

Technology-Mediated Collaboration among Children with Special Educational Needs: Definitions and Measurements

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Abstract

In this paper, we present the results from a systematic literature review on technology-mediated collaboration among children with special educational needs. The review is based on searches in four databases and focuses specifically on definitions and measurements for collaboration between children mediated by digital technology. Although collaboration is often vaguely defined in the reviewed literature, the paper contributes with an overview of various definitions, measurements, and common references, which together with recommendations for future work can be helpful when designing technologies for collaboration among children with special educational needs.

CCS Concepts

• **Human-centered computing** → **HCI theory, concepts and models**.

Keywords

Collaboration, children, special educational needs, Child-Computer Interaction, Human-Computer Interaction, HCI

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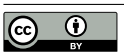
1 Introduction

Collaboration has emerged as a prominent area of research, particularly since its recognition as one of the '4 Cs' - communication, collaboration, critical thinking, and creative thinking - of 21st-century skills [158]. As a fundamental skill for effective learning and future workplace success [89], collaboration has gained increasing attention across multiple disciplines. This is especially evident in fields such as Human-Computer Interaction (HCI) and educational research, where interest in understanding and fostering collaboration continues to grow [19]. At the same time, with increasing technological development, digital tools for improving teamwork have become increasingly critical to workplace success [89] and adopted in educational settings around the world [123, 147]. This development led the Organisation for Economic Cooperation and Development (OECD) to develop an assessment framework for collaboration that utilized a technological solution, which was used in PISA 2015 [114]. All children need to learn how to collaborate with their peers, and there is a continuous effort in this direction starting in early educational settings [36]. Children with special educational needs, such as those with attention deficit hyperactivity disorder (ADHD) or autism spectrum disorder (ASD), often face challenges in peer collaboration due to difficulties in various areas of development, including theory of mind and perspective-taking [58], communication, and the formation of social relationships and friendships [70, 98], among other developmental challenges. To help children with special educational needs not fall behind, great emphasis is placed on developing educational interventions to address the challenges they face. Interventions for children with ASD or ADHD focus on developing skills in socialization, language and communication, academic learning, and adaptive behaviors to enhance independence, quality of life, and family well-being [144, 156]. Less clinically focused are the technologies and activities that are developed within the child-computer interaction (CCI) or human-computer interaction (HCI) research community. These interventions are not developed with the intention of being clinically tested, but as exploration of what could be possible, extending the existing therapeutic or classical interventions. For example, it has been found that collaborative interactions can be mediated and scaffolded by engaging children in playful collaborative activities, such as playing collaborative games [26, 32]. Collaborative games have been shown to benefit children with special educational needs by promoting social interaction [32] and increasing their prosocial behaviors, such as collaboration and cooperation [75]. However,



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designing technologies such as collaborative games has been identified as extraordinarily difficult [161], requiring an expanded view of group dynamics, social roles, and interactions between players [71, 93, 125], and there is still no systematization of the terms used in the field of collaboration in games [131].

In this paper we are interested in reviewing research studies that in involve digital technologies in the collaborative process. As such, we apply the definition of technology-mediated collaboration as defined by [86] as "the use of digital technologies in order to work together on a set of tasks". Further inspiration for understanding technology-mediated collaboration can be found in, for instance, the field of computer-supported cooperative work (CSCW) [43, 45], and in Activity Theory (AT) [8]. To our knowledge, only a few definitions and frameworks for collaboration exist and are used on research in children and technology in general or specifically among children with special needs. In Human-Computer Interaction (HCI), one such framework is Activity Theory [53], which Bardram [8] adapted to analyze collaborative interactions between users and mediating technology. In educational psychology, Child and Shaw [42] propose a framework that distinguishes between collaboration as a process and collaboration as an outcome. A more recent definition from early childhood education emphasizes the role of social skills in peer collaboration [36]. A closer examination of these frameworks (see Discussion) reveals that collaboration is not universally defined [157], highlighting the diversity of perspectives across disciplines. Collaboration is understood and used in many different ways: it is sometimes considered as one component of social skills, at other times viewed as an umbrella term for a wide range of social skills, behaviors and/or activities (e.g., cooperation, coordination, teamwork, etc.), and in some cases it is used synonymously with these terms [20, 21]. At the same time,several researchers (e.g., [20, 21, 36, 83, 157]), have highlighted the need for a clear definition of the multifaceted concept of "collaboration" or at least a consistent use of terminology within this field. . Overall, while there is a clear need for a well-defined concept of collaboration, which this review does not aim to establish, there remains a lack of systematic understanding of how existing definitions are applied and operationalized within this field of research. These gaps in the literature have led us to formulate the following research question: **RQ:** What are the existing definitions and measurements for collaboration between children with special educational needs, particularly when using digital technologies? In this paper, we extend previous work with a review of the literature from four databases and focus on investigating the *definitions and measurements* of technology-mediated collaboration among children with special educational needs.

2 Methodology

The current study focuses on identifying the existing definitions and measurements for technology-mediated collaboration among children with special educational needs. Since this aim involves research across multiple disciplines (human computer interaction, psychology, education among the most predominant), we identified four databases as relevant for our review: Web of Science, SCOPUS, ProQuest, and the ACM Digital Library.

Building on the increasing use of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [100] in HCI research [142], we used the PRISMA framework as shown in Figure 1. The review was carried out in Covidence[1]. The four authors of this paper were involved throughout the review process stages (as explained below in each stage): a) title and abstract screening; b) full text review screening and c) extraction.

2.1 Retrieving Publications and Search Query

Our review focused on children aged 6-18 years with special educational needs. Within the realm of special educational needs, there is a wide range of diagnoses and learning difficulties. The most commonly studied conditions include Autism Spectrum Disorder (ASD) and ADHD. To broaden our scope and capture a diverse set of diagnoses, we incorporated general search terms such as "special education" and "learning difficulties" to ensure a more inclusive review. We kept our search consistent across the four databases we searched for and kept the terms as including as possible using the keywords: (collabo*) AND ("special education" OR "learning difficulty" OR "learning difficulties" OR "autism" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND (child* OR student*) AND (game OR gaming OR technolog*) in the abstract of the papers (see all full search queries for each database in the Appendix). The search queries resulted in a total of 977 papers (Scopus - 452, Web of Science - 445, ProQuest - 45, ACM - 35). 294 duplicates papers were identified automatically by Covidence and manually by the authors. In the first round of screening there were 683 papers.

2.2 Abstract Screening

The 683 abstracts were first screened by two of the authors. We excluded papers:

- that were focused on other populations than children or students up to 18 years of age
- where the target group was not children with special educational needs (autism, learning difficulties, ADHD)
- where collaboration did not take place among peers
- where there was no indication of technology use (i.e., robots, computers, tablets, phones)
- that were not peer-reviewed or not in English

After the first abstract screening with two of the authors, we had 31 conflicts, which were discussed. This ended up with an agreement for all abstracts.

2.3 Full text screening

A total of 124 paper went into full text screening. All four authors were involved in this step, with each paper being reviewed by two of the authors. The final 23 conflicts were resolved by a third author. The exclusion criteria used were:

- No definition or measurement of collaboration could be identified,
- The target population was not children with special educational needs,
- There was no technology-mediated collaboration,
- The focus group was not children 6-18 years old.

[1]Covidence: https://www.covidence.org/

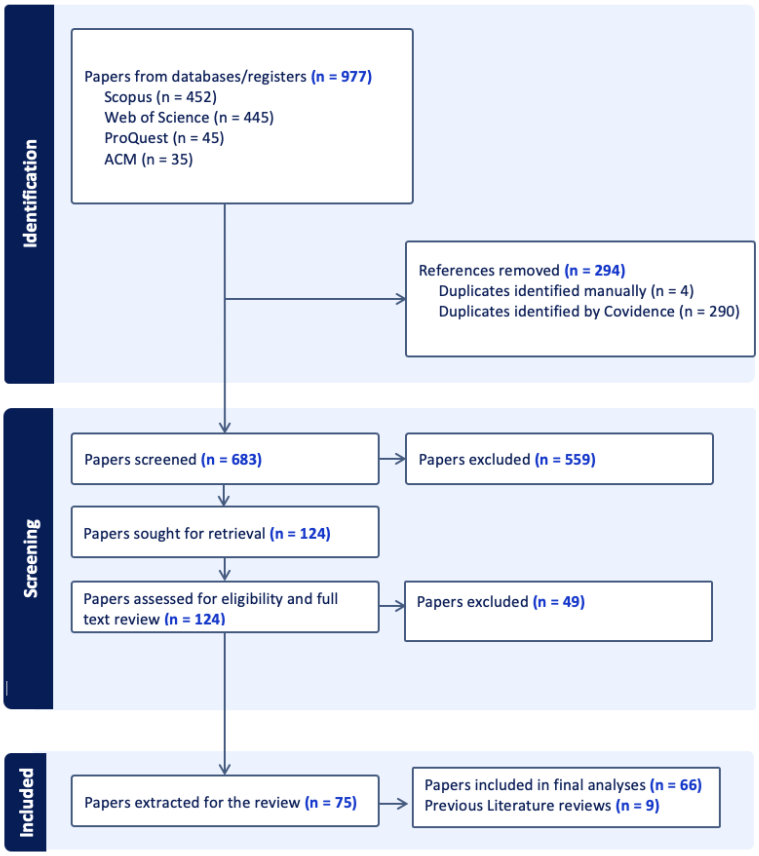

Figure 1: The PRISMA protocol stages.

