A Systematic Review of Ability-diverse Collaboration through Ability-based Lens in HCI

Lan Xiao
Global Disability Innovation Hub,
UCL Interaction Centre, University
College London
London, United Kingdom
l.xiao.22@ucl.ac.uk

Maryam Bandukda
Global Disability Innovation Hub,
UCL Interaction Centre, University
College London
London, United Kingdom
m.bandukda@ucl.ac.uk

Katrin Angerbauer
VISUS, University of Stuttgart
Stuttgart, Germany
Katrin.Angerbauer@visus.uni-stuttgart.de

Weiyue Lin
Peking University
Beijing, China
linweiyue@stu.pku.edu.cn

Tigmanshu Bhatnagar
Global Disability Innovation Hub,
UCL Interaction Centre, University
College London
London, United Kingdom
t.bhatnagar@ucl.ac.uk

Michael Sedlmair
VISUS, University of Stuttgart
Stuttgart, Germany
michael.sedlmair@visus.uni-stuttgart.de

Catherine Holloway
Global Disability Innovation Hub,
UCL Interaction Centre, University
College London
London, United Kingdom
c.holloway@ucl.ac.uk

ABSTRACT

In a world where diversity is increasingly recognised and celebrated, it is important for HCI to embrace the evolving methods and theories for technologies to reflect the diversity of its users and be ability-centric. Interdependence Theory, an example of this evolution, highlights the interpersonal relationships between humans and technologies and how technologies should be designed to meet shared goals and outcomes for people, regardless of their abilities. This necessitates a contemporary understanding of "ability-diverse collaboration," which motivated this review. In this review, we offer an analysis of 117 papers sourced from the ACM Digital Library spanning the last two decades. We contribute (1) a unified taxonomy and the Ability-Diverse Collaboration Framework, (2) a reflective discussion and mapping of the current design space, and (3) future research opportunities and challenges. Finally, we have released our data and analysis tool to encourage the HCI research community to contribute to this ongoing effort.

CCS CONCEPTS

• **Human-centered computing → Accessibility theory, concepts and paradigms**.

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KEYWORDS

Interdependence, accessibility, collaboration, ability-based method

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1 INTRODUCTION

Over the past few decades, accessibility research within Human-computer Interaction (HCI) has experienced substantial growth [81], reflecting an evolving understanding of inclusion and its importance in technology use and design. While HCI and accessibility research have previously sought to foster the independence of people with disabilities by helping overcome barriers presented by physical, sensory, or cognitive challenges, a growing body of research is now exploring the relationship (or interdependence) between people with different abilities and the role of technology in facilitating this interdependence [15, 78]. Bennet et al. [15] proposed 'interdependence' as a frame to enhance inclusion within assistive technology research. The Interdependence framing, adapted from disability studies, argues for the design of technologies to support better collaboration among technology users regardless of their abilities. Since its publication, the framework and underlying concepts have been widely applied to investigate ways to support inclusive interactions between people with different abilities. For instance, research conducted by Vincenzi et al. [134] delves into the design of AI-enabled assistive technologies to bolster the collaborative navigation dynamics shared between individuals with visual impairments and their sighted guides. Similarly, the PLACES framework proposed by Bandukda et al. [8] offers a comprehensive view of the interdependence between blind and low-vision (BLV) people, sighted companions, and people with diverse abilities in outdoor leisure settings. Building on the concept of interdependence, This research highlighted the interplay between 'interdependence' and 'independence', evidenced by the need to engage with and contribute to the social experience while negotiating the infrastructural barriers to access open space leisure activities. The popularity of the interdependence framework has also led to a plurality of interpretations. From *'carework'* [16], *'access intimacy'* [89] in disability studies to *'cross-ability collaboration'* [15], *'asymmetric collaboration'* [48], *'mixed-ability collaboration'* [79] in HCI studies, this divergence in perspectives and expanding number of methods has led to disparate terminologies. The motivation for this paper came initially from a first exploration into this domain by the first author, weaving together a fragmented understanding of this new and emerging domain in HCI research.

To inform future discourse and create a unified understanding of the interdependence within HCI research, we performed a systematic review of HCI literature to provide a synthesised view of the field. Our analysis of 117 papers covered dimensions in collaboration, contexts, technologies, and evaluations, resulting in a unified taxonomy and an overview of the current state of the art. Furthermore, we delve into the open challenges and issues within the domain and suggest implications for designing technologies for diverse-ability collaborations.

We intend this work to be a cornerstone of accessibility and HCI research, providing a well-defined starting point. At the same time, we aim to offer a common platform for established researchers to engage in meaningful discussions and reflections on interdependence between people with diverse abilities. In summary, this paper makes the following contributions:

(1) a unified taxonomy and a framework for ability-diverse collaboration research,
(2) a reflective discussion and mapping of the current design space (across contexts, collaboration methodologies, technology spectrum, and evaluation strategies), and
(3) the identification of future research opportunities and challenges in ability-diverse collaboration.

We invite the research community to contribute to this ongoing effort and welcome extensions of the taxonomy of ability-diverse collaborations by adapting our open-source data and analysis tool available on our live database.

2 BACKGROUND & RESEARCH QUESTIONS

2.1 Evolving understanding of disability and ability within HCI

In the early stages of the intersection between Human-Computer Interaction (HCI) and accessibility research, the focus was primarily on designing assistive technologies for people with special needs. This included developments like motorised wheelchairs and alternative and augmentative communication devices. It wasn't until the mid-1970s that researchers began to thoroughly explore how individuals with disabilities utilised these devices in their daily lives [41, 132]. The first publication(in 1986) at the Conference on Human Factors in Computing Systems (CHI) focusing on this topic was titled "Human Interface Design and the Handicapped User"[28]. Originally introduced as part of a panel discussion, this paper investigated the complex connections between different impairments associated with specific conditions and the role of assistive technologies (AT) in enabling computer access for individuals with these impairments. Moreover, the study emphasised the crucial impact of design and research choices in the development of computer systems, particularly regarding their accessibility for people with disabilities. During this period, HCI research and practice perceived *disability* as a problem stemming from functional impairment, which technology was expected to correct or bridge [83].

Subsequently, concepts like Universal Design (UD) [93] and inclusive design [26] gained prominence. These design philosophies were grounded in the principle of creating products and environments usable by the widest possible audience without necessitating adaptation or specialised design. This 'design for all' approach reinterpreted *disability* as a challenge for designers to accommodate a broader range of users.

The most influential shift in this field came with the introduction of Ability-based Design[140], which emphasised a positive affirmation of individual abilities. This paradigm urged designers of assistive technology to focus on what people are capable of doing('*ability*') rather than their limitations('*disability*'), paving the way for the development of customised and personalised technologies. This approach marks a significant turn in HCI and accessibility research, highlighting a future where design is increasingly tailored to the unique abilities and needs of each user.

2.2 Understanding ability-diverse collaborative interactions

Building on concepts within Disability Studies and the Disability Justice movement, Bennett et al [15] explained how independence—the oft-cited ambition of prior accessibility research—has several limitations. Amongst these are the social nature of interactions within communities and broader society and the impact of disability stigma resulting in reduced use of technologies that would provide independence [86]. The concept of Independence also promotes the idea of complete self-reliance as the ultimate goal whilst denigrating or ignoring the collaborative work done between people with disabilities to overcome structural inequities, discrimination, and poor design choices [84]. The Interdependence frame [15] added a new dimension to HCI accessibility research, building on prior advances such as Ability-based design [140]. In the years since its publication, it has been widely utilised within the HCI community to frame prior systematic reviews [81] and technology design [34, 134].

This review aims to illuminate the nuances of interactions and collaborations, especially in scenarios where such interactions either magnified the abilities of individuals with disabilities or when an ability was momentarily harnessed from someone to bridge an accessibility chasm prevalent in society. To this end, we posed the following research question:

RQ1: How do individuals interact with each other in ability-diverse collaborations?

2.3 Deciphering Technology's Role in Ability-diverse Collaborations

In recent years, there has been an increased focus on harnessing technologies to foster collaborations that are not just efficient and effective but also enjoyable. This requires a systematic understanding of the contours of cooperative work, simultaneously spotlighting the technological interventions that bolster various facets of collaborative endeavours. For instance, Johansen et al.'s groupware taxonomy [64] delves into the ramifications of spatial and temporal disparities on the technological prerequisites of collaborative platforms. Another insightful paradigm is the functional classification proposed by Ellis et al. [43]. This classification segregates groupware into four distinct categories, each distinguished by the functionalities they offer: 1) storage and access of artefacts, 2) synchronisation of activities, 3) facilitation of communication, and 4) deployment of "intelligent" components tailored to augment group dynamics.

Collaborations in ability-diverse settings present a unique set of challenges. Collaborators, given their diverse abilities, might grapple with divergent collaborative objectives. Moreover, the inherent asymmetry between collaborators— in terms of abilities and access to information—might precipitate conflicts [56]. Therefore, we pose the following research question:
RQ2: How does technology streamline and enhance the collaborative dynamics in ability-diverse settings?

3 REVIEW METHODOLOGY

To address the nuances of diverse-ability collaborations in HCI research, we performed a systematic literature review targeting publications in the ACM Digital Library (DL). Our selection and screening methodology was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [90]; Figure 1 illustrates our review methodology. Next, we conducted quantitative and qualitative analyses of the included studies.

