnaire, Wizard of OZ	ego-moving, time-moving, front and back for time domains, Position to show perspective	Conceptual processing (data representation), Perception (control, position)	Image, Colour	Assumed role of the participant
16	Malinverni et al. [84]	Full body interactive	Visual, Tactile and spatial movements	Performance and perceived collaboration	Questionnaire using self-report evaluation, Sociometric tests	Balance, creating connections for building, sliding down as gravity, dragging down into water, building bridge for movement, falling for failing	Conceptual processing (buoyancy, nodes, organisation), Perception (Mass, density, gravity, coordination, position)	Pictures, Symbols, body movements.	2D projected environment or play area, physical behaviours of objects and characters

17	Petersen et al. [85]	Hands, Body, ears	Auditory	Understanding of concept, Ideas and sounds generated	Observations, Informal conversations of self-report, artefact	Modelling, Matching, building blocks, Connecting/Closing a block for closing the circuit, Blocks for chords and instruments	Perception(sound), Conceptual processing (Circuits and Conductivity)	Shapes, Gestures, sounds	3D constraints of shapes, Sound produced and objects in the surrounding
18	Sylla et al.[83]	Hands, Eyes	Touch, Auditory	Interaction time, Wish to play longer, Collaboration, Interaction strategies and narratives created, Embodied construction of the narrative, Reflections over the narrative	Indirect observation (Video diaries at home), direct observation techniques, field notes, as well as semi-structured interviews with the preschool teachers	Physical Blocks as virtual story elements, building blocks as building a story	Language processing, Perception of settings, characters, objects and nature elements.	Images, Sound Number of block combinations	
19	Mora-Guiard et al.[62]	Full body	Gestures, Light	Motivation to play, propensity of the child to engage with other people, and visible social interaction attitudes.	Direct observation, tracking system, and questionnaires	Looking through fog, Hunting insects for fostering, Matching colours to show partnership and companionship, Insect dance to show socialization, copying for replication and sharing, Merging to show collaboration	Perception of emotion, intent and social cues, Conceptual processing (collaboration, companionship)	Light, colour	Number of types of virtual objects, Virtual 2D play area
20	Xiao et al.[88]	Hands, ears, eyes	Auditory, light, touch	Emotional engagement, Awareness to the structure and expression of sound, Score and Preoccupation with Correctness,	Indirect observation (requirement gathering), Direct observation	Melodies as figures, head corresponds to the pitch and the feet to rhythm, Houses as harmonies, showing expression with different walks, Clapping and singing with piano notes,	Perception of sound and melodies, Conceptual processing (Music notations)	Sounds, Image symbols	Number of melodies and notes available on the piano. Student knowledge of the piano,

21	Kang et al. [87]	Full body interactive	Images, gestures, movement, Auditory	Facial expression, Physical movements, social interaction, Learning potential, enjoyment, design preference	pre-and post-questionnaires, video recordings of the sessions, and the program staff interviews, Self-report	Mirror to show reflection and sensation of peering inside one's own body, Circulatory and respiratory system, labelling to show ownership, animal characteristics to show which animal (hopping like a grasshopper))	Perception (shape, position, orientation), Conceptual processing (breathing, circulatory and respiratory organs)	Images, gestures, sounds	3D anatomical model of the body and organs
22	Soleimani et al. [86]	Hands, Ears, eyes	Images, gestures, auditory, spatial movements	usability, aesthetic design and storytelling engagement, personal expression, Decomposition of problems, pattern recognition, Pattern Abstraction, Algorithm Design	Dual Task, Direct observation, Post study questionnaire (Smileyometer), artefact	House of cards, constructing meaning by restructuring spatial elements, Building blocks as elements of a story or problem	spatial computational –thinking, Perception (Space)	Image, Symbols, Sound	Icon cards available and 3D
23	Keifert et al.[90]	Full body	Gestures, Movements, Spatial location	Understanding of concept, Task completion, discipline-specific roles in sociodramatic play	Direct observation	Bodies as particles, Hugging and holding to show atomic bonds, movements and colours as states,	Perception (States, Bonds, particle movement position), Conceptual processing (States of water)	Images, Gestures	State of the matter and bond being formed, Physical constraints of tracking space
24	Mora-Guiard et al. [89]	Full body	Gestures, Light	Motivation to play; children's level of participation, activity level and flexibility while playing the game. Socialization, and visible social interaction attitudes	Direct observation, Questionnaires, post-session interviews	Looking through fog, Hunting insects for fostering, Matching colours to show partnership and companionship, Insect dance to show socialization, copying for replication and sharing, merging to show collaboration	Perception of emotion, intent and social cues, Conceptual processing (collaboration, companionship)	Light, colour	Number of types of virtual objects, Virtual play area

