Diversity for Design: A Framework for Involving Neurodiverse Children in the Technology Design Process

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ABSTRACT

The neurodiversity movement seeks to positively reframe certain neurological conditions, such as autism spectrum disorders (ASD) and dyslexia, by concentrating on their strengths. In recent years, neurodiverse children have increasingly been involved in the technology design process, but the design approaches adopted have focused mostly on overcoming difficulties of working with these children, leaving their strengths untapped. We present a new participatory design (PD) framework, Diversity for Design (D4D), which provides guidance for technology designers working with neurodiverse children in establishing PD methods that capitalize on children's strengths and also support potential difficulties. We present two case studies of use of the D4D framework, involving children with ASD and dyslexia, showing how it informed the development and refinement of PD methods tailored to these populations. In addition, we show how to apply the D4D framework to other neurodiverse populations.

Author Keywords

Participatory design; children; neurodiversity; autism; dyslexia.

ACM Classification Keywords

H.5.2. User Interfaces: User-centered design.

INTRODUCTION

The term 'neurodiversity' refers to a subset of neurological conditions, which typically result in a child being labeled as having special educational needs (SEN). These conditions include (among others) attention deficit hyperactivity disorder (ADHD), autism spectrum disorders (ASD), dyslexia, anxiety disorders and intellectual disabilities [4]. Neurodiversity seeks to reframe how these conditions are viewed by arguing that they constitute alternative cognitive processing styles occurring across a wide spectrum. This perspective offers a new way of thinking about the involvement of these children in design by recognizing that these conditions have associated *strengths* alongside the *deficits* that often define them. Indeed, as Armstrong [4] points out, the view of these different cognitive styles as disabilities is dependent on the social and cultural context of the individual; for instance in a pre-literate society dyslexia would not be seen as a disability at all.

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The benefits technology can bring to children with SEN are now widely acknowledged within the child-computer interaction research community. More researchers are now seeking to involve them within the technology design process through approaches such as participatory design (PD), where users are actively involved throughout the design process [12,14]. However, there is a tendency for this work to focus predominantly on how to overcome the *difficulties* of working with these children e.g. [1,14,23].

The importance of revisiting how disability is viewed in HCI has recently been discussed. Armagno [3] has argued in favor of applying a social model of disability, which shifts the focus from the functional limitations of individuals to problems resulting from limits of environments, barriers and cultures. He highlights the need for methodologies that adopt this alternative model such that the solutions developed by designers, responsible for creating and developing interactive digital products, are not also subject to the same limitations [3]. In employing the neurodiversity perspective, Dalton [9] has called for the specific development of "neurodiverse design protocols and methods – for example, for participatory design".

While the moral proposition of neurodiversity raises questions for designers, the development of design methods that balance children's strengths or weaknesses requires time and careful consideration. Technology projects often have tight schedules, and designers are rarely experts in the subject matters they pursue. In following Armagno and Dalton's suggestions, if design methods are informed by incorrect assumptions and preconceptions of the neurodiverse community, resulting technologies may serve to further marginalize these groups.

In this paper, we provide designers with a framework that guides them in adapting PD to account for neurodiversity. The framework facilitates the development of PD methods, which direct designers' attention to children's strengths, while supporting their difficulties. We

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demonstrate how the framework can be used in practice through two cases studies, the first involving children with ASD and the second involving children with dyslexia. These examples illustrate the flexibility of the framework in accommodating designers' resources and preferences, and demonstrate how the resulting methods evolve on the basis of theory and practice. Our framework serves as a unifying resource that can guide the development and documentation of new PD methods for neurodiverse children. In guiding designers to record and justify their methodological decisions, our framework can contribute towards capturing designers' tacit knowledge, facilitating a deeper understanding of designerly practices. Finally, we propose that the implications of our framework can go well beyond the neurodiverse population to empower individuals from the wider population by reinforcing their strengths.

BENEFITS OF NEURODIVERSITY TO PD

There are a significant number of children labeled as "gifted and talented" who have also been diagnosed with a neurological condition such as ADHD, ASD, or dyslexia [24]. Armstrong [4] has identified characteristic strengths associated with different neurodiverse conditions. These strengths are presented in Table 1 alongside some of the difficulties that typically define the conditions, although we note that these characteristic strengths/difficulties are not necessarily observed in *all* individuals diagnosed with these conditions. Furthermore many associated characteristics can be viewed as either a strength or as a difficulty depending on the situation or the lens through which it is viewed.

Alper et al. [2] highlight that gifted children with diverse needs are "at risk of growing frustrated or bored with existing interactive technologies because their needs…are not well understood or identified". This emphasizes the importance of involving them directly in the technology design process rather than using proxies, such as parents, carers or teachers, to make design decisions on their behalf.

Creativity is a strength commonly associated with all of these conditions. Creativity is a much-debated concept and while there are many definitions of the term, most refer to the generation of ideas that are both novel and appropriate [29]. Creativity is viewed as a key skill within PD, with Warr and O'Neill [29] proposing "the more creative we are in design, the greater the probability of designing useful and usable software applications and software". The creative strengths of neurodiverse individuals along with other talents such as, for example, the spontaneity and risk-taking of individuals with ADHD, or the strong visual-spatial skills and innovative thinking of individuals with dyslexia, could result in extremely valuable, and potentially unique, contributions to the design of new technology.