3.1 Identification Process

To create the dataset for our analysis, we undertook a systematic search within the ACM Digital Library (DL) covering the time frame from July 2003 to July 2023 (the past 20 years). We searched for the pertinent keywords "collaboration", "accessibility", and "interdependence" appearing either in the title, abstract, or as a keyword. The finalised search criterion was articulated as: (("*interdependence*" OR "*collaboration*" OR "*collaborative*" OR "*collective*") AND ("*accessibility*" OR "*access*" OR "*disability*" OR "*disabled*")). To narrow the results, we filtered the results to research articles in English, considering only journal and conference proceedings.

3.2 Screening Process

The initial search yielded 491 research articles, then uploaded to Rayyan, an online tool designed to review search results [100]. Twenty articles were manually added based on the authors' knowledge of publications omitted by the search string, yielding 511 articles. The lead author and a co-author then reviewed these papers for relevance, mainly by examining their titles and abstracts. The focus was on keywords from our search criteria and a highlight on interactions between individuals with varied abilities. During this phase, 346 irrelevant papers were filtered out. For instance, papers that mentioned "access" and "collaborative" in a privacy and information security context or those that centred on information access in collaborative information systems (e.g. [119, 147], which were out of the scope of this research, were excluded.

3.2.1 Eligibility Criteria. The review process narrowed our list to 165 full-text research articles to further evaluate their eligibility. To determine this, two authors independently assessed the entire content of each article, ensuring they met the following criteria:

- *The paper constitutes original and peer-reviewed full research articles.* Items such as extended abstracts, workshops, keynotes, and doctoral consortiums are not considered.
- *The paper showcases a user study, prototype, or system involving collaboration between two or more participant groups.* For example, studies solely examining technology usage among different groups without a collaborative component are not considered. An instance of such omitted research is [120].
- *At least one of the participant groups comprises people who identify as being disabled.* Since, studies that delve into collaboration solely between humans and technology are not included. This excludes topics like human-AI collaboration [139] and human-robot collaboration [20]. Additionally, studies focusing on collaboration involving the elderly are excluded since they fall outside the primary scope of this review, as seen in works like [108].
- *The primary research contribution of this article must centre around enhancing the interactive relationship between people with diverse abilities.*

For the specified inclusion criteria, the initial three were predefined prior to the screening process. The fourth criterion was introduced at this stage because, although some papers touched upon our desired topic, their primary focus diverged from the objective of this review. For example, although some studies integrated individuals with disabilities into the co-design process, any final research contributions (technical or prototype designs) that didn't support interdependence between individuals of varied abilities were excluded. However, those studies whose primary contribution is to research how to include individuals with varying abilities in the co-design methodology are included (e.g., [51], [114]). The eligibility criteria were developed collaboratively among the authors. When one of the authors was unsure if a paper should be excluded, it was marked, and the authors decided in a final group discussion. The last step of the screening process led to a final corpus of 117 included papers.

3.3 Analysis

To address our research questions, we adopted a multi-faceted analytical approach. Starting with our curated set of 117 papers, the lead author pioneered the formation of an initial codebook. This codebook encapsulated various facets of our research questions, providing a structured approach to get insights. Following the completion of the first coding round, four co-authors embarked on a

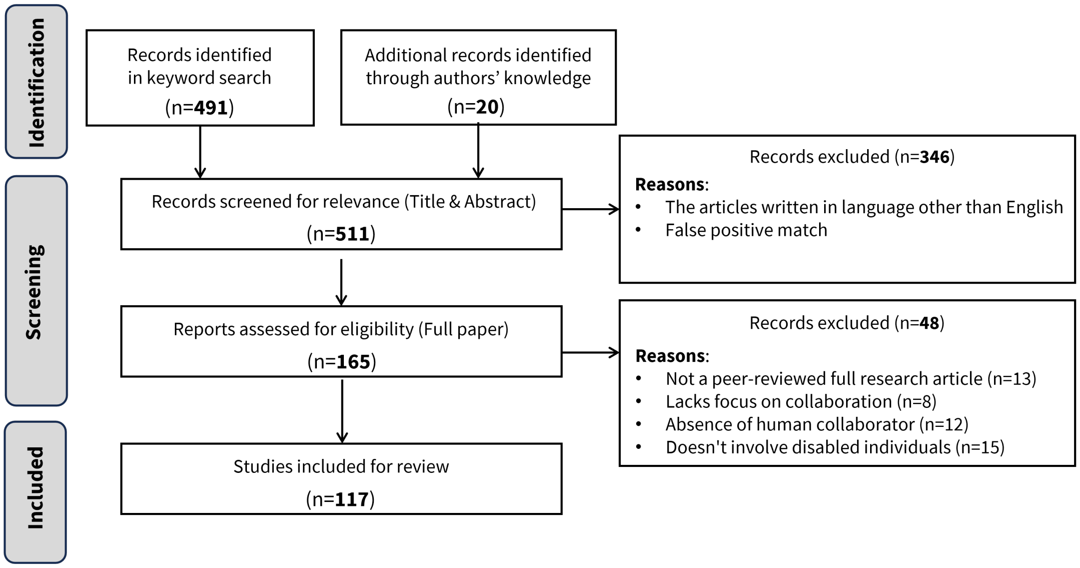

Figure 1: The PRISMA flow diagram, delineates the stages of our literature review process

second round of coding to reinforce its fidelity. This entailed an equitable distribution of the 117 papers among these coders, ensuring each paper was meticulously analysed. Any discrepancies or conflicts identified during this phase were earmarked for collective deliberation, culminating in a refined and updated codebook. An average inter-rater agreement of 83% was achieved. With a consolidated understanding of the codebook, the lead author undertook a comprehensive third review of the entire corpus to ensure uniformity and coherence of coding. The final dataset and codebook is available at our live database[1] for the benefit of the HCI research community.

4 RESULTS

4.1 General study characteristics

In recent years, HCI researchers have become more interested in how people with different abilities work together. Our review covers studies from 2003 to 2023, shown in Figure 2. We can see a clear growth in the number of papers on this topic over time. While only a few published works were of this nature in the 20 years between 2003 and 2014, a growing increase can be noticed in the following years, with a more steep rise from 2015 onward. A pivotal moment in this research trajectory occurred in 2018 when the interdependence framework for assistive technology design was introduced [15], thus sparking more research in this area. Our observations discerned that the global shift to remote working and technologies to support remote collaboration catalysed scholarly inquiries into collaborative dynamics under distinctive circumstances. For example, a substantial body of literature from 2021 and 2022 predominantly focused on the collaboration amidst the challenges posed by the COVID-19 pandemic (e.g. [80, 130]). however, that the dip in the number of papers in 2023 could potentially be attributed to incomplete data for that particular year.

Table 1 delineates the distribution of publication venues within the corpus under consideration. The CHI (Conference on Human Factors in Computing Systems) emerges as the most frequently occurring venue in our dataset. Notably, CHI boasts more than double the number of literature reviews compared to other venues examined in this study. However, one must consider the broader scope and larger scale of CHI as a venue, which naturally results in a higher volume of published papers than other forums. Additionally, significant contributions are observed in ASSETS (n=21) and PACM HCI (n=16). This underscores the burgeoning interest in ability-diverse collaboration across central platforms in the broader HCI domain, including accessibility research and Computer Supported Cooperative Work (CSCW).

In our comprehensive review of 117 publications, two primary categories of contributions[141] stood out: artefact contributions—concerned with the design and evaluation of technologies that enhance/enable collaboration—and empirical contributions, which delve into the nuances of collaboration across diverse groups or varied contexts. Both categories were equally represented, accounting for 51.3% (n=60) of the total papers. Notably, seven papers (6%) synthesised both artefact and empirical dimensions. Only six papers are categorised as theoretical or opinion-based contributions in the corpus (5.1%), including Bennett et al.'s exploration of interdependence as a framework for assistive technology [15] and Flórez-Aristizábal et al.'s study on design of accessible interactive tools to support teaching to children with disabilities [45]. Methodological contributions, although equally represented at 5.1% (n=6), showcased a specific thematic consistency: all honed in on optimising the involvement of distinct groups in the Participatory Design method across varied contexts [6, 12, 52, 66, 128, 136].

[1]https://www.atinnovationportal.com/innovation-research-database-1

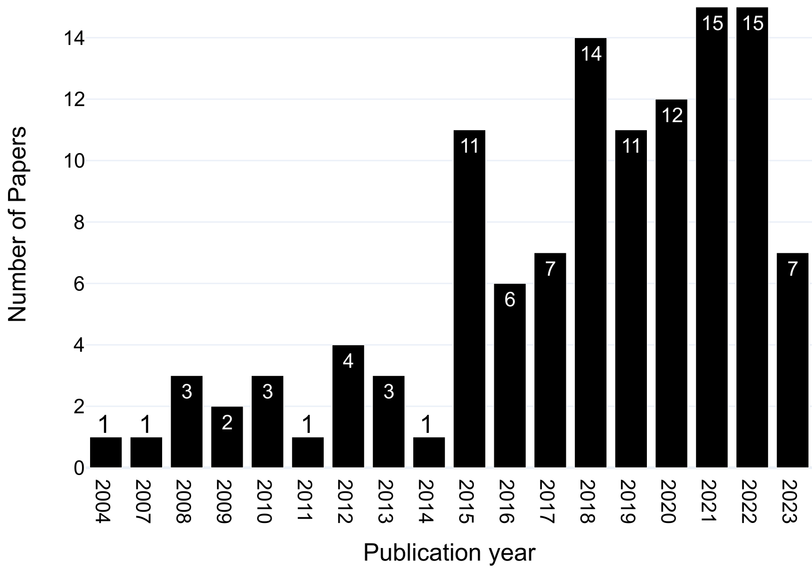

Figure 2: Publication Year and Frequency of Reviewed Studies

Publication venue	# of papers
CHI	42
ASSETS	21
PACM HCI	16
TACCESS	5
UIST	4
Other venue*	29
In total	117

*Less than 3 papers in the corpus per venue

Table 1: The distribution of the publication venues of papers in the corpus.