25	Kourakli et al.[19]	Full body touchless	Gestures, visuo-spatial, Auditory	Recall number, recall word, Conceptual thinking, Expressive vocabulary, Completion tries, hand instability, performance, horizontal movement, Success rate, Reaction time, Feeling towards the game	pre- and post-assessment test; ‘’Psychometric criterion of cognitive adequacy for children and adolescents”, Interviewing parents and teachers, Artefacts and Real-time psychological markers	Driving, farming, walking to move the famer, Hand gestures to move objects, unboxing to find,	Memory, Perception (position, weight, muscle movement), Language processing, Computation,	Shapes, gestures, sounds, Images	Type of 2D game, Play area and sensors
26	Malinverni et al. [93]	Hands, Eyes	Gestures, Spatial,	Verbalisation of Context, Markers, Device and Virtual elements, understandings of the experience, Drawing made	Semi-structured interviews, Tests for both scenarios	Questioning suspects and watching events play, Hide and seeking of clues using hidden markers	Perception (Vision Imagination), problem solving	Sound, Image	Physical marker location, Characters involved and storyline, Device used
27	Wilson et al.[92]	eyes, ears, Hands	Auditory, Visual images, touch,	Representation of the self, others, and interests; Dynamic action and play in the creation of entries; Varying levels of personal choice and agency in the creation of entries.	Direct and Indirect observation, 8 Interviews with school staff, including teachers, speech therapists, teacher aides and team leaders.	Collecting words into a dictionary	Language processing, Perception (Vision, auditory), memory	Audio, Images	Physical objects they can find
28	Chu et al.[91]	Hands, eyes	Visual, movement	Understanding of concept, Artefact created, Approaches used to solve problems, engagement	Direct and Indirect observation,	Balancing cycles, Modelling and Making, Earthquake simulation, Circuit to show food chain and water cycle, lights in the room ceiling and batteries for the sun. Wires and arrows to show energy transfer, Lights to correct connections	Conceptual processing (Cycles, energy transfer, food chain, soil properties), Perception (Earthquake movement, Cycle flow), Balance	Light, Movement, Image	Model type and kits objects

29	Kawas et al. [95]	Hands, eyes, whole body	touch, Visual, auditory, gestures	Ideas generated during co-design, direction of attention, personal relevance, peer engagement, parent-child engagement	Direct and indirect observation, artefacts, Self-report	Children as designers/explorers, scavenging for and collecting items,	Perception (Visual),	Visual plants, Tactile movements, Smell	Plants in their surrounding
30	Chu et al. [99]	Whole body	All types of stimuli	What time children reflect about science In everyday contexts, location of science reflections, Distribution of confirmed recordings over time, Motivations for reflection, How the reflection was carried out and in what context	Pre and post questionnaire, Indirect observation, semi-structured interview.	Locations and objects as memory Palaces,	Conceptual processing (Food Chain, Adaptation, Inherited/Learned traits), Perception of Science reflections	Audio, Tactile, Gestures, environmental triggers	Whatever context the children were in
31	Beşevli et al. [98]	Hands, eyes	Gestures, Touch,	Answers to the math questions, Engagement, Attention,	Semi-structured interview with Children, Self-report, Discussion with teachers, Indirect observation (Facial expressions)	Balance to show numbers, social agent and interaction partner as a friend wanting to go home, Position on the roadmap to show progress	Conceptual processing (non-symbolic math), Perception (Quantity, space, area, volume), Balance	Gestures, Images, Tactile	The number of 3D objects
32	Zimmermann-Niefield et al. [97]	Whole body (arm, leg, torso)	Gestures, movement	Understanding of concept (models), evaluation of model performance	Self-report, Focus groups, Worksheets, Indirect observation	Modelling and building the real world to build a program, how bodies should move while playing sports to construct models, good or bad passes/throws to show data types	Conceptual processing (Data model and training), Perception (location, speed,)	Movements, Images, Symbols	Range of physical movement, Type of pass made
33	Desai et al.[94]	Hands, eyes	Touch, Visual, Movement	Intuitive interaction (time taken to decide irrespective of a win or loss), Type of interaction, Aspects of embodiment, Successfulness	Self-report, Direct and observation,	Balance equals not falling, Stored memory associations, swiping to move blocks, Warning signs using white, pink and red coding, Green for safe	Balance, Problem solving, Perception (Visual, spatial orientation, position, mass, rigidity, mobility)	Haptic and tactile Movement, Visual Symbols,	real-time 3D physics simulation, Physical toy

34	Litts et al.[96]	Whole body	Movement, Visual	Artefacts created, Understanding of concept	Direct and indirect observation, Self-report	Factory production as manufacturing code, Boolean logic, variables, and conditional flow control, through metaphors of “characters,” “quests,” and “scene” transitions.	Conceptual processing (Debugging and coding), Perception(location)	Haptic and tactile Movement, Visual Symbols	3D objects created, Physical location
35	Vartiainen et al.[102]	Whole body	Auditory, Visual	Verbal and nonverbal initiation toward a computer, Feelings about the process, Understanding of concept	Indirect observation, Interview carried out by parents	Programming by showing emotions and representational gestures	Conceptual processing (Programs, Model), Perception(location)	Auditory, Gestures, Facial and bodily expressions	Emotion taught or express to the model
36	Ali et al.[101]	Hands, eyes, face	Visual images, movement	Interaction with Jibo, Level of Children creativity, children’s perceptions of the robot’s creativity and peer-like influence during the interactions	Direct observation, TTCT test	Social agent as a peers and playmate	Conceptual processing (Collaboration), perception(vision)	Auditory, Gestures, Facial and bodily expressions	Type of 2D drawing
37	Lechelt et al. [108]	Hands,	touch (temperature) movement,	Understanding of how sensors worked, Reflection on the properties of sensors, Tasks carried out	Direct observation, Self-report	Relating sensors to everyday activities like telling a lie, solving a hard problem	Conceptual processing (sensor technology), Perception (emotions, temperature, light, pulse, movement)	Light, Symbols,	Type of stimuli and sensor
38	Almjally et al.[107]	Hands, Body	Light, movement, Visual	Gestures during reflection; relationship between children’s spontaneous gestures on and their learning outcomes, how the interface type (TUI or GUI) affect children’s spontaneous gestures, Task completion	Direct observation, Dual task (Pre and post Questionnaire)	Squares and paths to show code algorithm, Construction blocks to show programming blocks, moving in a path repetitively to show iterations, Gestures to show robot movement	Conceptual processing (algorithms, coding, debugging), Perception (location, movement sequences)	Light, Symbols, Movement, Gestures,	three body-based axes when referencing temporal sequences

