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Hands-On Experiences With Assistive Technologies for People With Intellectual Disabilities: Opportunities and Challenges

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ABSTRACT In the recent years, the use of Information and Communication Technologies (ICTs) to enhance the educational and developmental interventions of individuals with intellectual disabilities has increased drastically. Current literature about the efficacy of assistive technologies for people with intellectual disabilities includes numerous examples of co-design and research involving people with intellectual disabilities and their stakeholders. However, literature regarding the challenges and opportunities presented by this research is scarce. The discussion and reflection presented in this work is based on the authors' previous experience and ground-breaking literature in the field. After a review of relevant work, the the authors' research is described in detail, in order to reflect on the challenges encountered, and on opportunities for new researchers and open questions. The paper concludes with a reflection on the use of technologies to support people with intellectual disabilities, adopted strategies and limitations.

INDEX TERMS Action research, assistive technologies, empirical research, human-computer interaction, intellectual disabilities, software engineering.

I. INTRODUCTION

Intellectual Disabilities (IDs), also known as cognitive disabilities, affect to 1% of the overall population according to the 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V [1]). They consist of a set of neurodevelopmental disorders that lead to difficulties in cognitive areas such as memorisation, organisation, social skills, and autonomy. Therefore, special education teachers and relatives of people with IDs employ a series of interventions to increase their autonomy in the adult life and equip them with skills fundamental to their well-being [2], [3].

In recent years, Information and Communication Technologies (ICTs) have been widely utilised by practitioners to enhance evidence-based interventions in the education and training of individuals with intellectual disabilities. This evidence is built upon a corpus of research studies reporting the efficacy of ICT–based interventions in varied contexts such as special education schools, mainstream schools [4], homes [5], and laboratory environments [6]. The use of ICTs for these purposes is called Assistive Technologies for Cognition (ATCs) by researchers, such as Pinard [7] and Scherer [8]. Literature provides many examples of ATCs, for instance [9]–[11] focused on brain injury, or [12], [13], related to dementia.

Additionally, the design and development of ATCs does not only constitute a technical challenge. Article 9 (Accessibility) of The Convention of Rights of Persons with Disabilities [14] promotes "the design, development, production and distribution of accessible information and communication technologies and systems at an early stage, so that these technologies and systems become accessible at minimum costs." Therefore, there is an additional moral and societal value in carrying out research that motivates us as researchers to reflect on the results, development, and further adoption of ATCs by the end users in their societal, cultural and educational context.

Designing ATCs entails some particularities that have an impact on the research setup, methodology, and the interaction with the stakeholders. This requires flexibility and

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open-mindedness when it comes to the traditional way of performing empirical research with human subjects. Some research paradigms such as Research Action or Participatory Design [15]–[17] have addressed the unique conditions surrounding ATC design as part of the conditions that determine the data collection and analysis.

The *Ambient Intelligence Lab (AmILab)* , is experienced in carrying out studies to prove the efficacy of ATCs in the education and autonomous development of individuals with intellectual disabilities (IDs) and autism spectrum disorders (ASDs). This study aims to provide a drawn and structured view of the conclusions that were extracted from the experience of designing, developing, and testing ATCs with real users. The main challenges associated with this kind of research will be described along with opportunities encountered that may contribute to the community of advocates, proxies, caregivers, educators, and researchers on this topic.

Thus, this paper aims to answer the following research questions:

- **RQ1**. What particular challenges does the empirical research on ACTs present, and what are the main strategies for overcoming them?
- **RQ2**. What particular opportunities arise from this kind of research in terms of contribution to the community, advocacy, and methodological innovation?

The paper is structured as follows: first, a review of similar analyses from literature on empirical research of assistive technologies for people with IDs is presented.Second, the experiments carried out by the AmILab addressing developmental and educational issues of people with Down's syndrome, IDs, and ASDs are listed and described. Third, a list of the main opportunities and challenges the arose from these research experiments is provided in response to the RQs. Finally, the main conclusions of the present analysis are extracted, accompanied by a discussion on its limitations.

II. RELATED WORK

Despite an increasing interest of the research community in assistive technologies [18], only a few works address the differences in methods and experimental design, challenges, and opportunities that this area presents compared to others, such as Human-Computer Interaction. In this section, the most relevant studies that address these issues are discussed, and the open questions identified in literature are pointed out.

One of the first works that studied the needs of people with IDs and their implications concerning Human-Computer Interaction was published by LoPresti, Mihailidis and Kirsch in 2004 [19]. This first review of the state of the art opened the field to the community. Moreover, the authors continued to research about new approaches and trends as long as technology evolved, defining new terms such as Assistive Technologies for Cognition [20].

An early study by Fleming and Sum summarized some of the most common limitations of research in AT: small samples, high drop-out rates, very basic statistical analysis, and poor performance of technology. These limitations arose from their systematic review [21] in which they studied 41 papers related to assistive technologies for dementia (and the related intellectual problems caused, mainly, by age). In addition to the limitations listed previously, the authors also found a common problem when moving from laboratories to the real practical and methodological problems appeared, limiting the outcome and practical efficacy of the supporting artifact developed.

A recent study by Desmond *et al.* summarised and discussed the current status of research on AT. The study resulted from the first Global Research Innovation and Education on Assistive Technologies summit [22]. The paper focuses on the need to follow a person-centered approach at all the stages of research, in order to empower people and optimize resources and outcomes. This means that new models and research methods are needed, or that the current ones must be adapted to make people central to the decision making process.