4.2 RQ1: How do individuals interact with each other in ability-diverse collaborations?

To achieve a thorough comprehension of Ability-diverse Collaboration, this review systematically examines multiple dimensions pertinent to this unique form of collaboration. These dimensions encompass the nature of the collaborator's disability, the type of collaboration undertaken, the roles assumed within the collaboration, the scale of the collaborative endeavour, and the context in which the collaborative activities occur.

4.2.1 Collaborator. Figure 3 illustrates a pronounced emphasis within ability-diverse collaboration research on visual accessibility. 47% (n=55/117) of the papers catered to the requirements of individuals with Blindness or Low Vision (BLV). 12.8% (n=15) focusing on individuals with motor or physical disabilities. Subsequent populations under study each garnered less than 10% of the research attention. Specifically, individuals with cognitive impairments constituted 9.4% (n=11) of the papers, those with autism and the deaf or hard of hearing community each represented 6.0% (n=7), while those with Intellectual and Developmental Disabilities (IDD) and the non-verbal community accounted for 3.4% (n=4) and 2.6% (n=3) respectively. Notably, 12.8% (n=15) of the papers either targeted multiple disability types or did not specify the type of disability in their scope.

4.2.2 The Ability-Diverse Collaboration Framework. To deconstruct 'collaboration' as a multifaceted collective endeavour, numerous studies have introduced diverse taxonomies or frameworks to gain deeper insights aligned with their specific research objectives. For instance, one of the simplest and most frequently cited taxonomies is Johansen et al.'s Four-Square Map of Groupware [65]. This taxonomy categorises collaborative interaction based on two primary dimensions: temporal differences (asynchronous versus synchronous) and spatial differences (local versus distributed). Also, Saavedra et al. [112] delved into the relationship between task and team form, resulting in a typology that identifies four collaboration types

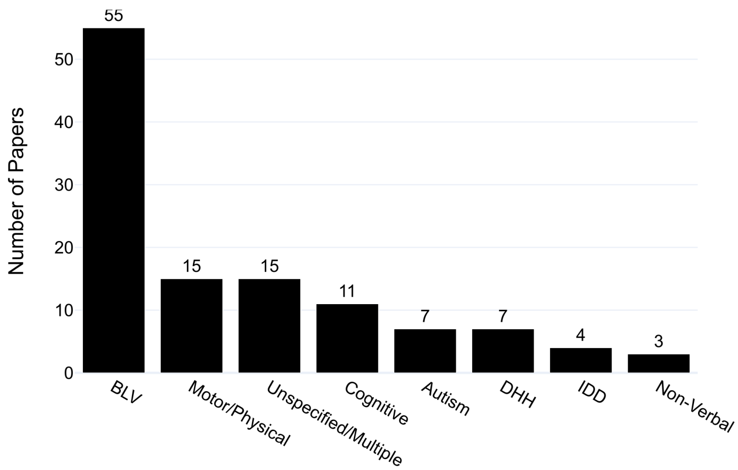

Figure 3: Distribution of disability type of collaborators

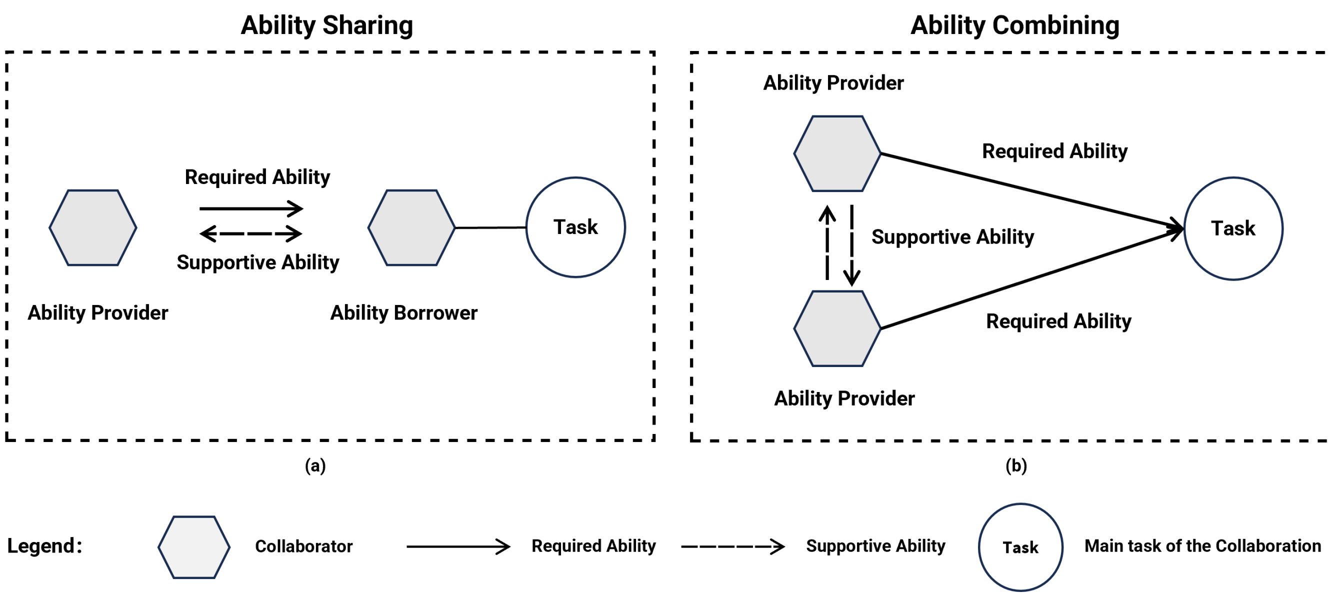

Figure 4: Two types of collaboration in The Ability-based Framework of Ability-diverse Collaboration (a) Ability Sharing, (b) Ability Combining

predicated on task interdependence: pooled, sequential, reciprocal, and team. Yet, these frameworks fail to encapsulate the interaction dynamics in ability-diverse collaboration. Previous literature [32] assumes that collaboration partners have the same access to information and are unified by a shared objective. Such assumptions, however, are not invariably accurate in ability-diverse collaborations. Two key reasons underpin this discrepancy:

(1) Collaborators may not always enjoy equal access to information, nor might they possess congruent knowledge concerning the content and process of collaboration [145].
(2) This inherent asymmetry in abilities and information access can engender distinct roles and potentially divergent goals in collaboration.

To encapsulate the asymmetric nature of ability-diverse collaboration, we introduced the Ability-Diverse Collaboration Framework (refer to Figure 4). This framework seeks to delineate the collaborative interaction space specific to ability-diverse settings. Anchored by the 'ability-centred' foundational principle of the Ability-based Design as proposed by Wobbrock et al. [140], our framework accentuates the dynamics of abilities, utilising them as a representative lens for the interactions that transpire throughout the collaborative process. Furthermore, drawing inspiration from Bennett et al.'s Interdependence Framework [15], we incorporated the principle highlighting the oft-neglected contributions of individuals with disabilities, offering a more nuanced depiction of collaborators' roles. The framework categorises the ability-diverse collaboration into two categories: **Ability Sharing** and **Ability Combining**.

Within the **Ability Sharing** scenario, as the goal of collaboration is not fully shared, collaborators are distinctly categorised into two roles: *Ability Provider* and *Ability Borrower*, based on the specific ability they contribute to the primary collaborative task. The *Ability Provider* offers the *Required Ability*, crucial for successfully completing the task closely intertwined with *the Ability Borrower*. Contrary to the conventional help-seeker and helper dynamic—where the help-seeker predominantly assumes a passive role to receive assistance—the *Ability Borrower* in our framework is an active and equal participant. They furnish the collaboration with *Supportive Ability* (e.g., facilitating communication to establish a shared understanding of the task) to support the *Required Ability* is aptly applied and directed towards task achievement. This model delves into the interdependence between collaborators and reveals the 'invisible work' they undertake, resonating with contemporary trends in ability-diverse collaboration research. To illustrate, Yuan et al.'s study [145], which explores the collaborative shopping scenario between individuals with Blindness or Low Vision (BLV) and their sighted partners, exemplifies this framework. In this context, the sighted partner assumes the role of the *Ability Provider*, leveraging their vision (*Required Ability*) to locate and retrieve the desired items. Conversely, the BLV, acting as the *Ability Borrower*, contributes to the *Supportive Ability* by precisely articulating their requirements and assessing the selected items.