39	Malinverni et al.[100]	Hands	Touch	Artefacts created, understanding of concept, becoming of the materials, the becoming of the project and the becoming of the children-as-makers.	Direct observation, Task	Modelling, making (child-as-makers), Everyday objects to envision imagination	Conceptual processing (Design thinking, 3D Modelling)	Object created	Play area, Object imagined
40	Spitale et al. [106]	Ears, hands	Auditory, Visual, touch,	The children's performance with different embodied agents, Perception of agents, familiarity, attention, likability of agents	Wizard-of-Oz, Questionnaire, Raven's Progressive Matrices (RPM) test, self-report	Toy, avatars and humans as other (embodied conversation agents, narrating a story)	Language processing	Audio, Images, Gestures, Body	Type of agent
41	Lee-Cultura et al. [105]	Body	Gesture, movement,	Movement, Fatigued, Arousal, Stress, hand movement, cognitive load, Focus, anticipation, on-task ratio, emotion	Real time psychological markers (eye tracking, HRV, blood-pressure, temperature and EDA levels), Indirect observation	Avatar as self	Perception(self), position, computational thinking	Gesture, movement, Visual	3D avatar
42	Pires et al.[104]	Body, Hands	auditory, tactile,	Robot anthropomorphisation, Agency of control, Preconceptions and First contact, Collaboration, Understanding of concept, Spatial orientation	Brainstorming, Focus group, Wizard-of-Oz, direct observation, Self-report of SNEs	Physical blocks as programming blocking, Building as programming, Robot movement as steps	Perception (Vision, space, orientation, location, distance, dimension), Conceptual processing (code blocks)	Movement, Tactile, gestures	3D blocks
43	Neto et al.[103]	Hands, eyes	Touch, Visual,	Robot interaction, collaborative and inclusive learning, activity experience	Direct observation, self-report	Following a path to drawing a shape line	Perception (shape, vision)	Visual, tactile and haptic, Light	2D shapes being drawn, Physical demarcation

Table 5: AppendixH2

No	Authors	Subject area and skills	What learning methods	Technologies	Materials; digital	Materials; tangible	Children variable or constant	Age group	Cognitive development phase	Roles of adults
1	Hemmert et al. [61]	Design, Secret Communication	Collaboration, Play, Creativity	-	-	Markers, Paper	Variable	6 to 12	Mainly Concrete operational, some pre-operational and formal operational	Facilitator
2	Peppler et al. [6]	Learning communication (Bees), Science	Collaboration (Participatory simulations), Play, Gamification	Arduino, the LilyPad Arduino toolkit (V3)	, Microcontroller board, XBee Wireless Module, XBeee Breakot Board, LEDS, power supply, resistor	Cork (V 1), Coloured water, eye dropper, Dixie cups and construction paper(V2), conductive fabric glove, Cloth beehive (v3)	Constant	7 to 8	Concrete operational	Facilitator, Expert
3	Kourakis et al. [5]	Learning Communication (Group Hunting Strategies)	Role Playing (cavemen), Gamification, Collaboration, experimentation, Open-ended Play	IR Reflection, FTIR, IR laser Scanning, C++ and OpenCV libraries	IR Camera Projector, IR laser light, Screen (Multi-touch surface)		Variable	All ages	Dynamic trajectory of development:	Facilitator, Expert,
4	Kynigos et al.[64]	Mathematics, Science, Problem solving, Learning communication	Collaboration, Problem-based learning, gamification, play		Projector, Screen, Laser, floor, virtual board		Constant	10	Concrete operational	Facilitators
5	Leduc-Mills et al. [65]	Mathematics, problem solving, Design	Prototyping and Making, Play	Arduino, UCube, Computer	MakerBot 3D Printer	3D printed shapes	Variable	12 to 14	Formal Operational	Facilitators
6	Novellis et al. [3]	Learning communication (Hydrology and dye tracing), Science	Role playing (town members), Problem-based learning, Collaboration (Participatory)	Spectrometer, SQL Server	Tablet computer, iButton reader, Ethernet Cable, USB Cable	Suction cup, Duct tape, water, food colouring, test tubes	Variable	Assumed 8 to 10 (Fourth grade)	Concrete operational	Facilitators, Experts