- The collaboration was not among peers (for example collaboration happened between interdisciplinary researchers and authorities, between teachers, researchers and parents or therapists, etc.)

Among these 75 papers, nine were literature reviews and were discussed separately in our results section. See Section 3.1 for more details. The final list of 66 papers extracted for the final analysis is presented in Table 1.

2.4 Data analysis

From the final 66 articles (excluding the nine literature reviews) we extracted a series of qualitative and quantitative measures. The descriptive statistics of the studies included the reporting of frequencies for the following: publication types, technology types, the context of the reported studies, type of special educational needs target group, and age range of participants. The qualitative analysis of the studies looked at the types of collaboration definitions and categories of measures for collaboration. To identify the types of collaboration definitions and categories of measures for collaboration, two reviewers coded the data independently and every inconsistency was discussed until agreement was reached.

2.5 Quantitative analysis of references

To investigate what sources have been influential in the development of tools supporting collaborative activities targeting children with special educational needs, a quantitative analysis of the secondary resources referenced in the 66 papers in the corpus (the nine literature reviews found in the corpus were not included in this analysis) was undertaken. To this end, all the references mentioned in any of the papers were collected into a spreadsheet. All references cited in more than one paper were classified as belonging to one of the broad groups 1) HCI & CS, that is, papers published in some Human-Computer Interaction (HCI) or Computer Science (CS) related venue, 2) Psychology, papers published in venues related to cognition, psychological development, autism, etc., 3) Learning Sciences, papers from venues with a main focus on learning and education, 4) Measurements, for example, The Social Responsiveness Scale [44], and 5) Other. The spreadsheet was

sorted and the number of times each publication was cited in the corpus was counted.

3 Results

3.1 Literature reviews

Among the 75 final papers in our final corpus, we have identified nine literature reviews (either systematic, scoping, or mapping) where collaboration or collaborative technologies have been explicitly or implicitly in focus and thus related to our research question. However, since these reviews do not conduct empirical studies themselves but rather summarize findings from such studies, and with different focus than ours, we analyze them separately from the remaining 66 papers. While none of these literature reviews provide clear definitions or measurements of collaboration, they offer valuable insights for positioning our own review as well as its results. Two of the reviews focus on summarizing the authors' work over several years in multiple case studies [127, 153]. Robins and Dautenhahn [127] present a narrative literature review on the development and use of KASPAR, a child-sized, socially interactive humanoid robot designed to improve communication and social skills in children with autism. Collaboration was in their paper implicitly defined by skills such as turn-taking, joint attention, and collaborative play. Similarly, Winoto and Tang [153] reflect on the lessons learned while developing educational games for children with ASD. They describe three types of collaborative games aimed at promoting parallel or cooperative play and improving social communication skills, including pattern-matching coordination and emotion recognition/expression in social communication, but no specific definition of collaboration was offered.

The other seven reviews take on a broader scope beyond their own works, which is similar to our approach to literature reviews. Cañete and Peralta [37] carried out an analysis of assistive technology to improve collaboration in children with ASD, where collaboration is presented as a tool for developing social and communication skills. Their results show a clear lack of products, design methods and tools dedicated to the development of products that improve the collaboration and social skills of children with ASD, and especially products that allow the participation of several users simultaneously through multi-user interfaces. Grossard et al. [67] present a review of serious games to teach social interactions and emotions to individuals with ASD. The authors view collaboration as inherent to social skills, including interaction and adaptation to specific social contexts. Collaborative skills are implicitly defined as activities such as negotiation, turn-taking, and joint planning. Serious games were found to be promising because they can support training for many different skills and are attractive to users. However, the serious games they reviewed exhibit some limitations: (i) most of them are developed for High-Functioning individuals; (ii) their clinical validation has rarely met the evidence-based medicine standards; (iii) the game design is not usually described; and (iv) in many cases, the clinical validation and playability/game design are not compatible.

Silva-Calpa et al. [136] made a systematic literature review on how co-located collaborative systems designed for individuals with ASD provide the users with collaboration support mechanisms to encourage the performance of collaborative activities and interaction with their partners. In this review, collaboration was across several dimensions: collaborative systems, collaborative work or collaborative performance and collaboration process. Collaborative systems are computer applications designed to facilitate group interactions aimed at achieving a shared objective [85] and are considered to enhance the quality and efficiency of collaborative work by supporting user participation and providing mechanisms for feedback [113]. By fostering awareness, these systems help users align their activities with those of others [23] and adapt their tasks to the actions of their peers in the workspace [130], thereby ensuring successful collaboration. The authors defined "collaborative strategies" as the constraints, cooperative gestures, or actions integrated into systems to foster collaborative tasks between users with ASD and their partners. Overall, the results evidenced different strategies to enforce or stimulate collaboration among users and identified a lack of resources for collaboration support, as well as a shortage of studies designed specifically for individuals with severe ASD.

Smart et al. [139] present a scoping review on programs promoting virtual social connections and friendships for youth with disabilities. The programs identified followed two approaches: training youth to use the internet independently and designing virtual activities to encourage interaction and collaboration. Collaboration was seen as youth working in teams to achieve program goals, either in creating relational products such as social norms and constructive feedback, or tangible products such as a rebuilt virtual village [10, 81]. The paper contributes with broad program considerations with specific design elements and outlines guiding principles. Syriopoulou-Delli and Gkiolnta [145] explored the documented effectiveness of robotics in enhancing the social skills of children with ASD in the areas of mutual attention, verbal communication and imitation skills, and also in the reduction of stereotypical behaviors. The results confirmed that robots can have immediate positive effects on the communication skills of children with ASD. Furthermore, they found that most researchers developed their own questionnaires, resulting in a lack of standardized measures for assessing the quality of interaction between humans and robots.

Khatab et al. [83] present a systematic literature review on collaborative play solutions with or without technology for children with autism. Their results show that digital technology provides a critical support system for autistic children and can support the development of social skills by mediating interactions and fostering peer relationships and teamwork. They especially highlight how technologies running on readily available, affordable platforms, such as tablets, can facilitate social interaction among autistic children. The definition of collaboration used in this paper was based on Roschelle and Teasley [129], who describes collaboration as "a coordinated, synchronous activity," highlighting efforts to establish a shared understanding of challenges, such as those encountered in a game. Collaborative interactions between players are therefore marked by simultaneous actions and mutual coordination aimed at achieving a common goal [125].