In the **Ability Combining** scenario, all collaborators adopt the role of *Ability Provider*, as each contributes a *Required Ability* directed towards a shared objective. Concurrently, these Ability Providers might exchange *Supportive Abilities* to facilitate information sharing or coordinate their interactions more effectively. Bennett et al.'s study [15] provides an apt illustration of this category. In their case study, the collective objective is to get items from a vending machine. The collaboration involves two individuals: one with a vision impairment and another who uses a wheelchair. Here, the wheelchair user provides visual information (*Required Ability*) while the blind collaborator offers mobility assistance by pushing the wheelchair and reaching for items that are otherwise inaccessible (*Required Ability*). The successful completion of the task is a direct result of the synergistic combination of their distinct abilities.

In summary, out of the analysed studies, 86 (73.5%) were classified under the **Ability Combing** category, 29 (23.0%) fell under the **Ability Sharing** category, and 2 studies were identified as fitting into both categories.

4.2.3 Role in Collaboration. To recognise the core responsibilities of each collaborator, we examined which roles, as identified within the two categories, were assumed by individuals with disabilities compared to those taken on by non-disabled individuals (Figure 5).

Within the **Ability Sharing** category, a predominant 76% of the studies (n=22) centred on scenarios where non-disabled individuals assumed the role of the *Ability Provider*, with People with Disability (PwD) acting as *Ability Borrowers*, which includes mainly includes assistance-providing scenarios(e.g. [27, 69, 126]). In contrast, a smaller fraction, 17% (n=5), explored situations where PwD took on the *Ability Provider* role. Of these six studies, four examined ability sharing from PwD to non-disabled individuals. Notably, these studies mainly focus on the inclusion of PwD in service provision on crowd work platforms [55, 107, 131, 150], centring on ability sharing solely between PwD. A notable instance of this is the work by Holone et al. [58], which describes an application that empowers wheelchair users to share their travel experiences with other wheelchair users, thereby contributing to creating an accessible map.

In the **Ability Combining** category, the majority, 65% (n=56), focused on collaborations between non-disabled individuals and PwD, which includes a diverse array of scenarios such as collaborative workplaces [30], asymmetric gaming environments [48], and pair programming setups [101]. A smaller segment, 13% (n=11), investigated collaborations solely between PwD. A notable exemplar is CreaTable [94], which facilitates individuals with aphasia in collaboratively creating accessible content through the use of tangible interfaces. Lastly, 22% of the studies (n=19) are not limited to one of the categories above but discuss a study or application spanning both realms. For instance, Mack et al.'s research [79] delves into mixed abilities working experience. Similarly, iGYM [49] introduces an inclusive exergaming environment that not only enriches the play experience for non-disabled individuals playing against PwD but also caters to matches exclusively between PwD.

4.2.4 Scale of Collaboration. We further explored the scale of collaborative efforts within both the **Ability Sharing** and **Ability Combining** contexts (Figure 6). Upon reviewing this characteristic, we discerned that the scale of collaboration appears to be intrinsically linked to the nature of the relationship between collaborators. For the **Ability Sharing** category, we delineated the studies into three scales: 1:1, n:1, and 1:n. Meanwhile, for the **Ability Combining** category, the scales were identified as 1:1, group, and both.

Within the **Ability Sharing** category:

A significant portion, 48% (n=14), falls under the n:1 scale. All these studies adopt a crowd-sourcing model for collaboration. The relational dynamics here can be encapsulated as 'volunteer-recipient' in assistance-providing contexts ([18, 50, 54]) and as 'worker-customer' in crowd work platforms like Mechanical Turk ([55, 131]).

45% of the studies (n=13) centre on 1:1 collaborative interactions. Such interactions predominantly manifest as either 'helper-help seeker' or 'mentor-mentee' dynamics. It is notable that in these studies, the Ability Provider is frequently labelled as roles like 'teacher'[105], 'supervisor'[70], 'helper'[126], or 'carer'[16].

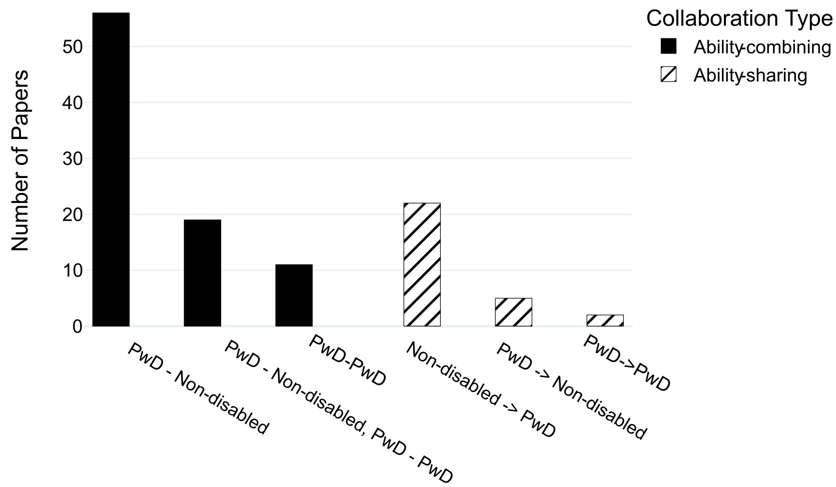

Figure 5: Role in both collaboration types, the arrow ('->') indicates the flow of ability, moving from the Ability Provider towards the Ability Borrower.

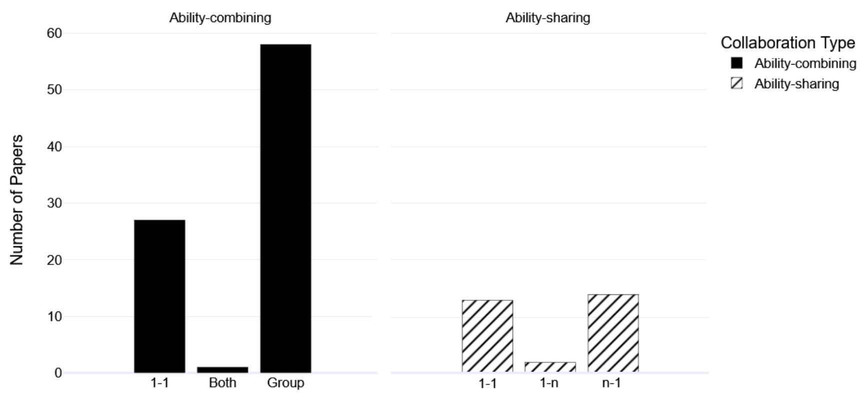

Figure 6: Scale in Ability Combining (left) and Ability Sharing (right)

A minority, 7% (n=2), aligns with the 1:n scale. Both studies detail scenarios on social media platforms where a collaborator contributes to a broader community ([59, 133]).

Within the **Ability Combining** category:

A majority, 67% (n=58), pertains to the group scale, where interactions involve multiple collaborators. This category predominantly captures collaborative endeavours characterised by relatively egalitarian relationships. Examples include collaborations among classmates, as illustrated in studies like [5, 33, 96, 149]; among colleagues, as showcased in [79, 123, 135]; and among family or friends, as depicted in [142, 143].

Conversely, 31% of the studies (n=27) fall under the 1:1 scale. Our analysis suggests that **Ability Combining** occurring within dyadic interactions tends to be more oriented towards professional or task-specific scenarios in contrast to the group setting. For instance, collaborations focusing on information-seeking are highlighted in [1, 2]. Other task-oriented scenarios include pair programming, as evidenced by [101, 106], and efforts to support workspace awareness, as discussed in [87].

4.2.5 Context of Collaborative Work. Our systematic review illuminated various contexts and scenarios in which collaborative efforts occur within ability-diverse settings. To gain a more comprehensive understanding of the current research interests in ability-diverse collaboration, we conducted an in-depth analysis and coding of the scenarios described in the papers we collected. This process yielded ten distinct contexts within which these collaborative endeavours have been explored: (1) **Learning**, (2) **Daily Life**, (3) **Productivity**, (4) **Creativity**, (5) **Work/Livelihood**, (6) **Research/Design**, (7) **Accessibility**, (8) **Crowd Work**, (9) **Social** and (10) **Rehabilitation** (The counts of papers within each category, along with examples, are detailed in Table 2.).

In our review of 117 papers, the predominant research area is the *Learning* context, represented in 25 papers (21.4%). These contributions span a broad spectrum of collective education endeavours from child development [22, 25, 85] to skill acquisition [44, 70, 71] and inclusive classrooms [33, 73, 148]. This is followed closely by *Daily Life* context, mentioned in 22 papers (18.8%), hinting at the pervasive nature of collaboration in everyday scenarios. such as outdoor activities [4, 13], gaming [48, 49, 125], and daily routine [27, 68, 143].

The *Work/Livelihood* context is also significant, covered in 18 papers, shedding light on experiences and challenges in both co-located [24, 30, 78, 138] and remote work settings [40, 79, 123], as well as the inclusion of individuals with disabilities in livelihood-related tasks. [10, 55, 150]. The *Productivity* context, represented in 17 papers, emphasises the importance of collaborative efforts in tasks like writing [36, 38, 39] and information seeking [1, 2]. While the *Creativity* context, in 13 papers, focuses on collective creative work including crafting [35, 37], music composing [63, 102], and art creation [9].