7	Antle et al. [10]	Learning communication (Sustainability), problem solving	Role Playing (sustainability engineer), Problem-based learning, Play	Interactive Map Station, Event-Table prototyping platform (reacTIVision)	RFID tags, Fiducial marker, display screen, speakers, Interactive digital tabletop, camera,	Stamps, lab coat, engineers' hat	Constant	7 to 10	Concrete operational	Facilitators, Experts
8	Abrahamson et al.[4]	Mathematics, problem solving,	Problem-Based learning	Mathematical Imagery Trainer	Display monitor	crosshairs	Constant	10 to 11 (Assumed from K-8 and Grade 5)	Concrete Operational	Facilitators, Experts
9	Leduc-Mills et al. [78]	Mathematics, Problem solving, Design	Prototyping and Making, Play	UCube, Computational kit,		3D-printed shapes	Variable	11 to 13	Concrete operational, Formal operational	Facilitator
10	Segura et al. [79]	Play, Multiple embodiment migration and mental model of robotic pets	Role playing (pet owners),	Pleo (Robotic pet; PhyPleo and virtual version;ViPleo)		Rectangular table,	Constant	10 to 11 (Grade 5)	Concrete Operational	Facilitators
11	Malinverni et al. [77]	Learning communication (Buoyancy and Archimedes' principle), Collaboration	Play, Gamification, Problem-based learning	Interactive slide (Archimedes)	Desktop computer with mouse control, computer vision system,	inflatable slide (projection screen)	Constant	9 to 12 with a mean of 11 years (Grade 5 and 6)	Concrete Operational, formal operational	Facilitators
12	Bartoli et al. [81]	Social interaction; Attention skill (Selective attention, sustained attention), Decision making skills,	Play, Gamification, role playing	Five motion-based touchless mini-games on the Xbox 360 Kinect			Constant	10 to 12	Concrete Operational, formal operational	Facilitators, expert Proxy (therapists and parents),
13	Soute et al. [80]	Play, Evaluation of rapid prototypes	Role Playing (farmer, robbers, cops), Gamification, Play, Collaboration	RaPIDO platform to create 4 games	RFID tags, sound processor, speaker. RGB LEDs, XBEE Chip	grass area, wood area	Constant	7 to 10	Concrete operational	Facilitators, Proxies (Parent's consent)

14	Mora-Guiard et al. [17]	Mathematics, Learning communication (nanoscale)	Gamification	NanoZoom	multi-touch table, two projectors, Monitor desktop	Floor projection, Table	Constant	11 to 13	Concrete and formal Operational	Facilitator, Expert
15	Roberts et al. [82]	Learning communication (census data map interpretation), Perspective taking	Collaboration, Gamification, role playing,	CoCensus	Tablet, RFID cards, Microphone	Lanyards	Constant	10 to 14	Concrete Operational, formal operational	Facilitators
16	Malinverni et al. [84]	Problem solving, Collaborative learning	Collaboration, Gamification, Problem-based learning,	Interactive Slide exergame, AR (Hamsterball and Archimedes)	Desktop computer with mouse control,	Large inflatable slide	Constant	Mean age 11	Concrete and Formal Operational	Facilitators
17	Petersen et al. [85]	Play (music instruments), problem solving, Idea generation, learning communication (intangible conductivity)	Creativity, play, collaboration, gamification, Making	MaKey MaKey boards,	Laptops	Lego bricks, copper tape, crocodile clips, scissors, stage, amplifier, microphone, dress up clothes, table	Constant	All ages	Dynamic trajectory of development:	Facilitators, proxies (parents)
18	Sylla et al.[83]	Oral language development	Free play, Storytelling, creativity	TOK (Touch Organise create)	Tablet		Constant	3 to 5 (Assumed from preschool)	Preoperational	Facilitators, experts, proxies (teachers)
19	Mora-Guiard et al.[62]	Social interaction, behavioural and cognitive skills,	Encouraged collaboration, Open ended Play, creativity, participatory design	Land of Fog, C++ with openFramework toolkit, Unity Game Engine, Middle VR	Projector	Projector surface play area	Constant	10 to 15	concrete operational, Formal operational	Facilitators, experts, proxies (teachers, parents)
20	Xiao et al.[88]	Music, Learning communication (Harmony and music reading), Self-directed learning	Play, Creativity	Andantino, Java, JavaScript	Laptop, Projector, fall board	Yamaha Disklavier grand piano	Constant	7 to 13	concrete operational, Formal operational	Facilitators, experts (Dalcroze-certified piano instructor)