Finally, Baykal et al. [20] conducted a systematic literature review on collaborative technologies for children with special educational needs. Collaboration is referred to as the process in which children with special educational needs work together, typically through

FIELD	CONFERENCE	JOURNAL
HCI & CS	**IDC:** Falcão and Price 2010 [55], Mora-Guiard et al. 2016 [103], Winoto et al. 2016 [155], Tang et al. 2017 [146], Barendregt et al. 2017 [9], Eriksson et al. 2019 [54], Glass and Yuill 2020 [64], Guneysu Ozgur et al. 2022 [69]. **CHI:** Marwecki et al. 2013 [95], Baykal et al. 2019 [18], Nonnis and Bryan-Kinns 2019 [111], Bei et al. 2024 [22]. **SeGAH:** Ribeiro and Raposo 2014 [126], Barajas et al. 2017 [7], Silva-Calpa et al. 2018 [137]. **Other:** Battocchi et al. 2009a [12], Battocchi et al. 2009b [13], Weiss et al. 2011 [151], Zancanaro et al. 2011 [162], Silva et al. 2014a [133], Zhang et al. 2016 [165], Zhao et al. 2016 [169], Zhao et al. 2017 [170], Baldassarri et al. 2018 [6], Iftene and Trandabăț 2018 [78], Babu et al. 2019 [3], Sinnari et al. 2019 [138], Baykal et al. 2020a [17], Huang et al. 2022 [77], Yang and Lee 2022 [159], Moster et al. 2022 [107], Jahadakbar et al. 2023 [79], Moster et al. 2024 [106].	**IJCCI:** Parsons 2015 [115], Mora-Guiard et al. 2017 [104], Laurie et al. 2022 [88]. **ACM Trans. Access. Comput.:** Boyd et al. 2015 [32], Wade et al. 2017 [148], Zhao et al. 2021 [168]. **AI & Society:** Gal et al. 2009 [59] **Other**: Battocchi et al. 2010 [11], Wainer et al. 2014 [149], Silva et al. 2015 [135], Bossavit and Parsons 2017 [30], Zhao et al. 2018 [171], Sturm et al. 2019 [143], Cerezo et al. 2024 [39].
Learning science	**CSCL:** Boyle et al. 2015 [33]. **ICL:** Dimitrova et al. 2012 [50]. **EDUCON:** Giannaraki et al. 2021 [62]. **ISLS:** Moon and Ke 2020 [101]	**Transactions on Learning Tech.:** Zhang et al. 2021 [164], Babu et al. 2022 [2]. **British Journal of Educational Tech.:** Ke and Moon 2018 [82]. **Frontiers of Education:** Hijab et al. 2024 [72]. **Other:** Winoto and Tang 2019b [154], Michalek et al. 2020 [96], Lee and Yang 2024 [90].
Psychology	X	**Autism and Developmental Disorders:** Zhang et al. 2018 [166], Zhang et al. 2020 [167], Glass and Yuill 2024 [65]. **Autism:** Ben-Sasson et al. 2013 [24], Bauminger-Zviely et al. 2013 [15]. **Research in Autism Spectrum Disorders:** Crowell et al. 2019 [46]. **Other:** Murphy et al. 2014 [108], Gal et al. 2016 [61].

Table 1: Chronological overview of the final corpus of 66 papers from 2009-2024 in terms of field and venue (top three most common venues listed).

tangible and embodied interactions, in school settings to achieve learning, entertainment, or task-related goals. The review highlighted a distinction among the identified papers to view collaboration either as end goal or as a means to facilitate communication, social engagement, and skill development among children with special educational needs.

While these nine literature reviews dive into each of their focus related to collaboration and technology in children with special educational needs, they do not specifically aim to identify the various definitions or measures of collaboration.

3.2 General overview

The final corpus of 66 analyzed papers contains 29 journal publications and 37 conference publications published between 2009 and 2024, see Table 1. The publication venues can be divided into the three main fields of learning sciences, psychology, and HCI & CS, with most publications in HCI & CS and the least in psychology.

3.2.1 Technologies. The categorization of technologies is based on an inductive approach when coding the papers. The most common technology found in the corpus is touch-based interaction technologies, with tabletop technologies (n=18) such as Diamond touch used in e.g., [59, 162], and secondly tablets (n=14), used for example in. [32, 138]. These were closely followed by PC (n=13), used for example in [108, 148]. The PC was often used together with some other technology, such as MakeyMakey [62], tangible user interface (TUI) [7], intelligent agent [164], as part of a Collaborative Virtual Environment (CVE) [151, 171], or with various game coding software [30]. There are several examples of papers using virtual reality (VR) technologies (n=8), and one with augmented reality (AR) [78]. Robots were found in five papers [50, 69, 88, 96, 149], and TUI's in four papers [7, 55, 79, 111]. There were also several movement and gesture-based interaction technologies, such as full body interaction system (n=3) [46, 103, 104], Kinect (n=2) [33, 143], and one occurrence of interactive floor technology[72].

3.2.2 Applications. The most common type of application across all the various technologies was games, probably due to the keywords we used for identifying the corpus (game OR gaming OR technolog*). However, there are a few exceptions, such as learning applications [2, 3, 55, 78], applications for play [79, 88, 111], and specific applications such as Discord [106] or coding software [96, 107], which are typically used for game design in the studies. The most common type of game applications was some sort of puzzle games, e.g., [11, 12, 167]. All touch-based technologies (tabletop and tablet) used game applications, while other technologies (VR, robots, TUI and PC) typically had more variations, such as game, learning application, or coding software.

3.2.3 Context. The most common type of context for the reported studies was some kind of school setting (n=26), which is also in line with our search keywords ("special education" OR "learning difficulty" OR "learning difficulties"). However, several studies were conducted in contexts other than schools (n=25). Many of these took place in university lab settings, although participants were often recruited through schools, as in, for example, [11, 12]. The context was also in a coding or summer camp [106, 107], some type of center (e.g., [146, 155]), online as an interview-based study with parents and teachers of HFA children [77]. In some papers the context was not described (e.g., [9, 13]). Some studies were performed in multiple contexts (n=5) [50, 103, 104, 143, 166], such as both in school and therapy center [50]. Nine papers describe studies taking place during therapy or in a therapy center, such as [39] in which a team of children with ADHD co-create a game using tangible tabletops. Another example is [7] which describes an empirical study that compares conventional clinical non-computer block-games with a serious game in a play therapy exercise with autistic children. One study focusing on virtual collaborative gaming took place in the home [82], with data collected via screen recording and on-site observation.

3.2.4 Participants / intended target group. In describing the participants, most of the papers involved participants with autism (n=55). However, several of these papers also involved typically developing (TD) children without any diagnosis (n=23), such as [148] that measured dyadic (ASD-TD) collaborative interaction for social skills intervention [132]. Other papers were quite explicit about targeting children with ADHD [39, 62, 138, 138], and six papers involved children with ADHD. Some papers involved participants with mixed diagnoses (n=12), such as in [146] where one participant was diagnosed with both high-functioning autism (HFASD) and ADHD, and where a distinction was made between participants with low-functioning autism (LFASD) and HFASD. Other examples of target groups were children with learning difficulties [55], [108] or participants with social communication difficulties and low-pragmatic-language-skilled (LP) [132]. Seven papers were classified as other participants, for example [77] involving parents and teachers of children with autism aged 5-7 years, and [78] involving children without diagnosis and their teachers, although the AR applications were explicitly intended for different types of children, such as children with autism. One paper did not describe any participants [9].

In terms of the participants' gender, most studies involved mixed genders (n=39) (e.g., [32, 151]), while some involved only boys (n=13) (e.g., [12, 59]). Two studies involved only girls [77, 79]. Twelve studies did not state the gender of the participants or did not involve participants (e.g., [115, 155]).

The most common age range of the participants was children aged 6–12 years (n=51), followed by teens aged 13–18 years (n=25). Five studies involved adults, while 11 studies either did not include participants or did not report the participants' ages.

Most studies involved 10 participants or less (n=38). A few studies involved a larger mixed population, such as [103] where 68 children were involved in total (34 TD and 34 ASD), or [11] with 16 ASD and 70 TD children. A few studies involved between 25 and 32 children with ASD [22, 46, 106].

3.2.5 Analysis of references. The analysis of the references used in the corpus collected 1852 distinct references. Of these, 1535 were only used in one single paper and were not analyzed further. The remaining 317 references were classified as Psychology 142 papers (48%), HCI & CS 115 papers (36%), Learning Sciences 32 papers (10%), Measurements 14 papers (4.5%) and Other 12 papers (3.8%). The most common reference was the definition of autism by the American Psychiatric Association [51], used by 32 papers in the corpus. This was not further investigated, as it is typically simply used in passing to refer to the notion of autism. An overview of the most cited publications in each category can be found in Table 2. It can be noted that HCI & CS contains both the most cited secondary sources and that there is a larger number of papers cited by many papers in the corpus. There are 20 HCI & CS papers cited more than five times (see Table 2 and [32, 40, 48, 60, 74, 76, 84, 97, 105, 151, 160, 163]) but only 10 Psychology papers (Table 2 and [15, 25, 56, 73, 118]), and 2 Learning Sciences and 3 Measurements papers (all in Table 2).