Co-design (or participatory design) method has been widely used for accessibility research and assistive technology development. This kind of collaborative work ensures that all stakeholders are actively and equitably engaged throughout the design process, resulting in outcomes that are well-received and effective [115]. In our review, 16 papers (13.7%) focus on *Research/Design* context emphasise strategies to enhance the participation of ability-diverse groups [52, 61, 66] in the co-design method, or how to implement co-design method across varied contexts [6, 13, 137].

Accessibility category includes 15 papers (12.0%) that discuss a range of collaborative activities to create access for disabled people, such as accessible information creation (digital [91, 92, 124], and physical [21, 23]), and general accessibility providing application [11, 42, 146].

With the rapid progression of technological innovations, crowdsourcing has emerged as a contemporary paradigm of collaborative work, finding extensive application in the domain of accessibility. A total of 15 articles have been grouped under the *Crowd work* theme. The spectrum of research focus within this category encompasses remote sighted assistance technologies such as VizWiz [18] and Aira [77], web accessibility [99, 121, 122], and navigation or route planning tools [11, 54, 58]. Notably, this category frequently intersects with other thematic contexts, including *Accessibility* (with 10 articles) and *Work/Livelihood* (4 articles).

Lesser attention is given to the *Social* and *Rehabilitation* contexts, with 7 and 3 papers respectively, focusing on collaborative activities in social networks [59, 82, 129, 133] and virtual societies [109], and enhancing rehabilitation processes [17, 29, 88].

4.3 RQ2: How does technology facilitate the interaction in Ability-diverse collaboration?

To address our second research question concerning the role of technology in facilitating interactions within ability-diverse collaborations, we conducted an in-depth analysis of 59 papers. These selected papers had each contributed to developing at least one prototype or application (termed 'artefact contribution') within their studies. Our review process involved coding the technologies based on three key dimensions: 1) temporal and physical characteristics, 2) role and function in collaboration, and 3) evaluation strategies.

4.3.1 Temporal and physical characteristics. To dissect the physical and temporal characteristics of the technologies employed in ability-diverse collaborations, we leveraged the Time-Space taxonomy for groupware, posited by Johansen et al. [65]. Our analytical findings are shown in Table 3. On the physical dimension, distributed systems (n=30, 51.6%) were observed nearly as frequently as co-located systems (n=29). Temporally, synchronous systems (n=46, 76.7%) dominated the landscape, more prevalent than asynchronous ones (n=14). Co-located synchronous systems emerged as the most prominent category, represented in 29 studies or 48.3% of the analysed corpus. Distributed synchronous systems constituted the next significant category in 17 studies or 28.3% of the total. Distributed asynchronous systems were represented in 14 studies, accounting for 23.3%. Lastly, co-located asynchronous systems were the least common, with a single study (1.7%) falling under this classification.

4.3.2 Roles and positions of technology in ability-diverse collaboration. Collaboration has been a growing point of interest in recent HCI research. For instance, Ellis et al. [43] delineate groupware into four distinct categories based on its core functionalities: *keeper* (responsible for storing and managing shared information), *coordinator* (orchestrating and synchronising collaborative activities), *communicator* (facilitating interactions and information exchange), and *team-agent* (proactive entities that anticipate team needs and automate tasks). Similarly, Benford et al. [14], in their exploration of children's collaborative endeavours, demarcate various technological approaches ranging from mere facilitation of collaboration to more proactive strategies that subtly encourage or even enforce collaborative behaviours.

To delve deeper into the roles and dynamics of technology within ability-diverse collaborations, we drew upon the *Ability-diverse Collaboration Framework*, which we developed earlier. From this synthesis, we identified four types of technology tailored to facilitate ability-diverse collaborations (Figure 7):

Ability Channel (Figure 7.a): Predominantly utilised in the **Ability Sharing** context, this category encompasses platforms or tools that act as conduits for abilities. These technologies facilitate the transfer of abilities from the "Ability Provider" to the "Ability Borrower", while also supporting the flow of "Supportive Ability" during collaboration. This kind of technology mainly supports these two abilities bi-directionally between the users. Noteworthy examples include remote sighted assistance technologies such as [50, 77], In these scenarios, the smartphone serves as a conduit for channelling the volunteer's visual capabilities to assist blind and low vision (BLV) users(required ability). It simultaneously facilitates two-way communication between the volunteer and BLV

Learning (25)	• Child Development: [22], [25], [85] • Skill Acquisition: [71], [70], [44] • Inclusive Classroom: [33], [148], [73]	**Accessibility (15)**	• Accessible Information Creation: [91], [124], [21] • Assistance Providing Application: [42], [11, 146]
Daliy Life (22)	• Outdoor Activities: [4], [13] • Gaming: [48], [49], [125] • Daily Routine: [143], [68], [27]	**Crowd Work (16)**	• Remote Sighted Assistance: [18], [77] • Web Accessibility: [122], [99] • Navigation/Route Planning: [54], [58]
Work/Livelihood (18)	• Workspace: [138], [79] • Office Tools: [87], [106] • Livelihood: [10], [55], [150]	**Creativity (13)**	• Crafting: [37], [35] • Music Composing: [102], [63] • Art Creation: [9]
Productivity (17)	• Writing: [36], [38] • Information Seeking: [1], [2] • Slide Authoring: [103]	**Social (7)**	• Daily Social Context: [16, 126] • Social Network: [133], [59], [82] • Virtual Societies: [109]
Research/Design (16)	• User Group: [66], [52] • Scenario: [137], [6]	**Rehabilitation (3)**	• Rehabilitation:[17], [29], [88]

Table 2: Ability-diverse collaboration contexts: Ten contexts categories(and sub categories) with examples use cases.

		Synchronous	Asynchronous
Physical context	Distributed	[77], [10], [146], [54], [75], [38], [48], [76], [129], [58], [106], [39], [4], [17], [92], [113], [18]	[122], [50], [82], [55], [27], [102], [99], [63], [5], [72], [11], [110], [121], [103]
	Co-located	[51], [52], [71], [53], [22], [127], [3], [98], [95], [87], [21], [25], [60], [67], [118], [125], [33], [111], [47], [37], [105], [7], [85], [116], [49], [88], [46], [148], [142], [44], [94]	[110]

Temporal context

Table 3: 2x2 matrix showing studies categorised according to the Time-Space Taxonomy of groupware [65].

users(supportive ability). This interaction is crucial for evaluating the visual task at hand. Occasionally, it may require BLV users to adjust their camera angle to ensure the successful completion of the task.

Ability Supporter (Figure 7.b): This category represents technologies that augment or amplify specific abilities, thus enhancing their contribution in a collaborative environment. Such technologies predominantly assist an *Ability Provider* during collaboration. Their essence closely mirrors traditional assistive technologies that enable individuals with disabilities to actively contribute to collaborative tasks. An illustrative example is Bornschein et al.'s initiative [21], which facilitated the collaborative design of digital tactile graphics. In their innovative prototype, individuals with blindness or low vision (BLV) were able to modify the tactile graphic, initially crafted by a sighted collaborator, using a pin-matrix device. It is noteworthy that such technologies can occasionally intertwine with the *Communication Supporter* category. For instance, the aforementioned prototype translates the graphics generated by the sighted collaborator, showcasing their combined efforts on the pin display.

Ability Combiner (Figure 7.c): Technologies in this category are designed to integrate diverse abilities, resulting in a synergistic collaborative output. Such tools or platforms seamlessly integrate the "Required Ability" from all collaborating "Ability Providers" to accomplish a task. A quintessential approach involves partitioning the main task and delegating specific sub-tasks to various "Ability Providers". In a recent study, Alasleem et al.[3] proposed a shared control system designed to facilitate skiing for individuals with tetraplegia. Within this system, the primary skier, seated in a power-assisted ski chair, assumes the role of steering and determining the chair's directional path. Concurrently, a tethered skier is tasked with ensuring that the chair's skis maintain the most suitable wedge configuration, considering factors such as the terrain, snow conditions, and the performance of the user. Similarly, Gonçalves et al.[48] introduced digital games wherein sighted players control characters that rely on visual capabilities, while players with visual impairments navigate characters necessitating auditory skills to accomplish in-game objectives. It is imperative to note that the *Ability Combiner* does not always manifest as a unified system, as previously discussed. In certain instances, it can function as multiple distributed systems. A case in point is the work by Barbareschi et al. [10], who detailed an inclusive café setting. In this innovative framework, workers with disabilities operated various robotic avatars to cater to customers, exemplifying the concept of distributed systems in enhancing collaborative efforts.