21	Kang et al. [87]	Science (Biology), Learning Communication (respiratory and circulatory systems)	Role playing (animals, players reporters), Gamification, Play, Collaboration (body mimicry)	Magic Mirror (SharedPhys, animal avatar), C++	BioHarness Sensors,	projection screen,	Constant	5-13 (M=8.8; SD=2.1)	Preoperational, Concrete operational, Formal operational	Facilitators, experts (Participatory design with Teachers)
22	Soleimani et al. [86]	Problem solving, Storytelling, Computational thinking	Collaboration, creativity	CyberPLAYce; open–source Arduino microcontroller and software platform,	magnetic modules, a light module, a temperature module, a sound module, a distance module, and an LED module.	action cards	Constant	8 to 12	Concrete operational, Formal operational	Facilitators, experts (Participatory design with Teachers)
23	Keifert et al.[90]	Science (Chemistry), Learning communication (changes in states of matter for water)	Play, Role playing (Directors and Particles), Collaboration	STEP,	Tracking Space, projection screen	Play area, Whiet boards,	Constant	6 to 8 (First and second grade)	concrete operational	Facilitators, experts (teachers)
24	Mora-Guiard et al. [89]	Social interaction, behavioural and cognitive skills,	Encouraged collaboration, Open ended Play, creativity, participatory design	Land of Fog; C++ with openFramework toolkit, Unity Game Engine, Middle VR	2 full HD Projector	Projector surface play area		10 to 15 (10 to 14 in Barcelona, 11 to 15 in London)	concrete operational, Formal operational	Facilitators, experts, proxies (teachers, parents)
25	Kourakli et al.[19]	Mathematics, Behavioural and cognitive skills, Motor and sensory skills	Play, problem-based learning	Microsoft Kinect with 5 games: Farm Walks, Space Motif, UnBoxIt, Melody Tree and Mathloons.			Constant	6 to 11	Preoperational, Concrete operational,	Facilitators, experts, proxies (special educators)
26	Malinverni et al. [93]	Play, Problem solving, Comparing WoW and WaS Tech	Role-playing (Dragon), Collaboration, Problem-based, creativity	Android Aquaris BQ tablet; Saint George's Dragon	a Bluetooth loudspeaker, and a pico-projector.	Paper graffiti markers	Constant	9 to 11 years old	Concrete operational	Facilitators

27	Wilson et al.[92]	Language and Verbal ability	Play, Collaboration, Creativity,	My Word,	iPad	Objects they find in real life	Variable,	5 to 8	Preoperational, Concrete operational	Facilitators, Experts, Proxies (two teachers and one speech therapist.), Users (Teachers)
28	Chu et al.[91]	Science, Learning Communication (Earth and Space: Rapid Changes, Earth and Space: Alternative Forms of Energy, Organisms and Environments: Food Chains, Matter and Energy: Water Cycle, Earth and Space: Examining Properties of Soil.), Programming	Creativity, Play	Arduino, 'Earthquake' Making kit, Solar Energy' Making kit, The 'Food Chain' kit, Water Cycle' kit, 'Properties of Soil kit	Vibrating motor, LED, solar panel, laptops	foam board, Kitty litter, wooden dowel rods, origami houses, Preprinted card, foam board, wired, foam board, electric circuits, loam, silt, sand, and clay, batteries, switches	Constant	9 to 11, (Assumed 4th and 5th grade)	Concrete operational	Facilitators, Experts (Teachers)
29	Kawas et al. [95]	Science, Co-designing, Verbal attention,	Play, Prototyping, Collaboration, Creativity,	Smartphone; NatureCollections app		Bag of Stuff (large bags filled with craft materials), the Big Paper (large Easel sized paper for collaborative sketching)	Constant	7 to 12	Concrete operational, Formal operational	Facilitators (Parents and researcher), Proxies (Parents), Experts (KidsTeam)

30	Chu et al. [99]	Science, Reflection, Verbal ability (recall/retrieval)	Situated learning, Creativity,	ASUS Zenwatch 2 loaded with ScienceStorie			Constant	10 to 11, mean age = 10.5 (fifth-grade science class)	Concrete operational	Experts
31	Beşevli et al. [98]	Mathematics (Non-Symbolic), Number series	Open-ended Play, Problem-based, Active learning, Gamification	MaR-T; OpenCV, Royale SDK, Bodymovin libraries	Sony CXN020X pico-projector, ToF(time-of-flight) depth camera, PMD CamBoard Pico flex	3D printedamorphous white tangibles, 3D location of markers	Constant	3- to 5-year-old,	Preoperational	Facilitators, Proxies(teachers)
32	Zimmermann-Niefield et al. [97]	Programming (Machine Learning),	Open-ended play, Gamification	AlpacaML; Dynamic Time Warping algorithm	Wearable sensors, Video camera, Phone	clipboard with worksheet, soccer ball	Constant	14 to 17 years	Formal operational	Facilitators
33	Desai et al.[94]	Problem solving, Intuitive interaction	Play, Collaboration	Jenga app	Tablet	Jenga, Table, Camera	Constant	5 to 11	Pre, Concrete and formal operational	Facilitators
34	Litts et al.[96]	Programming, Learning communication (principles of traditional computer)	Play, Creativity, Designing, collaboration	Augmented Reality and Interactive Storytelling (ARIS) platform	Smartphone, GPS, iBeacons, AR markers, QR codes.		Constant	10 to 13	Concrete operational, Formal operational	Facilitators
35	Vartiainen et al.[102]	Programming (Machine Learning based emotional classifier), Socialization (emotional expressiveness)	Learning by teaching, Designing, Collaboration	Teachable machine	GoPro camera or a smartphone.		Constant	3 to 9	Pre and Concrete operational	Facilitators (Parents/ trusted adult), Proxies (Adults)
36	Ali et al.[101]	Play, Flexibility, creative thinking	Play, Collaboration, Creativity,	Jibo; Sketch-RNN, QuickDraw Dataset	Tablet		Constant	6 to 10	Concrete operational, Formal operational	Facilitator