CATEGORY	TITLE	COUNT
HCI & CS	SIDES: A Cooperative Tabletop Computer Game for Social Skills Development [119]	27
	Dimensions of collaboration on a tabletop interface for children with autism spectrum disorder [63]	17
	Collaborative puzzle game: A tabletop interactive game for fostering collaboration in children with autism spectrum disorders (ASD) [12]	15
	DiamondTouch: A multi-user touch technology [49]	15
	Multitouch Tablet Applications and Activities to Enhance the Social Skills of Children with Autism Spectrum Disorders [75]	13
	Collaborative puzzle game: A tabletop interface for fostering collaborative skills in children with autism spectrum disorders [11]	10
	Enhancing Social Communication in High-Functioning Children with Autism through a Co-Located Interface [59]	10
	Exploring collaboration patterns in a multi- touch game to encourage social interaction and collaboration among users with autism spectrum disorder [135]	10
Psychology	Use of computer-assisted technologies (CAT) to enhance social, communicative, and language development in children with autism spectrum disorders [120]	10
	The use of collaborative interfaces to promote social skills in children with high functioning autism spectrum disorder [24]	8
	Development and evaluation of a computer-animated tutor for vocabu- lary and language learning in children with autism [31]	8
	Vocabulary acquisition for children with autism: Teacher or computer instruction [102]	8
	Using virtual environments for teaching social understanding to 6 adolescents with autistic spectrum disorders [99]	7
Learning	State-of-the-art of virtual reality technologies for children on the autism spectrum [116]	7
	Exploring the social competence of students with autism spectrum conditions in a collaborative virtual learning environment [41]	6
	Enforcing cooperative storytelling: first studies [38]	5
	Designing educational software dedicated to people with autism [68]	5
	Virtual environments for social skills training: comments from two adolescents with autistic spectrum disorder [117]	5
Measurements	Social responsiveness scale (srs) [44]	13
	The Social Communication Questionnaire: Manual [141]	10
	The autism diagnostic observation schedule-generic: a standard measure of social and communication deficits associated with the spectrum of autism [92]	9
	Wechsler Intelligence Scale for Children [150]	5
	The Friendship Observation Scale (FOS) [14]	3

Table 2: Overview of the results from quantitative analysis of referenced secondary resources, outlining the top results from each category.

3.3 Definitions of collaboration

We analyzed the definition of collaboration provided in the papers using a two-pronged approach. First, we examined the clarity of the definitions of collaboration provided in the studies, classifying them as explicit, implicit, or vague. This step allowed us to present the level of definitional precision across the literature. Second, we investigated how the studies conceptualized collaboration as a phenomenon, categorizing it as either a collaborative skill or a collaborative interaction. By combining these two layers of analysis, we aimed to provide a comprehensive understanding of how collaboration is both defined and characterized within the context of

technology-mediated interactions for children in special education. The results of this analysis are presented accordingly, beginning with the clarity of definitions and followed by the conceptual framing of collaboration as a phenomenon.

3.3.1 Definition Clarity: While reviewing the definitions of collaboration in our corpus, we found that they varied in their level of explicitness. Thus, we categorized the approaches to defining collaboration into three distinct levels based on the clarity of the definitions provided: explicit, implicit, and vague.

Explicit Definitions: This category encompasses studies that provide a concrete and clear definition of collaboration. These definitions typically outline the fundamental characteristics and parameters of collaboration, specifying its essential elements such as shared goals, mutual engagement, and coordinated efforts. Studies in this category directly address what collaboration entails, offering a well-defined conceptual foundation that can be systematically applied or analyzed when studying collaboration as a skill or an interaction. In our corpus, we found 14 papers that explicitly identify collaboration (see Table 3).

Implicit Definitions: Studies in this category define collaboration indirectly, often through related concepts or phenomena. Rather than presenting a standalone definition, these studies describe collaboration as a component or consequence of other constructs, such as enforced collaboration (e.g., [9, 13, 24, 169], or encouraged collaboration in [95]), social skills (e.g., collaborative play [7, 54, 72, 82, 101, 165, 168, 171], interpersonal communication skills [2, 30, 39, 61, 126, 138, 143, 167], awareness of other's actions [155]), and cognitive mechanisms (e.g., joint attention [88], synchrony [64], Theory of Mind [15]). In such cases, the understanding of collaboration emerges from its contextual application or its relationship with other elements, rather than from an explicitly articulated definition. The majority of papers in our corpus (n=31) fall under this category by identifying collaboration implicitly as part of another concept.

Vague References: This category includes studies that mention collaboration, for instance in their discussion or introduction, without providing any clear or operational definition. Unlike the implicit definitions, which still consistently use specific terminology to address collaboration, the papers we categorized as using vague definitions may use the term in passing or as a general descriptor, leaving its meaning totally ambiguous and up to interpretation. The lack of specificity in these references often limits the ability to discern how collaboration is conceptualized or applied within the study, posing challenges for analysis and synthesis. We found 21 papers in this category.

3.3.2 Framing Collaboration as a Phenomenon: The definitions of collaboration were found to be generally split into two categories. The first category emphasizes collaborative skills and behaviors, defining collaboration based on the abilities and competencies of the individuals involved in the interaction. The second category focuses on the collaborative interaction itself, defining collaboration as a process in which conceptual frameworks, methods, or practices [16] were studied and prioritized over individual skills.

Framing Collaboration as a Skill: The definitions falling under this category focus on collaboration as a set of skills and behaviors, emphasizing individual competencies such as communication (e.g., in [30, 39, 61, 82, 103, 115, 159, 166]), teamwork (e.g., [46, 55, 69, 78, 164]), turn-taking (e.g., [2, 6]), cognitively active engagement in joint actions (e.g., joint attention [64, 88, 154], problem-solving [138], understanding others [3, 108], mutual planning [22, 148, 151]), or motor skills in eye-hand coordination (e.g., [170, 171]) that contribute to collaboration as a desired state of behavior. This perspective often highlights the role of children in demonstrating specific abilities to employ collaboration. A total of n=19 papers framed collaboration by defining it as a skill.

Framing Collaboration as an Interaction: The second category frames collaboration as a dynamic process of interaction among individuals or groups, emphasizing shared activities, mutual engagement, and coordinated efforts mediated by methods or artifacts. This perspective prioritizes the collaborative process as an emergent phenomenon arising from interactions facilitated by techniques or tools rather than solely dependent on children's abilities. When analyzing this category of definitions, it became clear that definitions within this category describe collaborative interactions at different underpinning perspectives, namely, concepts, methods, and practices. The categorization was borrowed from a pedagogical framework on designing technology that mediates collaborative interaction [16].

- *Concepts* - Explains the underlying conceptual and theoretical foundations in the design of technology for collaborative interaction. This type of definitions helps us to understand and frame the underlying factors and principles of collaborative interaction. A total of eight papers had definitions of collaborations in the concepts category. Enforced collaboration (EC) was the most common concept found in our corpus [12, 24, 33, 59, 88]. EC refers to a computer-supported interaction paradigm wherein participants are required to carry out joint actions on digital objects during a common activity (e.g., simultaneous touch or drag). Another example for concept was found in Baykal et al. that adopted the three levels of collaborative activity derived from Activity Theory [8] as an analytical framework to describe the collaborative interaction that took place in children's gameplay activities [17, 18].
- *Methods* - The methods and approaches for investigating, analyzing, and stipulating guidelines for designing technologies for collaborative interaction. A total of six papers had definitions in this line of work. The most common collaboration definition of this kind was the collaboration patterns identified by Giusti et al. [63] (i.e., choosing together, constraints on objects, different role, and ownership) that was utilized as framing strategies in collaborative applications to force/encourage the collaboration among children with autism (i.e., in [15, 22, 133, 162]). Similarly, collaborative design patterns introduced by Silva et al. [135] (i.e., Passive sharing, Active sharing, and Joint performance) have been adopted as a model to develop interactive applications for children with autism to engage in joint activities [135, 155]. The shareability aspect of interactive technology for children with autism was also used as a pillar for design (in [111]. Synchrony in social motor actions was another core component for collaborative interaction in design to enable joint attention in children with autism [65].