While adapting PD to support the involvement of children has been relatively common for over a decade [15], recently some researchers have begun recognizing the strengths of neurodiverse children. After involving children with high-functioning autism (HFA) in the design of a technology-enhanced learning environment, Frauenberger et al. [12] stated that they "have a tendency to become very good at what they like, whatever skill that might be" and emphasized the importance of their input within the end product. Gibson et al. [13] also highlighted the positives of working with 'difficult' children in mainstream classes, which can frequently include those with ADHD, stating that "the benefits far outweigh the problems". These benefits included strengthening the enjoyment of the group, quickly understanding the need for a "different and fun" product, and being more innovative and less inhibited in their ideas.

Despite this movement, within the HCI community there

Associated Characteristics (✓ = a strength and **x** = a difficulty)	**ADHD**	**ASD**	**Dyslexia**	**Anxiety disorders**	**Intellectual disabilities**
Spontaneous and high energy/Restless	✓ **x**				
Divergent or innovative thinkers	✓		✓		
Creative (in specific areas)	✓	✓	✓	✓	✓
Risk-takers/Impulsive	✓ **x**				
Attention to details or high precision	✓			✓	
High focus (related to interests)/Distractible	✓ **x**	✓ **x**	✓ **x**		
Strong systemizers/Obsessive routines		✓ **x**			
Prodigious memory/Poor memory		✓	**x**		
Visual-spatial skills		✓	✓ **x**		**x**
Exceptional talents in very specific areas		✓			✓
Ability to see "big picture"			✓		
Social skills		**x**			✓
Reading, writing and/or spelling abilities			**x**		
Cognitive abilities					**x**
Communication skills		**x**	**x**		✓
Intense phobias				**x**	

Table 1. Characteristic strengths and difficulties associated with neurodiverse conditions [4]

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remains a tendency to focus on the barriers that need to be overcome to enable the participation of neurodiverse children e.g. [1,11,23]. Guha et al. [14], for example, have developed a model for involving children with special needs more generally within the technology design process. The authors propose three layers to their model including (1) level of children's involvement; (2) nature/severity of disability; (3) availability/intensity of support. This model has combined best practice from special education teaching with technology development [19], but as Fohlin [10] points out, the second layer of this model can be viewed as "an obstacle that needs to be overcome" in the third layer. Exemplifying researchers' focus on the limiting factors of neurodiversity, Dalton [8] conducted a meta-review of papers in the ACM digital library (1999-2013) referencing dyslexia or autism and found "no paper made any positive mention of any aspect of either of these conditions".

In reflecting on the challenges of PD more generally, Sanders et al. [27] observe that it can be "difficult for many people to believe they are creative and behave accordingly". PD methods must thus support a design environment in which individuals feel comfortable and confident generating and sharing creative ideas alongside designers. Crafting design environments that provide the best possible opportunities for children to realize their potential and make meaningful design contributions becomes even more critical in the context of neurodiversity. Armstrong [4] discusses the importance of *niche construction* in the education of neurodiverse children. This concerns adapting the environment to match the particular needs of an individual, to maximize strengths and minimize weaknesses. In this spirit, Kärnä et al. [19] propose a framework for involving children with special needs in technology design and development, called Children in the Centre (CiC). CiC has five levels, with the central component focusing on the children's interests, strengths and needs, which can facilitate the emergence of the children's potential and hidden skills. CiC therefore acknowledges children's limitations, whilst not restricting participation to being exclusively limitation-centric. Though Kärnä et al. describe rich examples of applying CiC to a technology design project, they do not present a practical framework that can guide future work. In summary, recognizing the importance of neurodiversity in HCI highlights a need for a flexible framework that can guide technology designers in the development of PD methods that support the specific capabilities of children from different neurodiverse populations. One way to achieve this is through the application of niche construction. The following section introduces the TEACCH program, which is based on this philosophy, and forms the foundation of our PD approach.

D4D: A FRAMEWORK FOR NEURODIVERSITY IN PD

TEACCH (Treatment and Education of Autistic and related Communication handicapped CHildren) is an evidence-based program that has been used internationally in the education of individuals with autism for over 30 years. Mesibov et al. [22] explain that the aim of TEACCH is not "being normal", but rather for individuals with autism to function as comfortably and effectively as possible within society. The primary link between TEACCH and the neurodiverse movement is the focus on the fundamental strengths of the condition. Although Mesibov et al. [22] do acknowledge "all programs should work on both strengths and deficits to some extent", they emphasize that the priorities of TEACCH are on strengths. The TEACCH program incorporates a *Structured Teaching* intervention approach. Structured Teaching is "an array of teaching or treatment principles and strategies" based on the understanding of and respect for the 'Culture of Autism', that can be applied to each person's particular situation [24,32]. These principles include the following:

(1) ***Understanding Culture***: TEACCH recognizes and responds to autism as a culture i.e. the "characteristic and predictable patterns of thinking and behavior" observed in the condition [22]. Examples of these characteristics include strengths related to, and preferences for, *visual processing* and following *routines* [28].
(2) ***Tailoring to the Individual***: TEACCH is premised on the philosophy that its application should be flexible and individualized, enabling its' concepts and methods to be relevant for a wide range of "developmental levels and behavioral profiles" [22]. Whereas the first principle targets typical ASD characteristics, here the focus is on characteristics specific to the individual, including "skills levels, talents, special interests, personality, feelings, quirks and potential" [22]. An example would be to theme a particular activity for a child with an interest in World War I with prominent WWI figures or battles.
(3) ***Structuring the Environment:*** TEACCH incorporates "situational modifications" to help mitigate potential difficulties by matching the environment to an individual's "abilities and ways of understanding and learning" [22]. One example of this is to set a predictable sequence of activities to make the environment more comprehensible and prevent anxieties related to uncertainty or surprises.
(4) ***Providing Supports***: TEACCH provides supports to make the specific activities more understandable to the individual [28]. Examples of supports include providing visual representations or physical demonstrations of task instructions to reinforce verbal explanations.

In abstracting the key TEACCH principles, it becomes apparent that the program's philosophy can be generalized to a wider neurodiverse population. Moreover, as Mesibov et al. [22] highlight, characteristics of ASD can also exist in conditions such as ADHD and OCD, as well as in typically developing children, for instance the attention to detail in ASD and OCD. This suggests that structuring the environment or incorporating supports that capitalize on typical ASD strengths could benefit children with other neurodiverse conditions associated with similar strengths (or difficulties). In using TEACCH to inform a framework

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for PD methods that broadly support the participation of neurodiverse populations, we must therefore consider how these four key principles can apply to PD.

A typical PD session centers on a design activity and collaboration between participants. The potential for collaboration and creativity is influenced by how the design activity has been crafted. Therefore, the construction of the design environment, and how strengths are promoted and weaknesses are accommodated (*structuring the environment* and *providing supports*) should be informed by the typical characteristics of the neurodiverse culture as well as by each participating child's own talents and strengths (*understanding culture* and *tailoring to the individual)*. Fig. 1 presents our proposed PD framework for neurodiversity, which we call *Diversity for Design (D4D)*.

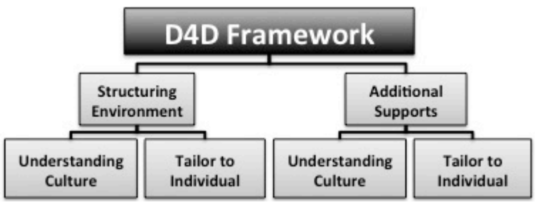

Figure 1: Diversity for Design (D4D) framework

We intentionally employ the term *framework*, as opposed to method or tool, as the term reflects the necessary flexibility D4D provides designers in developing methods appropriate to their specific context and constraints, whereas *method* implies more rigidity and precise replication. In considering designers' agency and need for flexibility in conducting design research, the D4D framework *guides them* in tailoring their PD methods to enable the participation of neurodiverse populations. To demonstrate how our D4D framework for neurodiversity can be employed in practice, we present two case studies, one using PD to inform math software for children with ASD, and the second employing PD during the development of software to assist children with dyslexia with their reading difficulties.

CASE STUDY 1: DEVELOPING PD METHODS FOR CHILDREN WITH ASD

The first case study describes a project that aimed to involve children with HFA and Asperger's Syndrome (AS) in the development of an intelligent tutoring system for helping children with ASD at Key Stage 3 (aged 11-14) to learn math. The lead designer in the project had two years to work with children on designing certain aspects of the system. This timeframe enabled taking an iterative stepwise approach to the process of developing a PD method for children with ASD. Here we describe those steps.

Theoretically-informed PD

Our first step involved reviewing existing literature in order to identify the typical strengths (e.g. visual-spatial skills) and preferences (e.g. preference for structure and routines), as well as potential difficulties (e.g. distractibility) of children with ASD, particularly those relevant in a PD context. The TEACCH characteristics of the Culture of Autism [22] played an important role here, as did other key literature within the field of autism, e.g. [5,16].

We then undertook a critical review of existing PD methods and techniques for children, e.g. [14,15,20], to provide inspiration for features that could be incorporated into a PD method for children with ASD. We selected PD features that we believed would either capitalize on the strengths or support the difficulties associated with ASD, both in terms of structuring the design environment or providing appropriate supports within the design activities. Next, we determined which of the features could be applied to benefit the wider ASD population, and which could be tailored to the individual child participants. The PD method established through this process is as follows (PD features responsive to ASD characteristics are presented in small caps, with the number of the corresponding feature from the D4D framework summarized in Fig. 2 in brackets):

In preparing the sessions, it was important to identify children's HOBBIES AND INTERESTS (8) through e.g. surveys or discussions with their guardian, with the aim to integrate them into PD – either within the overall design task, specific activities, or as a form of reward for participating. Children with ASD often have exceptional knowledge or skills in areas related to their special interests [22] and therefore integrating these into the design process allows them to contribute their knowledge/skills. Moreover, it was essential to choose design task CONTENT APPROPRIATE FOR THE CHILDREN'S ABILITY LEVEL (9) to mitigate any concerns about failure. Also due to preferences for routine and potential auditory sensitivities, each session was to take place in a QUIET/FAMILIAR ENVIRONMENT (1), e.g. in a separate classroom at the children's school.