37	Lechelt et al. [108]	Learning communication (Sensors), Problem solving reflection and critical thinking	Open-ended play, Collaboration, Gamification, problem-based learning	the Magic Cubes toolkit; Arduino,	a galvanic skin response (GSR) sensor; a pedometer, a pulse sensor; a temperature sensor, a light sensor	finger gloves, LED	Constant	9 to 11 (Year 5 and 6)	Concrete operational	Facilitators (teachers and researchers)
38	Almjally et al.[107]	Programming, problem solving	Gamification, problem-based learning	mBot and the Robot Mat	Tablet	Stickers, Paper	Variable, Constant	6 to 7 (Grade1)	Preoperational	Facilitators
39	Malinverni et al.[100]	Play, problem solving, Idea generation, designing	Creativity, Imaginative play, collaboration, Prototyping, problem-based learning	Arduino, Mblock, Scratch, Makey Makey, Tinkercad		craft materials (e.g. cardboards, coloured papers, tapes, EVA foam, modelling clay, aluminium foil, etc.), Vignette	Constant	9 to 11	Concrete operational	Facilitator, expert
40	Spitale et al. [106]	Verbal ability, Reading comprehension, Language development	Collaboration, Play		Two tablets	Toys	Constant	6 to 8	Pre and Concrete operational	Facilitators, Experts (a linguistic specialist), Proxies (a trained person.),
41	Lee-Cultura et al. [105]	Mathematics, Literacy or Geometry,	Play	Kinect; Sea Formuli, Marvy learns	Tobii eye-tracking glasses, an Empatica E4 wristband, Screen, webcam		Constant	8 to 12	Concrete operational, Formal operational	Facilitators
42	Pires et al.[104]	Programming, Abstract thinking	Designing, Collaboration, Play, Creativity	Clementoni´s DOC robot, DASH, BLOCKLY, PUZZLETS	audio-rich blocks	boards, maps	Variable, Constant	5 to 11	Pre, concrete and formal operational	Facilitators, Experts (SNEs), Proxies(SNEs)
43	Neto et al.[103]	Geometry, handwriting	Collaboration, Play	Cellulo Robot	Tablets	Dotted paper sheets, Cloison, LEDs	Constant	6 to 10 (Average of 6.6)	Preoperational	Facilitators

Table 6: AppendixH3

No	Authors	Year	Sample size	Duration	Location	Journal/conference	Instrument	Study type	experimental design
1	Hemmert et al. [61]	2010	6 children (4f, 2m)	2 days	Street lab in Berlin-Neukölln	Proceedings of the 9th International Conference on Interaction Design and Children	Artefacts, pictures	Qualitative	Post test
2	Peppler et al. [6]	2010	2 groups of 20 children	45 seconds ()	Lab	Proceedings of the 9th International Conference on Interaction Design and Children	Pictures, Video recordings	Qualitative	Within Groups
3	Kourakis et al. [5]	2010			Center for the Interpretation of Cave Art" in Ulldecona	Proceedings of the 9th International Conference on Interaction Design and Children		Qualitative, Self-report from children and experts	Within Groups
4	Kynigos et al.[64]	2010	12 children		Polymehcanon, an interactive educational gaming centre in Athens,	Proceedings of the 9th International Conference on Interaction Design and Children	Video and audio recorder	Qualitative	Within groups
5	Leduc-Mills et al. [65]	2011	14 (5 girls and four boys)			Proceedings of the 10th International Conference on Interaction Design and Children		Qualitative	Within groups
6	Novellis et al. [3]	2011	21 students	five 45-minute science period over three weeks	Classroom	Proceedings of the 10th International Conference on Interaction Design and Children	Daily notes, video recorder	Qualitative and Quantitative	Within Groups
7	Antle et al. [10]	2011	30 children (Gender balanced)	20 to 30 minutes	Museum, Lab	Proceedings of the 10th International Conference on Interaction Design and Children	Observational notes, audio recorder	Quantitative	Pre-test, Post-test (individually)
8	Abrahamson et al.[4]	2011	22 students from a private K-8 school	duration mean 70 min.; SD 20 min.	Lab	Proceedings of the 10th International Conference on Interaction Design and Children	Note taking	Qualitative	Individually and within groups
9	Leduc-Mills et al. [78]	2012	10 (2 girls, 8 boys)	1 day; 25 mins sessions, total of ten minutes for the matching exercise,	Lab	Proceedings of the 11th International Conference on Interaction Design and Children	Timer	Quantitative	Within groups and Individually