PAPER	DEFINITION OF COLLABORATION
Battocchi et al. [11] & Battocchi et al. [12]	Enforced Collaboration is a computer-supported interaction paradigm wherein participants are required to carry out joint actions on digital objects during a common activity (e.g., simultaneous touch or drag a puzzle piece) [38].
Baykal et al. [17] & Baykal et al. [18]	Three levels of collaborative interaction from Activity Theory (coordination, cooperation, co-construction) [8]. Implicitly, collaboration is narrowed to collaborative interactions/skills manifested in co-located collaborative games.
Boyle et al. [33]	Model of collaboration patterns [133]. The three patterns are: 1. Passive sharing pattern, 2. Active sharing patters 3. Active sharing and joint performance pattern
Crowell et al. [46]	Collaboration is an interpersonal process which builds upon social skills and mutual understanding. Collaboration occurs when two or more people coordinate related actions to achieve a common goal. Social activities such as collaboration lead to the development of cognitive skills based on active participation in the environment and learning from the tools and conversations within the social context [128].
Guneysu Ozgur et al. [69]	Collaboration is one of the four human-human interaction modalities (among co-activity, competition and cooperation). Collaboration happens when the players work together to complete the common tasks and are assigned the same role.
Silva et al. [133]	Four collaboration patterns [63]: 1. choosing together, 2. constraints on objects, 3. different role, and 4. ownership that encourage collaborative activities among users with High Functioning Autism.
Silva et al. [135]	Define Collaboration Patterns as interaction strategies on elements in a multiuser interface that gradually encourage collaboration among people with ASD. (...).
Silva-Calpa et al. [137]	Based on Enforced collaboration paradigm, proposed a set of four gradual collaboration patterns: Passive Sharing (a different role for each user), Active Sharing (exchange of information to share resources), Joint-Performance (simultaneous interaction), and Unrestricted Interaction (free interaction).
Wade et al. [148]	The use of the word "collaboration" most closely matches the formalization of shared cooperative activity [34]. This definition lays out the kinds of activities that may be correctly regarded as collaborative and identifies three necessary features of shared cooperative activities: mutual responsiveness, a commitment to the joint activity, and a commitment to mutual support.
Zancanaro et al. [162]	Mentions : "enhance social competencies, specifically collaboration (p. 124)" and focuses on dimensions of collaboration [63].
Zhang et al. [164]	Collaborative game-based interventions, which usually target two users' ability to convey information to one another (communicate) and to work together to achieve a common goal (collaborate) [112].
Zhao et al. [170]	The term "collaborative" refers to cooperation between two hands as well as between two players. To play these games, the players should coordinate the manipulations of two hands which requires precise and quick hand movement manipulations, eye-hand coordination skill as well as interaction skills to communicate and cooperate with the partners.

Table 3: The 14 papers with explicit definitions of collaboration.

- *Practices* - The practices and pedagogies include defining ways of practicing collaborative interaction. The instances that emerged in this line of work are what types of practices children in special education engage in when being involved in technology-mediated collaborative interaction. We found three types of practice-driven collaborative interaction studied with children in special education: collaborative play [7, 50, 54, 72, 78, 79, 95, 101, 126, 146, 149, 159], collaborative virtual environments (CVE) [46, 165, 167–169], and group work [55, 62].

However, the three lines of work for framing collaborative interaction are not mutually exclusive and are interconnected at times. For instance, we found two papers using definitions that apply them all, in which a theoretical framework was incorporated into an analytical approach to inform design practice (i.e., [18, 167]). Furthermore, 21 papers in total had definitions at both the two major categories of definitions - collaborative skills and collaborative interactions, [9, 22, 46, 50, 62, 64, 69, 77, 78, 88, 90, 101, 103, 148, 149, 151, 159, 162, 165, 168, 171].

3.4 Measurements of collaboration

A total of 57 papers had some sort of measures of collaboration. Nine papers did not use any measures at all [6, 9, 33, 55, 79, 95, 146, 154, 162]. Upon reviewing the measures used across our corpus of papers, we identified a wide variety of approaches. We first categorized these into two groups: standardized measures (i.e., using existing

measures from the literature) and unstructured measures (created inductively from the data itself). 74% of the papers of papers (n = 49) used unstructured measures while 26% of papers (n = 17) used structured measures. Six papers out of these 57 had both structured and unstructured measures [22, 78, 90, 108, 136, 151].

3.4.1 Unstructured measures. Our analysis of unstructured collaboration measures revealed five broad categories:

(1) Measures based on observing social skills and social interactions (including cognitive skills and affective skills),
(2) Measures based on observing task performance measures,
(3) Measures observing communication (verbal or nonverbal),
(4) Measures including subjective experiences (feelings or attitudes about the task performed),
(5) Measures focused on evaluating technologies or games.

The three measures based on observation included observation as a main research method (either in situ observation or based on video or audio analyzes of the data). Subjective experiences typically involved interviews or questionnaires with study participants (or the teachers/parents). Finally, evaluating technology measures refers to measures used specifically in the context of playtests, using for example game design patterns (i.e., conventions for describing and documenting recurring design decisions within a given context) such as movement, mutual goal, collaborative actions, making decisions, and social interactions. Among these unstructured measures, a great majority of papers (n = 30) focused on observing social skills or social interactions, followed by measures observing communication patterns (n = 22), observations of task performance (n = 17), measures focused on subjective experiences (n = 14), and those focused on measures related to game mechanics/design patterns (n = 7). In Figure 2 we display the frequencies of papers across the five categories of measures. The overlapping areas inthe diagram represent the number of papers that used measures spanning multiple categories.

Furthermore, within each of the five categories of measures, there is a large variation in the variables assessed. For example, in the category *observing communication*, the measures used varied widely among studies. Examples include assessing the "the total number of words uttered or acknowledged" (see [167]), determining "whether one can understand the line of thought of the partner before reciprocating" (see [3]) or evaluating "whether children could seek assistance from peers or researchers and whether they could communicate with peers to find solutions" (see [159]), among many others. A similar variety of measures was present for measures *observing social skills and social interaction*. For example, the behaviors we coded in this category spanned from social behaviors such as social initiations, requesting for help and responding to request (see [46]), to joint attention (see [146]), overall quality of rapport (see [96]), willing engagement or distance between players (see [103]) or mutual attention, collaboration (i.e., actions that serve the common understanding of a problem), proximity and turn-taking (see [159].

3.4.2 Structured measures. The following structured measures for collaboration were found in the corpus:

- **The Theory of Mind Scale (ToM)** [152]) is a measure of the ability to take another person's perspective. In [22] the scale has been applied to 5-6 years old children with ASD (in a control group and an experimental group) in two rounds (pre-test and post-test). The aim was to see whether after playing the StarRescue game the children will have better scores in the ToM scale, respectively children will get better at taking another person's perspective.
- **Fine Motor Skills** [140] used in [22], is an adapted version of a classical test for dexterity in the neurodiversity population [140]. In [22]children were instructed to insert twelve pegs one by one using one hand as quickly as they could. They measured the total time to obtain information on the fine motor skills and repeated the test three times to obtain stable performance.
- **The Measure of Self-Initiated Social Contact** [91] used in [50] is a measurement tool that assesses social interaction during therapy. Social interaction is distinguished in three elements: "(1) initiation of social contact with peers, reflective of social interest and motivation for social contact; (2) duration of social interaction, which reflects the development of communication and play skills; and (3) decreases in autistic aloofness and rigidity, with development of age-appropriate social and play behaviors" [91]. In [50] only the first element was measured - initiation of social contact with peers, reflective of social interest and motivation for social contact. The social interaction between two children with ASD was observed and recorded on video while they performed three collaboration tasks and interacted with a multi-agent system of moving robots on a table. The study was recorded on video and assessed on self-initiated social contacts (SISC) by the researcher and an unbiased expert.
- **The Friendship Observation Scale** [14] used in [24, 61] is an interactional coding system designed to assess manifestations of friendship including behaviors, verbalizations, and affects. This scale was originally developed to measure qualities of friendship in children on the autism spectrum. In [24], 12 children with high functioning ASD played puzzle games in dyads. Their play was videotaped and the videos were analysed with FOS. The five categories from this scale that were used in this study for video coding included: the Positive Social Interaction (PSI), Negative Social Interaction (NSI), Affect, Play, and Autistic Behaviors. The PSI includes Goal-Directed Behaviors (e.g., offering a goal-oriented action), Sharing Behaviors (e.g., showing and directing attention), Prosocial Behavior (e.g., encouraging), Conversation (e.g., negotiation), and Nonverbal Interaction (e.g., eye contact). The NSI includes items such as Teasing and Aggression. For the purpose of their study, the Affect scale was divided into a Positive Affect and Negative Affect score. The Play scale includes Parallel Play, Simple Social Play, Collaborative Play, and Unoccupied Play. The Autistic Behaviors scale includes items such as Repetitive Stereotypical Motor and Verbal Behaviors.
- **Joint Engagement** [4] used in [88], is a coding scheme that aims to rate joint engagement among children. In [88], several measures were identified for this coding scheme: joint