In providing structure to the sessions, we would use a VISUAL SCHEDULE (5) for displaying each of the activities, using both text and images, and also a set of rules agreed on by all participants to guide appropriate behavior during sessions. This would be visible throughout the session with a child TICKING OFF EACH ACTIVITY (6) on completion. To capitalize on the children's visual strengths the session would begin with A VISUAL RECAP (2) of what happened in the previous session (if appropriate), incorporating images of activities undertaken during the past session, a summary of the main achievements and how they linked to the current session. Next, the current sessions would be VISUALLY INTRODUCED (2), involving references back to activities displayed on the schedule and explanations of what each would entail. Where possible all ACTIVITIES WOULD INTEGRATE VISUAL COMPONENTS (14). Each session would finish with a SUMMARY OF THE SESSION AND AN INTRODUCTION TO WHAT WOULD HAPPEN NEXT WEEK (2), to highlight what the children had achieved and to prevent anxieties about unknown, upcoming activities. To reflect the systemizing approach of children with ASD each session would FOLLOW A SIMILAR STRUCTURE (3), i.e. same

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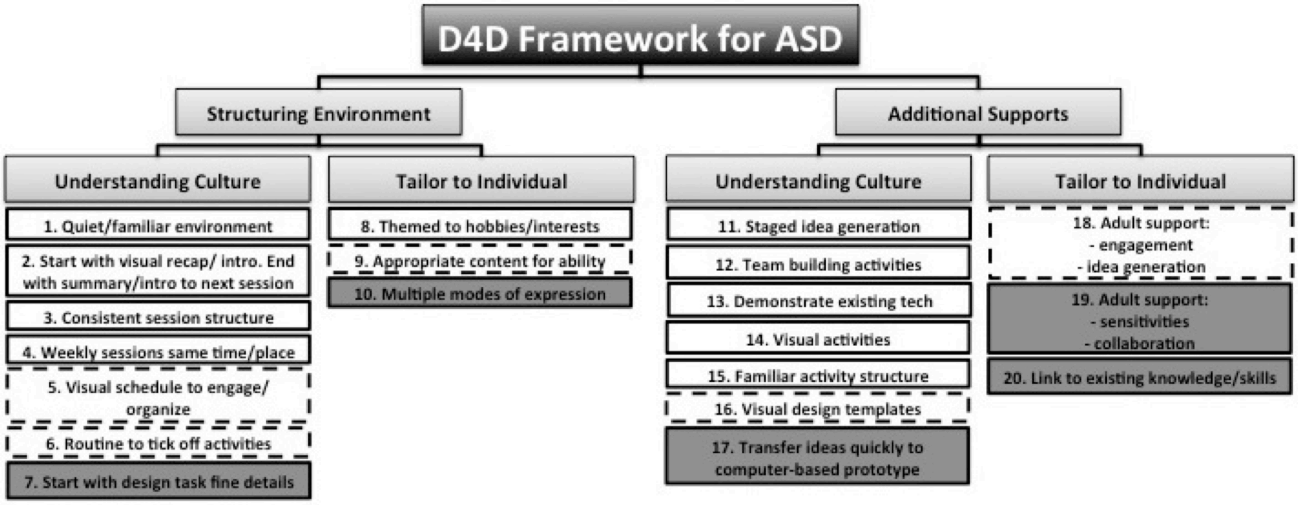

Figure 2: D4D framework applied to the development of PD features for the ASD population

start/end, and design activities would be CONSISTENTLY STRUCTURED (15) wherever possible. Lastly, the sessions would ideally be SCHEDULED AT THE SAME TIME AND PLACE (4) each week to provide some familiarity for the children.

In performing design work within sessions, during initial sessions we would incorporate fun, structured ACTIVITIES FOCUSED ON BUILDING TEAM RAPPORT AND SKILLS (12), e.g. Lego building challenges, to help the children feel comfortable and confident about working in a collaborative design environment. In introducing the main design task, SIMILAR EXISTING TECHNOLOGY WOULD BE DEMONSTRATED (13) and critiqued, to build on the children's reality-based creativity style. The IDEA GENERATION PROCESS WOULD BE SPLIT INTO EXPLICIT STAGES (11) and incorporate VISUAL DESIGN TEMPLATES (16), to guide the process of generating and documenting individual ideas, and combining these with other design team members. If a child appeared to be struggling to make progress an ADULT WOULD INTERVENE AND PROVIDE ADDITIONAL SUPPORT (18) to enable the child to successfully complete the activity.

Fig. 2 summarizes how the various features were informed by our D4D framework. White boxes (with solid or dashed lines) indicate PD features that were informed by theory. Next, we describe how our method was trialed with children with ASD, and additionally how we refined it by reflecting on our design practice.

Practice-informed PD: one-to-one workshops

Our second step involved applying our theoretically-inspired PD method in one-off design workshops with individual children with HFA/AS (see [6] for full details). The aim of these workshops was to explore the children's strengths and difficulties during participation within typical design activities. Given our inexperience with the user group at the time, we intentionally used one-to-one design sessions to create a safe design context that was easier for us to control. Ten children with HFA/AS aged 11-14 from three specialist ASD schools participated in the workshops.