				corresponding to two minutes per shape					
10	Segura et al. [79]	2012	51 primary school students	30 mins with 2 parts	Primary school in Portugal	Proceedings of the 11th International Conference on Interaction Design and Children	Video recording	qualitative and Quantitative	Within groups of 2 and one having three
11	Malinverni et al. [77]	2012	331 children (using Schools from different neighbourhoods), 4 to 5 participants for each group	Three-week period, sessions lasting 2 and a half hours (2 different experiments)	A Multipurpose space and full-body interaction lab	Proceedings of the 11th International Conference on Interaction Design and Children		Quantitative	Pre-test, Post-test (Solomon four group design)
12	Bartoli et al. [81]	2013	5 autistic boys,	5 gaming meetings (45 mins each for a total of 3 hours 40 mins), on a weekly basis for two and a half months (November to January)	A therapeutic centre	Proceedings of the 12th International Conference on Interaction Design and Children	Video recorder	Qualitative analysis of recordings, Quantitative analysis	Individually Coded video data, Graphical data
13	Soute et al. [80]	2013	16 children (mostly boys), groups of 4-5 children, some 2-3 sharing devices	3 design iterations; three weeks for prototyping, 3 evaluation sessions, 5-week study with each session lasting 2 hours	Scout home	Proceedings of the 12th International Conference on Interaction Design and Children	Video and audio recorder	Qualitative	Individually and Within groups
14	Mora-Guiard et al. [17]	2014	64 Children (33 girls and 31 boys)	5 mins for Pre-test, Experiment for 10 minutes, Post-test (6 minutes)	CosmoCaixa Science Museum commissioned	Proceedings of the 13th International Conference on Interaction Design and Children	logfiles	Quantitative	Pre-test (Card sorting game), Within groups
15	Roberts et al. [82]	2014	28 participants (12 for V condition and 16 for H condition) in groups of 2	2 days, 35 sessions (Interact with the system as long as they wanted)	mid-sized urban science museum.	Proceedings of the 13th International Conference on Interaction Design and Children	5 video cameras, Microphone	Quantitative (verbal transcripts)	Within groups
16	Malinverni et al. [84]	2015	48 children (groups of 4)	Two mornings	University	Proceedings of the 14th International Conference on Interaction Design and Children		Quantitative	Within groups, Individual post- study evaluation

17	Petersen et al. [85]	2015	$\frac{1}{4}$ girls and $\frac{3}{4}$ boys. 350+ kids	4-day workshops between 10 am and 4pm. 10-60 minutes with average time of 20-30 mins	Stand at the Lego World Fair	Proceedings of the 14th International Conference on Interaction Design and Children	Pictures, video recordings	Qualitative	Within groups
18	Sylla et al.[83]	2015	24 pairs (five pairs of girls, seven pairs of boys and 12 mixed pairs.4.1.3.)	4-month period, 45 mins of free-play (mean of 16.64 mins)	Pre-school Classroom	International Journal of Child-Computer Interaction 2015	Video camera and Microphone	Qualitative, Quantitative	Within groups, individually
19	Mora-Guiard et al.[62]	2016	68 children in pairs	15 mins sessions, six weeks of trials in Barcelona (N=28) and one week in London (N = 40)	Lab in Universitat Pompeu Fabra, Barcelona, The Elmgreen School in London	Proceedings of the 15th International Conference on Interaction Design and Children	video camera, note taking	Qualitative, Quantitative	Within groups, individually
20	Xiao et al.[88]	2016	8 children (some pairs of 2)	2 preliminary studies, 30-60 mins sessions		Proceedings of the 15th International Conference on Interaction Design and Children	Video cameras both on the screen and the hands	Qualitative	Within groups, individually
21	Kang et al. [87]	2016	69 children participated (42 boys, 27 girls), six groups of children	˜2 hours, 6 sessions in two after-school programs	School	Proceedings of the 15th International Conference on Interaction Design and Children	Video cameras, pictures	Qualitative and Quantitative	Within groups, individually
22	Soleimani et al. [86]	2016	12 children, 2 pairs	3 days; 2.5 hours per session	Middle School in USA	Proceedings of the 15th International Conference on Interaction Design and Children	Video recording	Qualitative	Within groups, individually
23	Keifert et al.[90]	2017	26 Children	Two different lessons in different classes	Classroom	Proceedings of the 16th International Conference on Interaction Design and Children	Pictures, video recordings	Qualitative	Within Groups
24	Mora-Guiard et al. [89]	2017	34 Children with HFASD (Predominantly Male and 4 Female)	Three months; one week of pilot trials, 15 minutes of open-ended play	London and Barcelona	International Journal of Child-Computer Interaction 2017	video camera, note taking	Quantitative	Within groups,
25	Kourakli et al.[19]	2017	20 Children with SEN and comorbid learning disorders (17 boys and 3 girls)	8 weeks ((May and June)	two primary schools	International Journal of Child-Computer Interaction 2018	Artefact (Kinem)	Quantitative	Pre-test, post-test, Individually