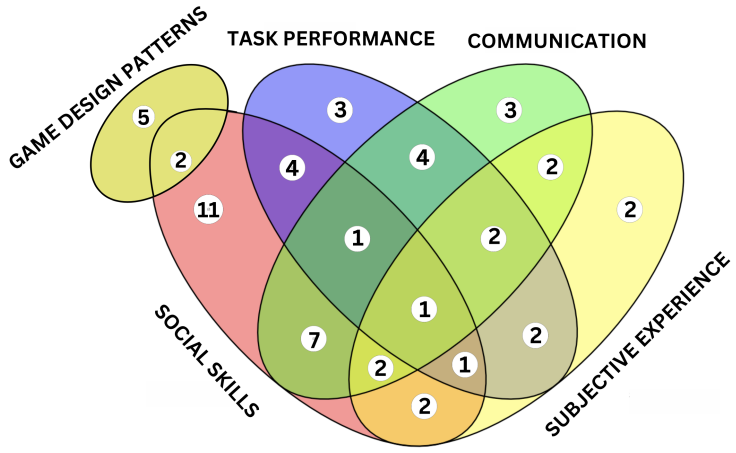

Figure 2: Frequencies of papers that used measures of collaboration across the five categories identified. The frequencies in the intersection of the Venn diagram display how many papers used multiple measures categories.

engagement with children or adults, unengaged, engagement with object, onlooking (what another child is doing), interaction (with peer or adult), supported joint engagement (peer), coordinated joint engagement (peer). Children aged 14-16 years with ASD played with several digital or physical games in pairs in two conditions - enforced collaboration and free play. The coding scheme was applied to all filmed interactions.

- **The Contextual Assessment of Social Skills (CASS)** [124] used in [96], is a measure of social functioning for people with ASD that employs role-play. The Contextual Assessment of Social Skills (CASS) was employed to evaluate the social skills of participants. The CASS is a role-play measure designed to assess conversational abilities in individuals with high-functioning autism. By utilizing the CASS in their study [96], the researchers were able to systematically observe and measure the social interactions of adolescents with ASD during a STEM activity (building robots), providing valuable insights into the effectiveness of peer collaborations in enhancing social communication skills.
- **The British Picture Vocabulary Scale (BPVS)** [52] used in [108] is a norm-referenced, standardized assessment of receptive (spoken) vocabulary for Standard English for use with children 3–15 years old. Prior to the intervention, the BPVS was administered to establish each child's level of receptive vocabulary. This baseline measurement helped ensure that any observed changes in social communication skills could be attributed to the intervention rather than variations in vocabulary comprehension. In [108] it has been used to assess children's with autism levels of receptive vocabulary.
- **Test of Pragmatic Skills (TPS)** [132] used in [108] is designed to assess the extent to which children select an appropriate message or interpretation in relation to communicative contexts (e.g., greeting, requesting, informing, rejecting, reasoning, closing conversation). The test is an elicitation one, assessing the child's use of different communicative functions in a standardized but natural setting, where test questions are embedded within an on-going conversation with guided play between an adult tester and the child. In [108] children aged 5-6 years were initially tested using the TPS. Their scores on this test were instrumental in selecting participants who exhibited social communication difficulties, ensuring that the study targeted individuals who could benefit most from the intervention. After the intervention, the TPS was administered again to evaluate any improvements in the children's pragmatic skills. The study found that children who received the intervention showed significant gains in their TPS scores compared to the control group, indicating enhanced social communication skills.
- **Child Communication Checklist-2, CCC-2** [27] used in [108] is designed to provide a measure of impairment in pragmatic language. The CCC-2 provided a detailed profile of each child's communication strengths and weaknesses, encompassing areas such as speech, syntax, semantics, coherence, and non-verbal communication.
- **The Communication Matrix** [57] in [6] is a tool that allows identifying the intentionality level in communication and oral skills. This matrix was collaboratively developed with a speech therapist and from participant observation [94]. By employing the Communication Matrix, the researchers were able to evaluate the impact of a videogame-based intervention on the children's communication abilities, providing valuable insights into the effectiveness of such interventions for children with ASD.
- **Social responsiveness scale** [44] and **Social communication questionnaire** [141] were used together or separately across several papers as a pre-measures, administered to the parents of the children to get estimates on the social functioning capability of the children: in [2, 3, 24, 46, 65, 90, 164, 169, 171]. Other measures were used as well as pre-measures,

focused on measuring intelligence or other abilities of participating children but since they were not measures related to collaboration we decided not to focus on summarizing them as well.

Other measures for collaboration were created by the researchers but were based on existing models from the literature such as:

- **The reduced version of the Positive Technological Development (PTD)**, [1], used in [39], is a framework used to investigate which soft skills are worked in a co-creation experience. PTD is based on six key behaviors, three related to intrapersonal skills (content creation, creativity, and choices of conduct) and three related to interpersonal skills of communication (collaboration and community building). PTD behaviors are evidence that children are developing positive character assets and can be supported by technology-rich classroom activities [1]. Cerezo et al., [39] applied the PTD framework with the aim to evaluate the enhancement of soft skills in children with ADHD, providing valuable insights into effective strategies for fostering these skills through participatory design and technology.
- **The SCERTS Model (the Social Communication, Emotional Regulation and Transactional Support** [121], used in [111], is an education framework based on core challenges faced by children with autism; contemporary Applied Behavioral Analysis (ABA), an approach used to influence behavior; Intensive Interaction [110] that teaches the fundamentals of communication and Attention Autism [47] to develop joint attention skills. The SCERTS defines three communicative stages for children with autism: Social partner (SP), when the child uses less than 3 words to communicate (e.g., using sign, language or pictures), Language Partner (LP) when the child uses more than 3 words, and Conversational Partner (CP) when a child uses 100 or more words and at least 20 are combined creatively [122]. In [111] the SCERTS model was used to determine autistic children's inability of sharing processes of attention (joint attention); and 2) by the inability to produce, follow and understand verbal and embodied communication (symbol use).
- Measures for evaluating games derived from **collaborative patterns** [63] were used across several studies in [22, 30, 32, 133]. These measures refer for example to design patterns implemented in games that addresses the specific characteristics of the target users, allowing them to maximize interest in the application, increase the ease of learning and interaction, and therefore to help in the social behavior of these users. For example, Silva et al. [133] designed a collaborative multitouch tabletop game with four collaboration patterns (choosing together, constraints on objects, different role, and ownership) to contribute to the social interaction skills of youngsters with autism. Participants had to play the games across multiple conditions and the analysis of the testing of each phase of the game was based on aspects of research related to the social interaction expressions shown by users. The kinds of behaviors analysed were various: verbal or gestural interactions: rectify, guide, ask questions, answer , encourage, thank, help, complain, commemorate, and reject, and gestural interactions: see, smile, laugh, perform task in the game and physical contact. The results suggested that each collaboration pattern motivates the need for collaboration and encourages the creation of social interaction intentions or situations among users.
- Measure for evaluating games based on **interaction patterns** [135], used in [155], refer to measures that evaluated how specific games designed with specific interaction patterns impact users' behavior. In [155] the games developed were implemented with four interaction patterns that have been recommended practical for implementing table-top enabled collaborative applications (i.e., Passive Sharing, Active sharing, Joint-Performance and Unrestricted Interaction Patterns [135]).
- **Measures based on Interaction Rules using Enforced Collaboration Paradigm**, used in [13, 137]. For example, Battocchi et al. [13] present the design and an initial evaluation of the Collaborative Puzzle Game (CPG), an interactive game designed with the purpose of creating a technology-supported activity for fostering collaboration in children with ASD. In the CPG, digital pieces can be dragged over the surface by direct finger touch and the interaction is enriched with visual and auditory feedback. The CPG features a set of interaction rules called Enforced Collaboration: to be moved from their original position, puzzle pieces have to be touched and dragged simultaneously by two players. The children in this study had to play the game under the Enforced collaboration paradigm and under free play and a series of task performance measures were identified for a group of autistic and typical developed children.