Our original literature review highlighted the talent, knowledge and focus children with ASD can have within areas related to their special interests. Therefore, we tailored the design task to match a common interest of children with ASD (and children in general): computer games [21]. To draw links with the intelligent tutoring system we sought to inform, the children were asked to design a *math-based* computer game for their peers. Each session involved four activities: 1) introduction to the workshop, 2) discussion of the child's previous experience of math and computer games, and demonstration of existing math games, 3) generation and documentation of design ideas, 4) physically drawing an interface design of best idea using provided art materials. These activities drew from features of our D4D framework for ASD presented earlier. The findings from these workshops are discussed below with the resulting implications in bold.

Our workshops revealed the need to **evolve existing features** due to difficulties that children faced. We found that VISUAL DESIGN TEMPLATES (16), in particular, needed to provide more guidance to children in the initial idea generation phase. At the beginning of sessions, when children were provided with a blank design template on which to document their ideas, many struggled to generate any. However, once we changed our protocol to incorporate example ideas and partially completed interface designs, children were able to expand on the ideas given, and in some cases generate their own idea(s) where previously they had been unable to do so.

We also discovered **emergent uses,** as features we had included were sometimes used in unexpected ways. The VISUAL SCHEDULE (5) worked well to prepare the children for which activities would be encountered during the workshop. To our surprise, it also proved useful as a tool for re-engaging any children who became distracted during the session, enabling them to see where they were and resume from where they had left off more easily.

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Our workshops highlighted the **flexibility** required for certain features, such as the provision of ADULT SUPPORT (18). An adult facilitator was present to re-engage some of the children if they became distracted. This facilitator was additionally able to support children who initially struggled with idea generation by providing them with inspiration and verbal encouragement. At the same time, we observed the importance of applying tacit knowledge about each child in providing support. For example, interventions that supported some children would stifle others, who remained engaged throughout and enthusiastically shared their own ideas without verbal prompts. Moreover, our sessions demonstrated the importance of tailoring content to the individual child participant's ability level. During the demonstration of existing math games, although the difficulty of the demonstrated levels was intentionally kept low, it still proved too difficult for some. An inability to understand the game had a strong negative impact on engagement. For example, instead of documenting his ideas, one boy wrote 'I hate the basketball', referring to the game he had been unable to understand. We thus modified this protocol to ensure that children's abilities be established in advance where possible, and to rely on video demonstrations rather than direct interaction with software, to avoid uncertainties about appropriate content level.

Finally, certain features such as the ROUTINE OF TICKING OFF ACTIVITIES (6) gained more **prominence** than originally intended. Many of the children appeared to enjoy this routine and some explicitly asked to tick off the last activity at the end of the session. This suggested to us that this responsibility could be further leveraged, thus in subsequent sessions this role was explicitly 'assigned' to a child.

From our workshops, we observed that while most of our proposed PD features enabled children to participate, others required modification. This prompted a first iteration of our PD method (see Fig. 2): while 10 of our original features remained the same (solid white boxes), five others were revised based on our insights (dashed boxes).

Practice-informed PD: collaborative workshops

In a third and final step, we applied the iterated PD method in a new design context involving two design teams of children with ASD, see [7]. The collaborative nature of this step created new demands, thus we anticipated adapting or adding new features. The method was used over six design workshops, with each design team involving three children with HFA aged 12-13, two researchers (one undertaking an interaction designer role), and one teaching staff member from the children's school. Our objective in the workshops was to explore children's preferences for types of feedback and rewards, to inform the design of the math tutoring system. As in the first series of workshops, we chose a design task related to computer games.

Our design workshops demonstrated a need to **evolve existing features**. Varying levels of ADULT SUPPORT were present throughout, and our facilitators focused on supporting engagement and idea generation. At the same time, however, we discovered individual difficulties that needed to be accommodated to enable the children to share their many ideas most effectively. For instance, one child was sensitive to touching paper, and thus required the facilitator to write/draw his ideas on the paper-based templates. Others struggled to work in teams, did not listen to each other's ideas, and were hyper-critical. Adult intervention was required to reposition the workshop as a collaborative activity. These emergent needs led us to redefine the role of ADULT SUPPORT (19) to additionally include responding to specific sensitivities and collaboration patterns to facilitate equity in participation.

Our experiences also highlighted the need to **introduce new features**. In one of the design teams, children initially found it challenging to generate design ideas. As a response, the teaching assistant directed them to generate ideas for a very specific aspect of the feedback system. This enabled children to begin generating focused ideas, which were later expanded and integrated in a wider variety of feedback mechanisms. Focusing early design sessions on the FINER DETAILS OF THE DESIGN TASK (7) and then extending the design context in later sessions is therefore one way to match the detail-focused processing style of children with ASD. A second feature concerned children's expressive preferences in sharing their ideas. We observed quickly that some children with artistic talents preferred to draw their ideas and appeared to lack confidence in sharing their ideas verbally, while others seemed restricted by their drawing ability, but were able to eloquently describe their ideas verbally. Children's individual expressive strengths evolved over the course of the sessions and evidenced the need to support MULTIPLE MODES OF EXPRESSION (10) by providing opportunities to share ideas verbally or visually.