Communication Supporter (Figure 7.d): Dedicated to enhancing communication and awareness during the collaboration, these technologies are crafted to ensure that collaborators of all abilities can interact effectively. While their primary function is to augment "Supportive Ability" in collaborative endeavours, they may not inherently address the "Required Ability" crucial for the task at hand. These tools are instrumental in promoting awareness throughout collaborative processes. This is underscored by numerous studies,

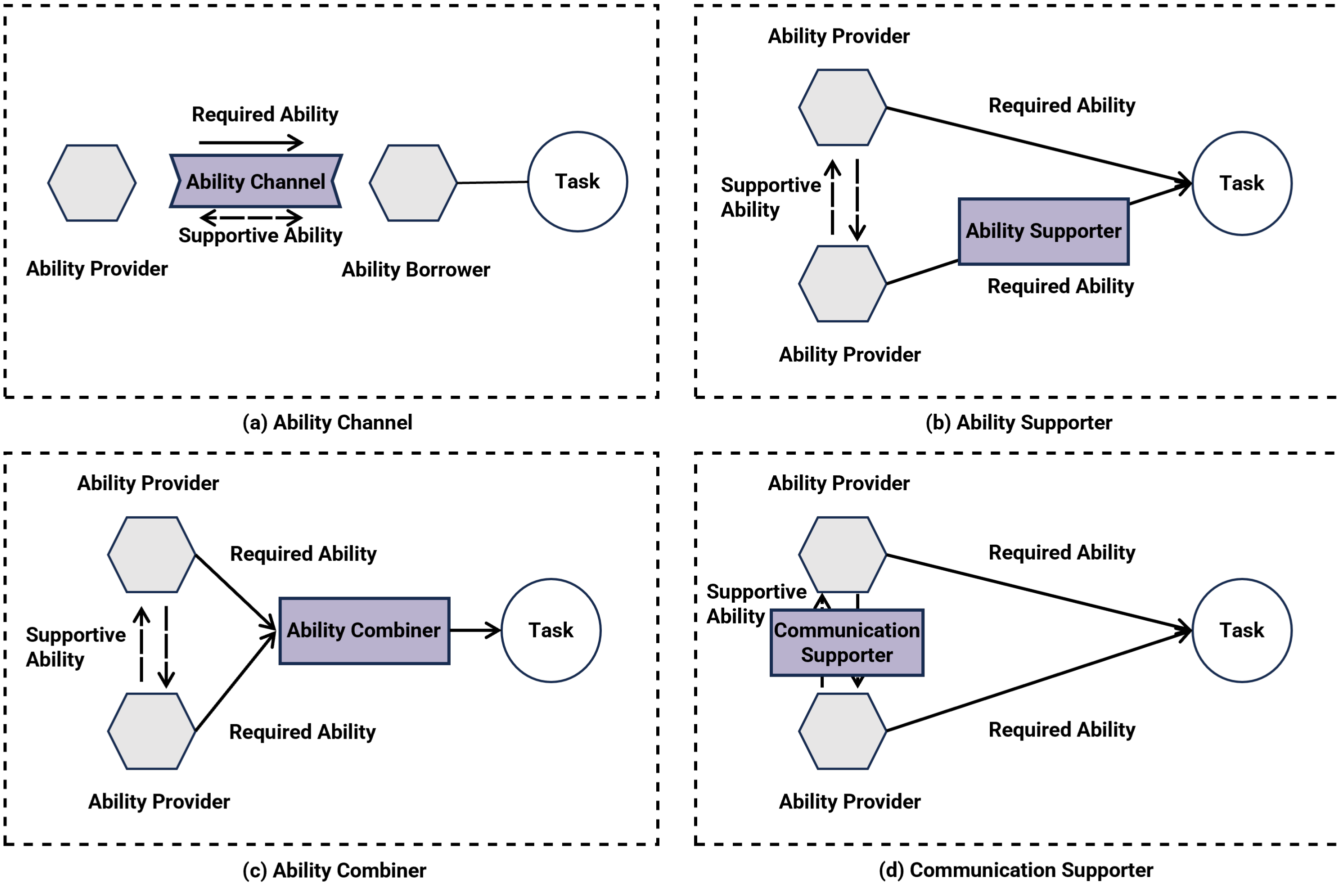

Figure 7: Roles and positions of technology (a) Ability Channel; (b) Ability Supporter; (c) Ability Combiner; (d) Communication Supporter

particularly those emphasising inclusive plugins for collaborative writing. These plugins enable individuals with visual impairments to be apprised of the actions taken by their collaborators, thereby streamlining the overall writing coordination [38, 76]. Another instance is the work of Potluri et al., who developed a plugin named 'Codewalk' [106]. This tool is designed to alleviate the coordination challenges faced by blind and visually impaired (BVI) developers. It achieves this by translating the navigation and editing actions of sighted colleagues into audio cues, utilizing both sound effects and speech for effective communication.

4.3.3 Evaluation Strategies. We undertook an in-depth analysis of the evaluation strategies adopted for technology in ability-diverse collaboration. The principal categories that emerged aligned with the classification proposed by Ledo et al. [74]: (1) evaluation via demonstration, (2) technical evaluations, and (3) user evaluations.

From the 59 papers we meticulously analysed, the results pertaining to evaluation strategies are detailed as follows:

User Evaluation: A majority (n=56, 93%) subjected their prototypes or technical solutions to user evaluations.

26 papers embarked on a qualitative thematic analysis of the collaboration process, which has been recorded through video or transcript, subsequently coding the results to assess the user experience. Notable examples include [21, 25, 71, 105, 111]. 20 papers gauged the usability of the technology through established usability metrics such as the System Usability Scale (SUS) or Likert-scale questionnaires. Pertinent references comprise [67, 75].

Technical Evaluation: 29 papers embarked on technical evaluations.

A predominant focus was on the task-oriented collaboration process, with evaluations centring on measures of task performance, such as latency, performance scores, and success rates. Exemplary papers in this regard are [3, 49, 50, 99].

Additionally, a few papers developed specialised indices to quantify collaboration success. For instance, Neate et al.[94] chronicled tangible interactions during collaboration to gauge the engagement of aphasic patients, while Wu et al. [142] employed the count of shared events as a collaboration metric between individuals with amnesia and their family members.

Evaluation through Demonstration: 10 papers leveraged demonstration-based evaluations.

This is typically manifested as proof-of-concept demonstrations of systems, as seen in [4], or through the workshops, exemplified by [38].

Lastly, two papers ([5, 129]) do not report any evaluation strategies or indicated intentions for future evaluation endeavours.

5 DISCUSSION

In this paper, we presented a comprehensive review of HCI research that emphasises collaboration in ability-diverse contexts. Our investigation led to the conceptualisation of the *Ability-Diverse Collaboration framework* (illustrated in Figure 4). Through this lens, we discerned the following dimensions characterising ability-diverse collaboration: (1) the collaborator's (dis)abilities, (2) the role of the collaborator, (3) the collaboration scale, and (4) the context in which the collaborative endeavour takes place. Furthermore, we classified technologies employed in ability-diverse collaborations into four distinct types (illustrated in Figure 7), and we have explained their physical-temporal characteristics and the methodologies employed in their evaluation. We now reflect critically on our synthesis, spotlighting potential avenues for further research and design within the space of ability-diverse collaborative research.

5.1 Reflections on the Ability-diverse Collaboration Framework

The Ability-Diverse Collaboration (ADC) framework is grounded in the principles of Ability-based Design [140], and the Interdependence Framework proposed by Bennett et al. [15]. Therefore, the ADC framework therefore wishes to acknowledge when abilities are used in the design process, and importantly, when these abilities are combined to develop something more than what would otherwise have been possible. Prior work [57] proposed AT as an extension of the mind and body as defined by Clark and Chalmers [31]. This work looked at the individual, however, when abilities are combined across people a collective extension of community is possible. We see a small number of papers in our corpus that highlight PwD-PwD sharing or collaboration. As this number grows, which we hope it will, we must be cognisant as designers and researchers of the tension between supporting ableist norms and simply asking more persons with disabilities to complete more 'invisible' work [24]. This invisible work has been called out by others as a form of epistemic violence [104]. It is not the case that technologies set out to exploit, instead the technologies being created within ability sharing for example can simply be designed to diffuse the work of overcoming accessibility gaps in the fabric of our digital world. However, this should not discourage us, as the ADC framework can also see people of diverse abilities being able to work more efficiently (and potentially more joyfully) together. Furthermore, the ADC framework can be used to understand better the ability-combining potential of the multitude of human abilities. To do this each element of the ADC framework must enable the flow of abilities and participation between collaborators of varying capacities. We, therefore, now turn to the elements within the framework to consider the design implications within each to aid future work.

5.1.1 *Ability Sharing.*

The "Ability Sharing" type of collaboration predominantly occurs in scenarios that revolve around providing assistance. In such collaborative contexts, the abilities of one individual can effectively compensate for the limitations of another. However, it is crucial to underscore that our framework refrains from portraying this complementary dynamic as a unidirectional interaction where the ability provider furnishes the necessary skills for task completion. Instead, our framework accentuates the interdependence between "required ability" and "supportive ability."

Foremost, by spotlighting the supportive ability given by the ability borrower, our approach underscores how foundational common ground of collaboration is formed [145]. This nuanced portrayal not only acknowledges the equal participatory role of the disabled collaborator but also elevates them from mere beneficiaries to active contributors within the collaborative landscape [15].

Furthermore, our framework prompts a heightened awareness of the nuanced means through which the 'required ability' is communicated. This is paramount for ensuring that assistance is aptly tailored, thereby sidestepping scenarios where the ability provider might inadvertently dominate or eclipse the contributions of the other, potentially relegating them to the periphery based on perceived inabilities [126].