3.5 Alignment between definitions and measurements of collaboration

When looking across the definitions and measurements of collaboration, we can see some examples of alignment. For instance [17, 18] have both an explicit definition focused on levels of activity from Activity theory (AT) and measures that focus on Gameplay Design Patterns (mutual goals, movement, togetherness) [28, 66] and the three levels of collaborative activity according to AT [8]. Another example of alignment can be found in the research from Silva et al. [135], where there is an explicit definition of collaboration focused on "Collaboration Patterns as interaction strategies on elements in a multiuser interface that gradually encourage collaboration among people with ASD" and the measures defined by the authors and focused on the number of verbal and gestural interaction expressions performed by users to collaborate with their partner in the restricted collaboration patterns that were implemented in the game they developed. Further, a third example of alignment can be found in the research from Wade et al. [148]. In this study, the definition of collaboration was the following: "the use of the word "collaboration" most closely matches the formalization of shared cooperative activity put forth in Bratman [34]. This definition lays out the kinds of activities that may be correctly regarded as collaborative and identifies three necessary features of shared cooperative activities: mutual responsiveness, a commitment to the joint activity, and a commitment to mutual support [34]." The cooperative activities

have been subsequently operationalized such that in their measures they analyzed the players' behaviors and task performance during play.

On the other hand, several papers did not align between the levels of their definitions and the measures used. For example, in the study of Jahadakbar et al., [79], we could identify on one side a vague definition of collaboration, which referred to collaborative play that fosters social interactions (thus a definition at the level of practices based on our analyses) and the side a measurement at the level of skills, focused on engagement in the play (which is also vaguely defined in the paper). Another misalignment between the definitional level and type of measurement could be found in Zhao et al. [168] where we could identify an implicit definition that focuses on the game mechanics that fosters peer collaboration (thus a definition at the level of methods) and a measure focused on fine motor skills (a very specific skill measure that is not necessarily definitory to collaboration).

4 Discussion

This systematic literature review of the existing definitions and measurements for technology-mediated collaboration between children with special educational needs is based on a sample of 66 peer-reviewed papers (out of 977 papers) from SCOPUS, Web of Science, ProQuest and ACM Digital Library data bases. Overall, we did not find a consistent definition of technology-mediated collaboration or a systematic way of measuring collaboration.

By organizing the definitions of collaboration into three categories (i.e., explicit, implicit, and vague), this study highlights the varying degrees of definitional clarity and their implications for understanding and advancing research on technology-mediated collaboration for children with special educational needs. Within the explicit definition category, we identified 14 papers that explicitly describe their perspective on collaboration. Among these papers, explicit definitions were found at multiple levels of description. Some describe collaboration as an interpersonal process that builds upon social skills and mutual understanding (i.e. [46]). Similarly, Guneysu Ozgur et al. [69], refers to collaboration as being a type of human-human interactions (among co-activity, competition, and cooperation). On the other hand, authors such as Wade et al. [148] and Zhao et al. [171] equate collaboration with cooperation. While the two concepts are related, they are not interchangeable and conflating them can lead to misunderstandings. For instance, cooperation occurs when a group of students divides a research project into sections, each working independently before combining their parts into a final report. In contrast, collaboration involves students actively discussing ideas, collectively revising sections, and continuously building on each other's contributions to create a cohesive final product [87, 129]. Other authors consider collaboration a form of social competence (see [163]), raising the question of which is the prerequisite of which: social competence or collaboration? We were expecting to find a commonality in defining collaboration through the "achievement of a common goal", but only a few papers specifically mentioned this in their definitions (see [46, 69, 164]). Research in fields such as organizational psychology, which has studied collaboration extensively for a longer period, emphasizes that collaboration is fundamentally directed towards achieving a shared goal [21]. Of course, we can achieve a common goal both through cooperating (working independently or in parallel) and collaborating (through joint effort, shared decision-making, and continuous interaction within the process), thus this part of the definition is not sufficient to capture the phenomenon completely.

Among the implicit and vague definitions, we have identified definitions of collaboration mediated by game technologies at two levels: a) at the levels of skills involved in the collaboration process and b) at the level of the process of collaborative interaction. Definitions of collaboration as a skill focus on collaboration as a set of skills and behaviors needed when engaging together toward achieving a common goal. On the other hand, definitions of collaboration as interaction focus on the emergence of collaboration through the interactions facilitated by the technologies or tools used. Among these definitions, we have identified papers that refer to specific types of collaboration, such as "Enforced Collaboration" which is defined as a computer-supported interaction paradigm wherein participants carry out joint actions during a common activity [13]. Finally, at a different descriptive level, we identified definitions that conceptualize collaboration through game design patterns. Two predominant models emerged as well: (a) Silva et al.'s [134] framework, which categorizes collaboration patterns into passive sharing, active collaboration, and joint attachment, and (b) Giusti et al.'s [63] model, which includes choosing together, object constraints, role differentiation, and ownership structures. These models highlight how the games implemented and tested in their studies facilitate distinct forms of interaction among peers with technology. One might question whether these patterns alone are sufficient for evaluating game technologies as effective tools or interventions for observing or fostering "collaboration" or if the aim of the evaluation should remain at the level at which they define collaboration - at the levels of patterns, within the narrow field of design.

Similarly, we did not find a consistent strategy for measuring collaboration mediated by technology, which might not be that surprising giving the lack of clarity on definitions. The majority of the papers (74%) had used unstructured or self-determined measures. Among these measures we identified measures focused on observing social skills and social interactions, measures focused on observing task performance, measures focused on observing communication, measures that focus on assessing subjective experiences and measures focused on evaluating the technologies or games used in the study. Even within each of these categories of measures there was a great variety of variables assessed. Our results are consistent with a previous literature review from Baykal et al. [20] where more limited findings regarding measures for collaboration were presented. Similarly, the current results are in line with the literature review from Syriopoulou-Delli and Gkiolnta [145] which similarly stated that "as most researchers typically create their own questionnaires there is no stable measures reported for such evaluations", referring to the effectiveness of robots to enhance social skills of children with ASD.

Among the measures identified in our corpus of articles we found a series of structured measures that have been previously used across different studies. However, none of the structured measures identified in our review directly assessed collaboration. Instead, these measures focused on related aspects or skills that may contribute to or be important for collaboration. We argue that if

authors make claims about collaboration it is crucial not only to define the term "collaboration", but also to measure it explicitly, rather than relying solely on its components or contributing factors. In case they rely solely on the components or contributing factors of collaboration, this should also be explicitly stated.

The analysis of the references used in the corpus confirms the picture that there is neither a common definition of what collaboration is nor a common approach to how collaboration can be measured. The papers refer to a large number of different sources, 83% being referenced by a single paper. The most commonly cited papers typically describe the design, development, and testing of some system aimed at supporting autistic children and adolescents. It is not possible to identify any publication with a focus on defining and describing collaboration as a phenomenon that appears to be commonly used in our field. The same goes for measurements of collaboration. Accordingly, the analysis of references becomes more of a starting point to get to know the field than a source of information for learning about collaboration and measurements.

As a general observation about the types of samples used across the studies in the corpus, we found that sample sizes were typically small, often comprising fewer than ten participants from the target group. Larger sample sizes are occasionally used when typically developing (TD) children are included for comparison. As highlighted in previous reviews (e.g., [20]), the majority of research focuses on children with ASD in the 6 to 12-year-old age range. Moreover, despite the increasing interest in understanding collaborative behaviors among neurodiverse children, there remains a notable gap in the literature regarding other special educational needs populations, such as children with ADHD or learning difficulties. Future research should work to bridge this gap by examining how these groups develop and experience collaboration skills across different educational and social contexts.

4.1 Moving forward

This review, consistent with some of the existing literature reviews, highlights the varying interpretations of collaboration, which is sometimes defined as a subset of social skills (e.g., social communication), other times as an umbrella term including concepts e.g., joint attention and turn-taking, and occasionally used synonymously with social skills, teamwork, or cooperation. When it comes to child-computer interaction (CCI) research, which deals with the mediating aspect of technology design for children, the term becomes even more fragmented, defined either as a collaborative skill or a collaborative interaction. Thus, measurement criteria also vary such as focusing on skills, performances, feelings/experiences, or evaluations of technology and/or game design patterns (e.g., togetherness, ownership, shared resources, etc.) linked to children's collaboration. A key contribution of this review is identifying nuances in how collaborative skills and interactions are defined, measured, and studied — whether conceptually, methodologically, or in practice.