After the fourth and fifth design sessions, one of the researchers converted the paper-based design ideas into videos of a digital prototype of the math game. The children asked to watch each video several times, which helped them generate ideas about how to improve the feedback and reward design. Children with ASD typically think about things in a concrete way, therefore CONVERTING PAPER-BASED DESIGN IDEAS VERY QUICKLY INTO CONCRETE COMPUTER-BASED REPRESENTATIONS (17) of the design product fit with their reality-based style of creativity.

During the sessions it became clear that some of the children had extensive knowledge of computer games. For example, one boy suggested useful game design resources to the researchers, and was able to analyze the many games he had played to reflect on what made them successful. This knowledge came to guide the team's idea generation, highlighting the importance of being able LINK THE DESIGN ACTIVITIES TO EXISTING KNOWLEDGE/SKILLS (20) of individual participants by identifying relevant skills in advance and explicitly encouraging a child to contribute to a design activity that links to their specific strengths.

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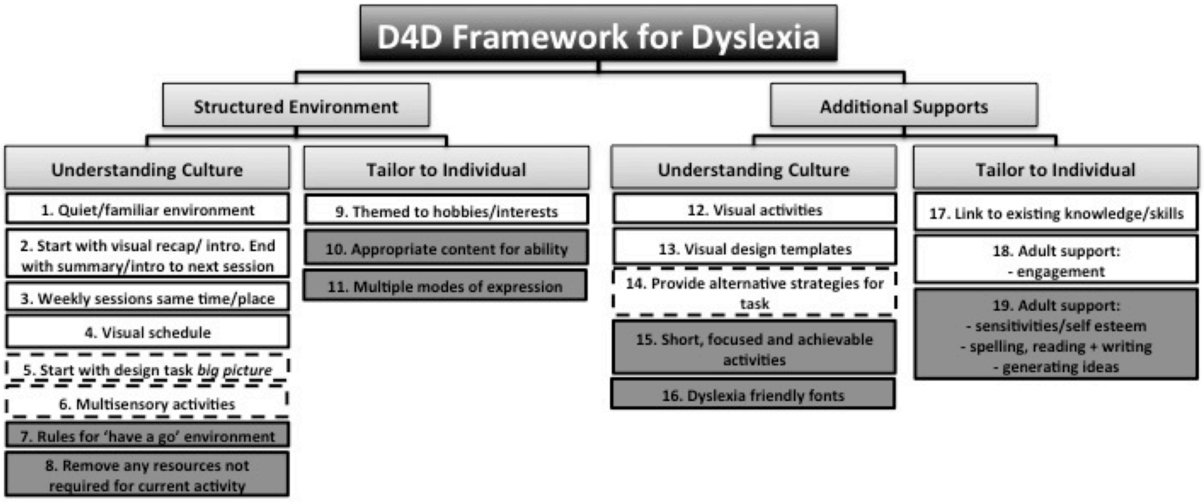

Figure 3: D4D framework applied to the development of PD features for a dyslexic population

Our collaborative workshops showed that while most of our PD features worked well in the new context, we needed to **evolve one feature**, and introduce four additional features (see grey boxes in Fig. 2).

CASE STUDY 2: DEVELOPING PD METHODS FOR CHILDREN WITH DYSLEXIA

Our second case study concerns an ongoing EU-funded project aimed at developing a learning tool to help dyslexic children between the ages of 9-11 improve their reading and writing skills. Given that our design research stage has been limited to one year, we had less time to develop a PD method, thus this case presents a considerable contrast to the previous one. As stated earlier, characteristics of ASD can also exist in other conditions, including dyslexia [26]. Thus, we built on the foundations laid during our previous case study. We describe the stepwise process of method development we used in the following sections, with the number of the corresponding feature in the D4D framework summarized within Fig. 3 in brackets.

Theoretically-informed PD

Our first step involved identifying typical strengths, preferences, and potential difficulties of children with dyslexia from the literature. We relied, in particular, on a recent review of dyslexia [26], which enabled us to identify shared characteristics between ASD and dyslexia. As presented in Table 1, two overlapping characteristic strengths are a high focus on activities related to interests, and strong visual-spatial skills. These similarities suggested that PD features previously developed in the context of ASD to support these strengths would be transferable to this context. These features were:

- Building on existing talents by theming design workshop to HOBBIES/INTERESTS (9) and capitalizing on CHILDREN'S EXISTING KNOWLEDGE OR SKILLS (17) during idea generation
- Taking advantage of visual strengths by Including A VISUAL RECAP (2) of the previous session followed by a VISUAL SCHEDULE (4) of design activities; integrating VISUAL COMPONENTS (12) within design activities where possible; and using VISUAL DESIGN TEMPLATES (13) for documenting ideas

Our review also revealed overlapping difficulties between ASD and dyslexia, such as anxieties related to failure, the unfamiliar, or the unknown. The PD features originally developed to overcome these difficulties were:

- Incorporating APPROPRIATE CONTENT FOR THE CHILD'S ABILITY LEVEL (10) to help mitigate failure
- Conducting session in QUIET/FAMILIAR ENVIRONMENT (1) and scheduling sessions at the SAME TIME/PLACE EACH WEEK (3) to limit unknown factors
- Providing an INTRODUCTION TO THE CURRENT SESSION and WHAT WILL HAPPEN THE NEXT WEEK (2) to ensure the child knows what to expect