Indeed, the focus on abilities presents an opportunity to reconceptualize and challenge prevailing norms wherein non-disabled individuals predominantly occupy the role of the 'ability provider'. This shift in perspective emphasises that when abilities are aptly matched, individuals with disabilities can also assume the mantle of 'ability providers', actively offering assistance or services based on their unique competencies. Such a technological interaction could overcome the challenges faced by disabled people daily in having to do additional work to simply overcome accessibility challenges, which can lead to epistemic violence towards disabled people [144]. However, such interactions will not necessarily make a disabled person feel integrated into society, instead, still feel on the outside, asking each time for permission or help to operate in the abled-bodied world. In this interaction paradigm, we can see examples of disabled people working together to overcome accessibility challenges. For instance, the advent of collaborative tools fostering real-time communication can facilitate a visually impaired individual using verbal inputs, while a hearing-impaired counterpart complements with visual inputs. Such scenarios exemplify a more inclusive and balanced collaborative model, wherein individuals are recognised and valued for their distinct abilities, rather than defined by their disabilities. This reframes the dynamics of collaboration but also champions a more inclusive and egalitarian approach to teamwork and mutual support.

In combining abilities the technologies developed are more aligned with the ideas contained in Ivan Illich's 'tools for conviviality', where convivial tools are explained as those that help people thrive, relate to each other and be resilient, rather than enslaving them to a system of constant consumption [62], or in the case of accessibility excessive work.

5.1.2 *Ability Combining.*

The "Ability Combining" model centres on the combination of abilities from several individuals, leading to the emergence of a novel or augmented ability that would be unattainable in isolation. Yet, it is imperative to approach this model with nuance. While it is tempting to laud the enhanced synergistic outcomes that such collaborations can yield, it is equally crucial to recognise and prioritise the participatory experiences of individuals with disabilities within these collaborative frameworks. In essence, both people are using their abilities and the technology has been designed in such a way as to be 'ability-based' for both disabled and non-disabled alike. By adopting an ability-centred lens, the emphasis shifts from merely the end product of collaboration to the process itself. This perspective values and celebrates the unique contributions of all individuals, irrespective of their abilities or disabilities. It underscores the principle that everyone brings distinct skills and perspectives to the collaborative table regardless of personal challenges.

Such an approach not only fosters inclusion but also has broader implications. By championing the idea of ability combining, organisations, workplaces, educational institutions, and other societal entities are incentives to actively cultivate and champion ability-diverse collaborations. This augments the richness and depth of collaborative outcomes and paves the way for a more inclusive, equitable, and holistic societal framework where every individual's abilities are recognised, valued, and leveraged.

The ADC framework underscores the significance of viewing collaboration through a multi-faceted lens. It goes beyond the immediate "required abilities" that collaborators bring to the table, drawing attention to the "supportive abilities" that facilitate seamless interaction and mutual understanding among participants. These supportive abilities play a pivotal role in ensuring the efficacy and success of collaborative ventures.

Taking the collaborative writing scenario as an example, even as tools like Microsoft Word or Google Docs are deemed accessible for blind and screen reader users, the intricate dynamics of collaborative awareness can be daunting [36]. Such complexities underscore the importance of supportive abilities. It is not just about ensuring that all participants can contribute to the task at hand, but also about ensuring they can coordinate, communicate, and comprehend the evolving collaborative process effectively.

By meticulously examining and fostering these abilities, which orchestrate work practices and engender a shared awareness, we can distribute the collaborative load more equitably. This approach minimises potential disparities, ensuring that no collaborator bears an undue burden or faces challenges that could be mitigated through a more balanced distribution of roles and responsibilities. Additionally, by creating technologies that support equitable diverse-ability collaborations, we can empower individuals to showcase the strengths of their abilities rather than being hindered by poorly designed technologies and collaborative interactions.

5.1.3 *Challenge and opportunity.*

Certainly, the ADC framework introduces transformative opportunities and intricate challenges to the HCI domain. An ability-focused approach necessitates a deep understanding of each collaborator's capabilities, placing a significant onus on individual collaborators and task organisers. While the Ability-Based Design framework [140] has been influential, the challenge persists in how to coherently perceive and model users within a design process. The conceptual user modelling approach by Nolte et al. [97], which contemplates the relationships between tasks, contexts, and abilities, offers a promising direction and could be seamlessly integrated into the ability-based framework. However, abilities and, consequently, disabilities are not static but are continuously negotiated through interactions among collaborators [126], especially in ability-diverse settings. This dynamic nature underscores the need for the HCI community to remain adaptive, ensuring the framework's continuous relevance and efficacy in an evolving collaborative environment.

5.2 Reflection on the context of ability-diverse collaboration

Over the past two decades, the research focus on ability-diverse collaboration has evolved. To glean insights into these shifts, we plotted the distribution of contexts, as categorised in a previous chapter, on a timeline spanning from 2003 to 2023, as illustrated in Figure 8.

Throughout this period, contexts such as 'Accessibility' and 'Crowd Work' have exhibited enduring activity, signalling their sustained relevance. This suggests that the commitment to ensure universal access to information, technology, and opportunities remains a cornerstone of HCI and accessibility research. On the other hand, contexts like 'Creation', 'Research/Design', 'Daily Life' and 'Working/Livelihood' seem to have garnered increased attention in the latter part of this timeline. This surge reflects a shift in the research paradigm: while the initial emphasis was largely on facilitating access as an outcome of collaboration, there is now a burgeoning interest in integrating individuals with diverse abilities into daily life activities, research and design processes, creative endeavours, and employment. This shift has been linked with the proliferation of smartphones and ubiquitous computing, thus moving technology use out of 'work' into daily living. Consequently, much HCI research in this period focused on learning, creativity, entertainment, and productivity [19].

A notable observation from our analysis pertains to the 'Working/Livelihood' context, in which 2021 exhibited a pronounced spike (evident as the dark blue block in Figure 8). We postulate that the pandemic that engulfed the globe in 2020 may have catalysed this surge, as it dramatically reshaped collaborative dynamics and work modalities [80, 130]). This hypothesis finds further credence in the noticeable increase in the 'Productivity' context in 2022. While direct evidence is scant, we contend that this uptick is likely attributable to the proliferation of online collaborative platforms in the post-pandemic world [38, 39, 75, 76], underscoring the rapidly evolving nature of human-human and human-computer interactions in response to global events.

5.2.1 *Collaborator as a stakeholder.*

Certain contexts within ability-diverse collaboration present intriguing dynamics wherein individuals with disabilities actively contribute to the process and derive tangible benefits from the collaborative outcomes. The 'Accessibility' context offers a compelling illustration of this. Several studies depict scenarios where individuals with disabilities assume the role of accessibility evaluators, actively involved in creating accessible content. Examples include tactile graphics [21], captions [72], sign language content [124], and ALT tags [91]. By actively engaging the target users—those who will ultimately benefit from the accessibility features—during the development phase, there emerges an enhanced potential to refine and optimise accessible content creation through ability-diverse collaboration.

In recent years, a discernible trend has emerged wherein individuals with disabilities are progressively incorporated into various research and design processes. Their firsthand experiences and insights are invaluable, enabling researchers and designers to gain

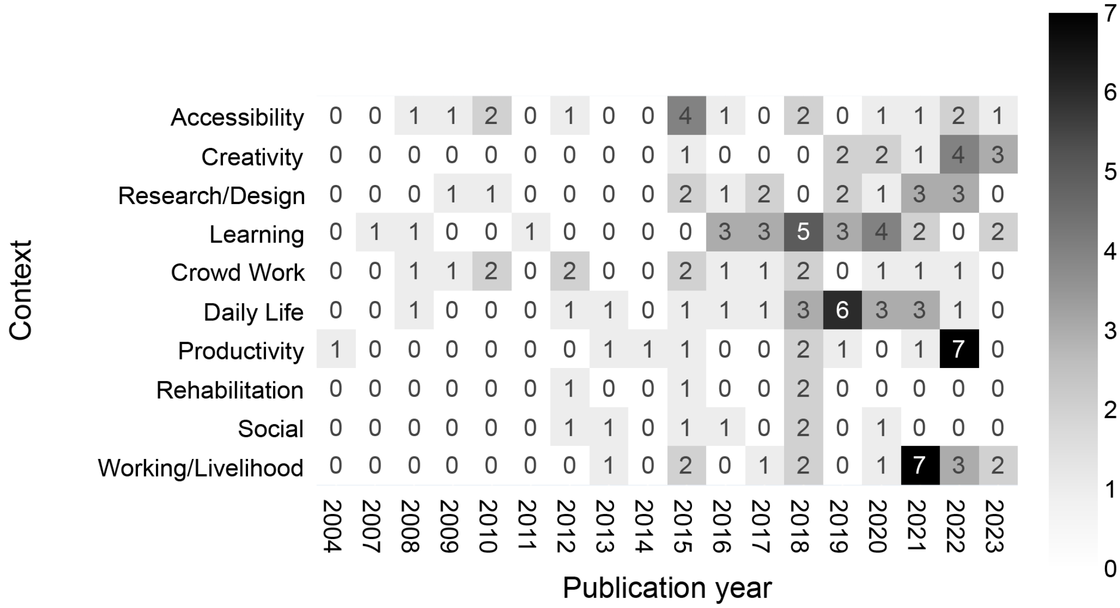

Figure 8: Heatmap of context distribution in the past twenty years

a richer understanding of their needs and perspectives. This, in turn, can catalyse innovative ideation and refinement of products or research initiatives. While co-design (or participatory design) methodologies have long been extolled for their inclusive approach to research and design, the infusion of ability-diverse collaboration promises to further revolutionise the fields of accessibility research and assistive technology development. The active involvement of individuals with disabilities in these processes not only enriches the outcomes but also heralds a more inclusive and empathetic design ethos.