26	Malinverni et al. [93]	2018	36 children (14 boys and 22 girls); 8 groups of 4 or 5	˜ 2 hours	two 4th grade classes from a local school in Barcelona.	Proceedings of the 17th International Conference on Interaction Design and Children	Video camera	Quantitative	Comparing between groups
27	Wilson et al.[92]	2018	12 children on the autism spectrum (11 boys, 1 girl); Class1; 6 children (all male) aged 5 to 6 years old. Class 2; 6 aged 7 to 8 years old (5 males, one female)	two class terms (20 weeks, plus school holidays); 30 hours of classroom interactions, 10 sessions lasting 2 to 4 hours	An autism-specific primary school in Brisbane, Australia	Proceedings of the 17th International Conference on Interaction Design and Children	Field notes, audio recordings, video recordings, text input and photographs.	Qualitative	Within groups
28	Chu et al.[91]	2018	48 students, 8 student-pairs per model type	two-year study, for six non-consecutive weeks; there were 9 simulation Making activities done, 9 concept-process Making activities, and 6 illustrative Making activities. 45 min for 4th grade and 1.5 h for 5th grade.	Elementary school	International Journal of Child-Computer Interaction 2018	Video and audio recordings	Qualitative	Within groups
29	Kawas et al. [95]	2019	25 Children: 7 Children ((three girls and four boys as co-designers), 18 children (11 females and 7 males for testing), groups of 5 to 7	three 90-minute codesign sessions over 3 months, three 25– 30 min testing sessions	Local park,	International Journal of Child-Computer Interaction 2019	Video recording, Photographs, field notes, analytic memos	Qualitative	Within groups
30	Chu et al. [99]	2019	18 participants (7 boys and 11 girls)	3-week period, with children having the watches 2.5 days per week	Wherever the students decide to go in everyday context	Proceedings of the 18th International Conference on Interaction Design and Children	Audio recordings,	Quantitative, Qualitative	Within groups

31	Beşevli et al. [98]	2019	14 participants; Preliminary studies (4), Final study (10, 7 females, 3 males)	10 to 15 minutes for each child	a room in the kindergarten to	Proceedings of the 18th International Conference on Interaction Design and Children		Quantitative, Qualitative	Individually
32	Zimmermann-Niefield et al. [97]	2019	5 participants (3 girls, 2 boys)	One three-hour workshop; informal sports play–mostly with soccer balls and frisbees–for 15 minutes, 45 minutes to work on thesport of their choice, 30 minutes semi- structured focus group f	A university's turf field	Proceedings of the 18th International Conference on Interaction Design and Children	Audio and video recordings	Quantitative, Qualitative	Some Individually, Within groups
33	Desai et al.[94]	2019	108 children (55 girls, 53 boys) in pairs	40 min to one hour		International Journal of Child-Computer Interaction 2019	Audio and video recordings	Quantitative, Qualitative	Within groups
34	Litts et al.[96]	2019	19 children, (3 girls, 16 boys)	12 hours over two after school workshops (six 2-hour sessions). Research (session 1), storyboarding (session 2), digital construction (sessions 3-6), and playtesting and debugging (sessions 3-6)	A field	Proceedings of the 18th International Conference on Interaction Design and Children	in-process video and audio recordings, design artefacts, photographs, field notes	Qualitative	Within groups
35	Vartiainen et al.[102]	2020	6 Children (3 boys, 3 girls)	Average of 10 minutes	At home	International Journal of Child-Computer Interaction 2020	Video and audio recordings	Qualitative	Individually, Within their family
36	Ali et al.[101]	2020	79 Children (40 females, 39 male)	15 to 20 minutes; three rounds of four minutes	Lab	International Journal of Child-Computer Interaction 2020	Video and audio recordings	Quantitative	Pre-test, Post-test
37	Lechelt et al. [108]	2020	86 Children, in pairs	a one-off, 90-minute session; 7-10 minutes to explore each of the five sensors	Classroom	Proceedings of the 19th International Conference on Interaction Design and Children	Video, audio recordings, field journal	Qualitative	Within Group

38	Almjally et al.[107]	2020	42 students. However, 4 sessions were damaged, therefore 17 sessions were coded (with a total of 34 participants; 18 F, 16M)	2 sessions; 1st 25 minutes briefing session, 2nd ˜60 minutes; a 45-minute learning activity. eight sessions, across 1020 gestures	Saudi Arabia primary-school during normal hours	Proceedings of the 19th International Conference on Interaction Design and Children	Pictures, Video recording	Quantitative	Pre-test, Post-test
39	Malinverni et al.[100]	2020	12 children, 10 Children	2 workshops (1 having 10 sessions and the other 8 sessions), 4 months,	primary school	International Journal of Child-Computer Interaction 2020	Notes, pictures	Qualitative	within Groups
40	Spitale et al. [106]	2020	17 children; 14 neuro-typical Children (7 girls, 7 boys), Three children (one female) with language impairment	3 sessions of 15 minutes, three experimental sessions were provided for three weeks (1 session/ a week).	A Quiet room	Proceedings of the 19th International Conference on Interaction Design and Children	Video recording, photographs	Quantitative	Pre-test, Post-test
41	Lee-Cultura et al. [105]	2020	46 children (28 F, 18 M)	9 gameplay sessions lasting between 2535 minutes	Science centre, local public elementary school in Trondheim, Norway	Proceedings of the 19th International Conference on Interaction Design and Children	Video recording,	Quantitative	post-test
42	Pires et al.[104]	2020	7 visually impaired children (5 M, 2F in groups of three based on age and ability), 6 SNEs, 3 IT instructors	30 minutes	School	Proceedings of the 19th International Conference on Interaction Design and Children	Video recording,	Qualitative	Within groups
43	Neto et al.[103]	2020	20 pupils (in pairs) with and without visual impairments, (7 girls, 13 boys); four participants had different degrees of disability	30 minutes	Classroom	Proceedings of the 19th International Conference on Interaction Design and Children	Video and audio recordings	Quantitative, Qualitative	Post test