Next, we reviewed existing applications of PD to establish how to capitalize strengths and support difficulties specific to children with dyslexia, focusing both on the broad level and at the level of the specific individual. In shaping our PD method to be specific to dyslexic children, we introduce the 'BIG PICTURE' OF THE DESIGN TASK (5) first, focusing on specific design components during later sessions as a way to capitalize on dyslexic children's global processing style. We employ a MULTISENSORY APPROACH (6) in design activities, incorporating visual elements to maximize typical visual strengths, and kinesthetic elements e.g. Lego-based tasks, to enable children to participate in ways more natural for them. Furthermore, ALTERNATIVE STRATEGIES FOR COMPLETING THE DESIGN TASK (14) would be provided to promote independence and encourage metacognitive thinking, e.g. providing different sources of idea inspirations, as dyslexic children tend to overgeneralize negative experiences.

Practice-informed PD: observations and interviews

Our second step involved balancing our theoretically-informed PD method with best practice notions from teachers. We conducted observations and interviews in two

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UK primary schools and two specialist dyslexia-teaching centers to capture strategies used by teachers to support neurodiversity, which would be useful to employ during PD. The lead researcher observed and took detailed notes documenting the teaching strategies employed by the teachers during one-to-one, small group and entire class literacy lessons. The same researcher then interviewed five of these teachers, including one mainstream primary school teacher, two SEN teachers, and two specialist dyslexia teachers. The interviews focused on teaching strategies witnessed during observations, including how teachers engaged children, built on their strengths to increase their confidence, selected appropriate content, supported particular difficulties, incorporated children's interests, and integrated technology into their teaching.

This step suggested a need for inclusion of two **additional features**. The specialist teachers sought to create a non-threatening environment where children felt confident enough to 'have a go'. This led to us ADAPTING THE RULES (displayed on the visual schedule) (7) to emphasize 'having a go' at an activity and to clarify that there were no 'wrong answers'. We also learned that specialist teachers employed a quick succession of short literacy tasks to keep children engaged, and constructed sessions with key achievable targets that children would not 'fail'. Thus, design activities incorporated into the PD method would be SHORT, FOCUSED AND ACHIEVABLE (15), with all tasks having precise objectives, being explained as simply as possible, and lasting no more than 10 minutes. Finally, in witnessing children's reading difficulties in practice, we proposed to **evolve the feature** ADULT SUPPORT (19) to include help with spelling, writing and reading, and for text to be avoided wherever possible.

Practice-informed PD: collaborative workshops

In a third and final step, we applied our revised PD method in three design workshops involving a single design team, comprised of four children with reading/writing difficulties, one researcher undertaking an interaction designer role, and one teaching staff member from the children's school who knew the children well. All children were aged 9-10 and were undergoing dyslexia assessment. The workshops were targeted at informing the design of a game forming part of a larger learning tool, for children aged 9-11. In particular, the goal was to generate design ideas for the game's navigation and reward systems.

Our work with children revealed further difficulties that **introduced new PD features**. Children frequently became distracted from current activities by resources for previous activities, such as the pens for ticking off activities on the visual schedule. This sensitized us to remove RESOURCES NOT APPLICABLE TO THE CURRENT ACTIVITY FROM VIEW (8) to maintain the children's focus on the activities. Difficulties the children encountered also required us to **evolve existing features**. For example, the VISUAL SCHEDULE (4) that detailed the structure of the workshop included the words 'The End', but unknowingly, we had used an elaborate font that was difficult for children to discern. While in this instance, reading the text itself was not essential, difficult-to-read text can lower children's confidence, potentially affecting their willingness to contribute to design activities. This highlighted the importance of overriding any aesthetic choices and using a DYSLEXIA FRIENDLY FONT (16) at all times. The workshops also **evolved existing features**, such as having MULTIPLE MODES OF EXPRESSION (11), with the children not only expressing their ideas visually via drawing and verbally during group discussions, but also sometimes with acting, using materials as props, e.g. using a board rubber to show how they interact with their mobile phone.

Fig. 3 summarizes how each of these steps was informed by our D4D framework. White boxes indicate theoretically-inspired features, with features appropriated from the ASD method presented in solid lines. Grey boxes represent features that were proposed by teaching practices and the design workshop sessions.

ADAPTING THE D4D FRAMEWORK

In illustrating the practical application of the D4D framework, we break down our process into a series of steps a designer might employ for another neurodiverse population. We use children with ADHD as an example.

Understand the Culture of ADHD: Examine the ADHD literature to identify the typical characteristics of the culture of ADHD, including strengths, preferences and difficulties. Reflect on how these might manifest within a PD context. Consider supplementing theoretical views with design research, such as observations or interviews with both the children and the adults that work with them, or trial design activities and workshops.

Understand the Individual Children: Consider how the method will be tailored to the individual children participating in the session. Identify in advance the children's ability levels in relation to the design task content, their existing knowledge/skills as well as hobbies/interests and how these could be linked in with the design activities. Decide on whether to involve an adult already familiar with the children, such as a teacher, for providing relevant information and additional support.