5.3 Reflection on technology in ability-diverse collaboration

In this section, we discuss our analysis of technologies employed in ability-diverse collaborations, present design implications and share insights into potential evaluation methodologies.

5.3.1 Temporal and physical characteristics of the collaboration. In the 'Ability Sharing' scenario, synchronous collaboration is favoured in contexts where assistance or service is provided. This makes sense, as people encounter an accessibility gap or challenge, they need immediate help. Within the workplace Lee et al. [77], have demonstrated that this type of ability-sharing can extend the capabilities of a visually impaired person helping to explain context such as social context to a co-worker for example. However, Ability Sharing is also often possible through asynchronous collaboration, this is particularly the case in distributed contexts using for example *VizLens* [50] which uses many possible people online to label an inaccessible interface for visually impaired users. People can flexibly contribute to overcoming the accessibility gaps fostering a more flexible and accommodating collaborative rhythm. In contrast, Ability Combining nearly exclusively has a focus on synchronous collaboration. This is logical given both (or all) parties are providing their capabilities towards a shared goal, where intricate choreography is often required to combine diverse abilities, with real-time coordination and feedback necessary. Notably, our data points to a significant proportion of these synchronous collaborations being co-located, underscoring the potential benefits of physical proximity in enhancing the collaborative experience through enriched interactions and instantaneous feedback.

Across both collaboration categories, there is a discernible trend towards distributed collaboration, mirroring the broader global shift towards remote work and collaboration, which has followed the COIVD-19 pandemic [117] and technological advancements of remote working platforms.. The representation of this trend within ability-diverse collaboration is heartening, suggesting that technological innovations are facilitating inclusivity, even in geographically dispersed settings. However, the limited presence or absence of certain collaborative configurations, such as asynchronous co-located collaborations, signals untapped avenues warranting further exploration. Investigating nuanced collaborative scenarios, such as how individuals with varied abilities collaborate on an assembly line in a factory, could yield intriguing insights and further enrich our understanding of ability-diverse collaborative dynamics.

5.3.2 Implications for technology design in ability-diverse collaborations(Table 4). **Ability Channel:** In conceptualising technology as a conduit between the "Ability Provider" and "Ability Borrower", we underscore the need for **accurate and effective transmission** of the required ability. The motivations, goals and user experiences will be different for the ability provider and borrower). The former wishes to help, or is hired to help support requests from the latter. The **choice of medium** is key in this design. As an illustration, 'conversational prosthetic' [77] predominantly harnesses the interpretation of visual cues into verbal insights. Translation between media, ensuring each medium aligns with the comfort and preferences of both collaborators is important. **Adaptability and flexibility** in the medium's design are non-negotiable for fostering holistic ability-diverse collaboration. For instance, in the example of remote assistance for blind people, leveraging transcription technology can bridge the communication gap between a blind user and a deaf or hard of hearing, nonverbal volunteer assistant. Here, vocal requests from the blind user can be transcribed and responded to in text by the helper. This text can then be vocalised using text-to-speech (TTS) technology, ensuring comprehension. Such adaptive designs not only refine collaboration but also support the inclusion of people with diverse abilities as stakeholders and contributors.

Ability Supporter: The "Ability Supporter" paradigm mandates that technology acts as a catalyst, amplifying and augmenting individual abilities to foster effective collaboration. A fundamental design consideration for such technology is **personalising**. Recognising abilities are intricate and distinct, the technology should offer avenues for customisation, ensuring it resonates with the unique strengths and requirements of each collaborator. Simultaneously, in an interconnected collaborative landscape, the capability for **integration with other tools** is essential. The technology should be designed to seamlessly dovetail with a myriad of collaborative platforms, ensuring enhanced abilities are harnessed optimally which in turn will require the inclusion of **training modules**. These modules should educate collaborators, empowering them to navigate and exploit the technology to its potential. Finally, given the augmentation-centric nature of these technologies, **feedback mechanisms** become indispensable. These mechanisms should be intuitive, allowing collaborators to effortlessly share their experiences, insights, and suggestions. Such feedback loops not only refine the technology but also ensure it remains alert to the evolving needs of its users, fostering a truly inclusive and empowered collaborative environment.

Ability Combiner: When considering the "Ability Combiner" paradigm, the technology should act as a combiner of varied skills, knitting them together to produce outcomes greater than the sum of individual contributions. A key design implication here is **modularity**. Technologies should be designed to dissect tasks into manageable sub-tasks, effectively channelling them to the apt "Ability Providers". Coupled with this is the need for robust **integration mechanisms** that fuse these diverse abilities harmoniously, ensuring the final collaborative product is not just a patchwork but a cohesive and synergistic blend. As the collaborative landscape is dynamic, the technology should be underpinned by **dynamic task allocation**. This implies the presence of intelligent algorithms or protocols that can, in real time, assign tasks contingent on the availability and ability of collaborators. Such a system ensures optimal utilisation of available skills. Finally, the user interface plays a pivotal role. A **collaborative UI** should be the hallmark of such technology, one that transparently showcases the contributions of all participants, which could work from goal setting through to goal completion, which bolsters transparency and encourages a sense of shared ownership and accomplishment vital for the continued success of ability-diverse collaborations.

Communication Supporter: Within the realm of the "Communication Supporter", the technology should act as an enabler, ensuring seamless and inclusive communication among collaborators with diverse abilities. Foremost in its design implications is the necessity for **multi-modal communication**. The technology must be versatile, catering to a spectrum of communication channels— text, voice, video, or tactile. Such a design ensures that irrespective of individual abilities, all collaborators find a mode that resonates with their abilities. Closely aligned with this is the introduction of **awareness indicators** embedded in the technology to offer real-time insights into the actions and contributions of peers, thus fostering a collaborative environment. Furthermore, recognising the varied preferences and abilities of collaborators, the technology should offer **customizable alerts**. Collaborators should have the autonomy to tailor notifications in a manner that aligns with their preferences. Lastly, in a world that is increasingly global and diverse, **translation and interpretation** tools are indispensable. Embedding these tools ensures that language or mode of communication isn't a barrier, but a bridge, allowing all collaborators to comprehend and contribute effectively thus ensuring the "Communication Supporter" facilitates interaction and celebrates the diversity of its collaborators.

5.3.3 Evaluation. The preponderance of studies emphasising user-based evaluations accentuates the pivotal role of the human dimension in ability-diverse collaboration technologies. While quantitative usability metrics remain a staple, many studies lean towards qualitative methodologies to unravel the dynamics and complexities of collaborative interactions. A meticulous analysis of collaboration processes—be it through transcripts, video footage, or direct observations—indicates a shift in evaluative focus. It is not just about the technology in isolation but the nuanced human interactions it catalyses.

Beyond task-oriented collaboration, some technologies aim to bolster engagement or catalyse participation, especially among collaborators with special needs. Evaluating these nuanced objectives often demands the crafting of bespoke indices. The emergence of such tailored metrics underscores a salient point: generic evaluative tools may occasionally fall short in capturing the rich tapestry of ability-diverse collaborations. While custom metrics can provide granular insights into collaboration intricacies, their design mandates a judicious approach to ensure they encapsulate the salient facets of collaborative dynamics.

Technology Category	Design Implications
Ability Channel	- Accurate and effective transmission needed. - Flexible and adaptable choice of medium required.
Ability Supporter	- Personalization to one's requirements and strengths is essential. - Provide the capability of integration into other tools. - Include training modules and feedback mechanisms
Ability Combiner	- modularization of key functionalities is crucial. - design for robust integration mechanisms - Allow dynamic task allocation. - Build a collaborative UI.
Commmunication Supporter	- Facilitate multi-modal communication - Offer real-time information with awareness indicators. - Alerts should be customizable.

Table 4: Overview of design implications mapped to technology category.

Lastly, the unique challenges posed by collaborators who might grapple with communication or self-expression cannot be overlooked [60]. In scenarios where direct feedback might be elusive, researchers and developers are often compelled to seek insights from caregivers or family members. While this offers a workaround, it is a clarion call for the research community to delve deeper. Innovative evaluative methodologies tailored to these contexts are not just desirable—they are imperative.

6 CONCLUSION

This systematic review offers insights into the interactions inherent in ability-diverse collaborations, offering a deep dive into the growing literature. We focus on the interactions which occur between people when collaborating. Through an analysis of 117 articles, we divided the works into those which shared abilities towards a goal owned only by one party with a disability and those which combined abilities towards a shared goal. Together these types of collaborations are presented within the proposed Ability-Diverse Collaboration (ADC) framework. This framework explores the interaction spaces that emerge in ability-diverse settings, offering an analysis which contains four distinct technological categories that underpin ability-diverse collaborations. We present design considerations for each with the aim that the categorisation and analysis combined will act as a tool for future researchers to create more ability-diverse collaborations as we create technologies which integrate abilities, and when needed possibly combine these to create not only more accessible technologies but more integrated experiences. We invite everyone, from newcomers to experts in ability-diverse collaboration, to contribute to our open dataset.

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