Definitions are fundamental to building robust theories. To develop a theory of technology-mediated collaboration, it is essential to start with a clear and comprehensive definition of the phenomenon—one that captures all observable dimensions of technology-mediated collaboration while excluding unrelated aspects. Our work began with the assumption (or hope?) that we might find a commonly accepted definition of collaboration mediated by technology, accompanied by aligned measures. However, we encountered a multitude of definitions, each offering valuable insights but none proving entirely satisfactory on its own. Worse, a substantial number of papers do not explicitly mention what definitions they use. Among those papers with explicit definitions, the common framework that we identified use definitions of collaborations at different dimensions of the phenomenon: either focused on skills or at the level of interaction (with focus on concepts, methods, or practices). Similarly, not all papers have an alignment between the type of definition used and type of measures. Overall, we have found that existing conceptualizations vary widely, often lacking precision or, in some cases, being entirely absent. While it is generally acknowledged that collaboration can encompass a broad range of meanings depending on the context, the lack of a unified definition or coherence of use remains a challenge in research. Specifically, this lack of consensus poses a challenge for designing effective interventions to foster collaboration with and through technology among children with special educational needs. Since most of the studies in our corpus focus in one way or another on developing interventions targeting collaboration, we believe that without a strong theoretical foundation and precise definitions, interventions risk being inconsistent, difficult to evaluate, and potentially ineffective. A well-defined and theoretically grounded understanding of collaboration ensures that interventions target the right mechanisms, promote meaningful engagement, and lead to measurable improvements. Clear definitions also facilitate the development of standardized assessment tools, enabling researchers and practitioners to compare outcomes across studies and refine best practices. Ultimately, stronger definitions (and ultimately theories) provide a roadmap for creating interventions that are not only evidence-based but also adaptable to diverse educational and technological contexts. Our observation is that the corpus of studies analyzed here generally has the opposite approach; they start from designing and testing small, specific game technology-based interventions, in specific situations, and make general statements about their impact on collaboration without having a solid theoretical understanding or definition of collaboration. Our analysis of the references used in this field revealed two key patterns: highly cited papers tend to come from Human-Computer Interaction (HCI) and Computer Science (CS), while the overall number of cited papers predominantly originates from psychology. One possible explanation is that HCI and CS have a few foundational, widely recognized papers considered canonical within their disciplines, yet they rely heavily on literature from other fields. This finding highlights an important gap: research on definitions and measures from related fields—such as education and psychology — has yet to significantly influence studies focused on developing digital interventions to support collaboration among children with special educational needs. Given the extensive work on collaboration in these adjacent disciplines, there may be valuable definitions and frameworks that could inform and strengthen this area of research. For example, according to the OECD, "Collaboration is a social process of knowledge building in which people work together towards clear objectives, resulting in well-defined final products, consensus, or decisions." None of the papers analyzed in this review adopted this definition focused on

the knowledge-building process, central to collaboration according to some other researchers as well (see [5]). In the 2022 cycle of PISA testing, 81 countries around the world participated in the assessment, and the number of countries participating is predicted to increase in 2025 [109]. Since the framework is used worldwide, it should be considered as one important guideline for those of us who do research on developing technologies for children with the aim of fostering their collaborative skills. Similarly, Child and Shaw [42] identified six key facets of the collaborative process: social interdependence, introduction of new ideas, cooperation/task definition, conflict resolution, sharing of resources, and communication. These six facets were also incorporated into the PISA framework from 2015 for assessing collaborative problem-solving [114].

Another example of a definition, this time focused on social skills comes from a scoping review from Burns et al. [36]. They proposed a broad definition of peer collaboration identified from studies where children (0-6 years) were engaged in peer-collaboration using technology [36]. They define peer collaboration as "the process through which peers communicate, share and learn skills, solve problems, and develop prosocial abilities to achieve a collective goal" [36]. Furthermore, they introduced a framework highlighting key domains: shared goals (role distribution and responsibility), prosocial skills (helping, supporting, sharing), knowledge exchange (listening, teaching, feedback), conflict resolution (problem-solving, compromise), and communication (verbal and non-verbal) [35].

Another framework for conducting research on technology-mediated collaboration can be found in Activity Theory (AT), which is a deductive approach, a theoretical model and method of understanding and analyzing a phenomenon, finding patterns, and making inferences across interactions [80]. Based on AT as a theoretical foundation, Engeström et al. defined three levels of collaborative interaction [53], and building on this definition Bardram introduced a framework for collaborative interactions between users and mediating technology [8]. This framework consists of three different levels of collaboration, from the simplest to the most complex form: coordination, cooperation and reflective communication. This theory has been applied with technologies and children with special educational needs in [17, 18].

However, we believe that these various definitions are not enough in themselves; they need to be adapted to the specific context and include the role of technology as an important facilitator or "entity". The OECD definition acknowledges collaboration as a process and the interaction aspects but is not related to technology as such. For instance, while the definition of collaboration from OECD states 'people', other definitions use the word 'entities' (e.g., [21]) or 'actor' [29], which covers both people and technologies as peers, such as social robots. Similarly, the definition and skills listed by Burns et al. [35, 36] have been identified in an inductive way, and as such miss out on the theoretical grounding. While AT definitely has a theoretical grounding, it is hard to apply in practice, which is the reason for why we see it combined with e.g., gameplay design patterns in order to be operational in [17, 18]. As a field, we must move beyond merely acknowledging the lack of definitions and measurements and begin developing clear guidelines and frameworks for defining technology-mediated collaboration that can be systematically studied within the special educational needs population. Examples of how to achieve this can be found in more established disciplines, such as work and organizational psychology, which have successfully addressed similar challenges [21]. Our message is clear: there may never be a single, universal definition of collaboration, as it is a complex, context-dependent, and evolving phenomenon [21]. While we are working toward a consistent framework for studying collaboration, technology, and children with special needs, we urge the research community to take a structured approach when conducting and reporting their research. Specifically, researchers should first clearly define what aspect of collaboration they are measuring, ensure that their methods align with that definition, and draw conclusions and implications based strictly on the specific measures used.

4.2 Limitations

This review includes only studies that were identified in the four selected databases. Searching in other databases could have provided additional references. Another possible limitation is the selection bias in search terms. Including only publications using the term 'collabo*' in the abstract. It may be argued that papers can address collaboration without using this term or by using related terms such as coordination, or teamwork, used interchangeably with collaboration in the literature [21]. However, we were specifically interested in research that used the word "collaboration" and not associated terms which we consider not to be synonymous. We further acknowledge that by coding the corpus we have a moral obligation to not color the results with our own personal opinions. We acknowledge that complete neutrality is unattainable, and some degree of bias may be present. Despite these limitations, we hope our findings will inspire others in the field.

5 Conclusion

In this paper, we have presented the results from a systematic literature review on technology-mediated collaboration among children with special educational needs. The review is based on four different databases (SCOPUS, Web of Science, ProQuest and ACM) and the final corpus of 66 papers (out of 977), has a specific focus on definitions and measures for collaboration. It is clear from the results that there is no agreement on either how to define collaboration or how to measure it. The review contributes with an overview of the current status of definitions, measurements, and common references, and provides suggestions for how to move forward.

6 SELECTION AND PARTICIPATION OF CHILDREN

No children participated in this work.

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A Appendix: Search Queries

Proquest: (APA PsycInfo® and ERIC): noft((collabo*) AND ("special education" OR "learning difficult*" OR "autis*" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND ("game*" OR gaming OR "technolog*") AND ("child*" OR student*)) AND la.exact("English") AND PEER(yes) AND PEER(yes)

SCOPUS: TITLE-ABS-KEY ((collabo*) AND ("special education" OR "learning difficult*" OR "autis*" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND ("game*" OR gaming OR "technolog*") AND ("child*" OR student*)) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "re"))

Web of Science: (collabo*) AND ("special education" OR "learning difficult*" OR "autis*" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND ("game*" OR gaming OR "technolog*") AND ("child*" OR student*) (Topic) and English (Languages) and Article or Proceeding Paper or Review Article (Document Types) and Article or Proceeding Paper or Review Article (Document Types)

ACM: "query": AllField:(Abstract:(collabo*) AND Abstract:("special education" OR "learning difficulty" OR "learning difficulties" OR "autism" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND Abstract:(child* OR student*) AND Abstract:(game OR gaming OR technolo*)) AND Abstract:(collabo*) AND Abstract:("special education" OR "learning difficulty" OR "learning difficulties" OR "autism" OR "ADHD" OR "Attention Deficit Hyperactivity Disorder") AND Abstract:(child* OR student*) AND Abstract:(game OR gaming OR technolo*) "filter": ACM Pub type: Proceedings, Article Type: Research Article, E-Publication Date: (* TO 10/31/2024)