Structure the Environment and Provide Supports: Determine the implications of these insights within the context of the designer's tacit knowledge on the environment structure and types of supports required, focusing especially on capitalizing strengths and supporting known difficulties. For example, a detail-focused or global processing style requires consideration of the initial presentation of the design task, while a particular preferred information presentation style impacts on what and how information in the visual schedule should be presented.

DISCUSSION

Many designers do not have experience of working with neurodiverse populations. Over continuous exposure to a

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neurodiverse population, designers can develop the expertise necessary to engage such individuals in design activities, but the time constraints of most technology projects do not allow for this. Furthermore, within PD, participants can play multiple roles, at various levels of involvement [17]. For meaningful participation, neurodiverse children require support to emphasize their strengths, and provisions to mitigate their difficulties. This enables a deeper level of involvement where designers 'learn with' the participants during the design process rather than simply 'learning about' [17]. We found that children were most suited to contributing ideas and evaluating different design options. However, as some children also had extensive technical knowledge/skills, they additionally had the potential to contribute towards assessing technical feasibility and developing design prototypes. The present paper proposed a new framework, D4D, to guide designers in supporting the meaningful participation of neurodiverse children. Our contribution is not in developing a novel PD method, as many of the features we identified in our neurodiverse PD methods are not novel. Rather it is the adaptation of the TEACCH education principles as a design framework that scaffolds designers in the creation of new PD methods for children with a range of neurodiverse conditions, guiding them to identify the specific combination of PD features most appropriate for their target population. The implications of our work are three-fold.

First, in many research projects involving neurodiverse children, methods are generated "on the fly" for use within specific project bounds. Often, only minimal details are provided about these methods, their rates of success, and reasons underlying success or failure. This makes it difficult for the research community to learn from each other's experiences. In hoping that HCI researchers will employ the D4D framework, and document the resulting methods, we aspire to *create a common point of reference and a practical resource that is enriched over time to benefit those working with neurodiverse children*. Indeed, given the overlap of characteristics between some of these conditions, PD methods developed for one condition can become reusable and transferable to another.

Second, researchers may hesitate to rigorously document their methods because of the complexity of methodological choices both at the inception and application stage. Additionally, parties involved in design activities draw on tacit knowledge and prior experiences. Reflecting on our case studies, the lead designer drew on experiences of conducting design workshops, observations of how teachers intervened in challenging situations, and conversations with individual children or their parents regarding the children's interests or difficulties. These influences led to new PD features guided by, and subsequently captured within, the D4D framework. The framework can thus serve to *capture and model designers' strategies and tacit knowledge longitudinally providing us with more insight into the often-elusive nature of design practice*.

Third, a practical contribution of our work is to demonstrate a *process through which the D4D framework can guide the development of features for incorporation in PD*, informed by theory and practice. Importantly, this process is flexible to the practices of different designers and their constraints. Case Study 1 presented an in-depth approach, where sufficient time was available to undertake iterative testing of the different feature sets with the target population. Case Study 2 presented a lightweight approach that partly reused the method from the first case study, and replaced the more time-consuming and resource intensive design workshops with ethnographic work. Whereas Case Study 1 is strongly informed by design practices including children, Case Study 2 takes a more teacher-centric approach.

An important feature of our process is the acknowledgement that methods are not only proposed but also practiced. Although theory was initially used to develop each PD method, the D4D framework facilitated the incorporation of insights gained from our application of these methods. Neurodiverse conditions, which entail a range of specific talents and difficulties, create an additional demand to reflect and capture the practice of design methods in a more *iterative* process. The D4D framework of neurodiversity therefore guides initial method construction, but also scaffolds reflection and further development. As systematically evaluating the outcomes of this framework is beyond the scope of this work, it would be valuable if designers using D4D evaluated and reported on the outcomes of their methods with different populations; potentially considering the quantity, quality and/or novelty of ideas generated using their method.

A final contribution of our work is the documentation and development of two PD methods for ASD and dyslexia. We note, however, that given the limited scope of our paper, the frameworks presented here should be viewed as illustrative rather than fully comprehensive, and may not cover a complete set of PD features for all children with ASD or dyslexia, let alone the wider neurodiverse population.

We conclude with some optimism about the far-reaching implications of neurodiversity for HCI. Kapp et al. [18] have argued that "many neurological conditions have variable traits, fluid boundaries among one another, a continuous nature within the general population, and strengths beyond or as part of significant challenges". While we have highlighted the many commonalities between different neurodiverse conditions, it is important to acknowledge that these conditions exist on a spectrum. Indeed, there is often no clear line demarcating a formal diagnosis of a neurodiverse condition. Consequently, many children remain undiagnosed, and characteristics typically associated with neurodiverse conditions can also be found throughout the child population. We argue that taking a strength-focused individualized approach to involvement in PD is a philosophy that can benefit the wider child population. It allows us to focus on each child's capability

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set, rather than consider where children are in accordance with a baseline. Guided by our framework, PD can be adapted to help maximize any child's potential for making meaningful contributions to the design process. This draws parallels with the work of Van Rijn [25] who highlights the challenges of designers working with 'extreme' user groups they share little in common with, and how insights from designing with one particular group can actually contribute to an understanding of how to design for any user group. We therefore hope HCI researchers begin to consider how a neurodiverse approach might apply more generally within the child population, as well as to teams of children with mixed cognitive styles.

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