Cumming *et al.* carried out a meta analysis on mobile technologies for the support of people with intellectual disabilities [23]. Their research was founded on a systematic literature review of single subject studies that used mobile technologies (smartphones, tablets, etc.) to support people with IDs in their daily living. Among other findings, the authors argued that these technologies, despite being very promising, require more evidence-based studies and generalization. The authors also state that the key elements to successful integration of supportive mobile technologies are proper selection and access to information. The most appropriate technology is one that is measured by how it meets user needs, rather than by how popular it is. Integration is also facilitated and more accurate when teachers and professionals are provided with additional information about the effectiveness of certain applications. Finally, the need to include different apps for certain areas (such as education) is also discussed, as the number of available apps is very limited.

One particular area in which technology is widely used to support people with communication needs (a very common need among people with IDs is Augementative and Alternative Communication (AAC). An updated review of the topic and a discussion on new trends and open issues is presented in [24]. Despite of increasing number of opportunities (thanks to mobile technologies) to support communication limitations, the authors caution that further research and collaboration is needed. In particular, they emphasize the need for more research to proof systems empirically, closer collaboration between researchers, developers, and stakeholders, and use of innovative technologies to serve people in need of communication support.

The study carried out by Motti [25] depicts a list of opportunities and challenges of wearables as ATs. Particularly, the author identifies three key opportunities that these devices offer:

- Monitoring and assistance. The nature of the devices and their conception relies on continuous monitoring of the user. This information can be used to provide adapted assistance.

- Autonomy. In relation to monitoring, autonomy can be enhanced by virtue of monitoring and AI supported behaviour recognition.
- Interaction. Given the advanced capabilities of these devices, interaction can be less obtrusive and more accessible. Voice commands, graphic displays, and haptic reponses, among other features, offer a wide variety of options to developers to adapt interaction to users' needs and preferences.

In contrast, the author found three challenges that arise in this particular area of research:

- Data governance. Privacy, ethics, and data collection issues are currently generalised and an open question. This issue is even more relevant to a scenario involving individuals with IDs, as users might not be aware of the information collected.
- Sustained engagement. Due to the limited time and settings (usually controlled) of the experiments, the level of long-term acceptance is unclear.
- Personalisation. Increasing the customisation options yields an exponential increase in complexity. Moreover, due to the inherent complexity of human cognition, covering all possible options is impossible and might not result in valuable research outcomes.

Despite the narrowed research presented in this paper on wearable ATCs, some of the challenges and opportunities can be extended to other ATCs. For example, data governance is an open question to everyone, and something that research should reflect on before, during, and after carrying out ATCs research.

Bächle *et al.* [26] presented a literature review on ATCs for people with dementia. Six conclusions were drawn from this study:

- Privacy is important, but may be overruled by other social values. The authors found that patients with dementia are less aware or concerned about privacy issues. This may be either motivated by the fact that these systems improve in their quality of life or related to a lack of information, as this generation is less aware of technology and its implications.
- Sensors are the centrepiece of AT. Gathering information about the user and his or her environment is the foundation of any AT system. Therefore, sensing is crucial.
- Participatory design is essential during the development stage. Including the stakeholders in the design and development processes seems to lead to better results and therefore, a decrease in failure rates.
- ATCs significantly support the work of caregivers. In general, when developing ATCs, the target stakeholder is the person with intellectual disabilities. However, the authors also identified an increase in the technology's ability to support to caregivers.
- The human or social dimension of AT requires more exploration. The limited literature on this topic encouraged the authors to emphasise the fact that the social aspect of the technology is less studied, despite its high relevance.
- Evidence of utility and cost effectiveness of AT can be demonstrated in different contexts. Due to limited evidence in analysed literature, the authors state that there is a gap in the research to address the relationship between cost and improvement in quality of life.

Brosnan *et al.* [27] analyzed a series of talks, keynotes, and seminars regarding participatory design in innovative solutions for people with ASD. Particularly, in their research they found a set of common problems and open questions. Based mainly on the reflections of Parsons and Cobb [28] they concluded that solutions must be beneficial to researchers and stakeholders alike. Otherwise, stakeholder may feel like "guinea pigs," resulting in a lack of interest and motivation on their part. This feeling also goes in the opposite direction of participatory design. The authors also argue in favour of providing effectiveness and discuss how outcome variables should be selected. Moreover, the authors conclude that involving stakeholders in research requires new methods and rethinking how research is carried out.

Finally, another relevant discussion is presented in [29]. In this case, the author discusses the suitability of Randomised Control Trials (RCTs) for AT research. The author argues that RCTs are not practical due to their high costs in terms of number of users and resources. In general, RCT studies require large and homogeneous samples, something that is nearly impossible to reach in AT research, due to the variability of users needs and capabilities [30].

In summary, the papers presented in this section support the notion that traditional methods may not be the most suitable for carrying out studies involving ATCs and people with IDs, and that new methods are necessary for ATC research. They also share the idea that this area of study presents challenges and opportunities alike. However, although some studies were based on literature reviews, none of them presented first hand experiences or empirical evidence of the issues addressed.

III. HANDS-ON EXPERIENCES IN ATCs

The *Ambient Intelligence Lab (AmILab)* of the Universidad Autónoma de Madrid has been working on ATCs for more than 10 years. The basis of its research is ambient intelligence and ambient assisted living [31], but research evolved to ATCs with an emphasis on massive and affordable technologies, such as mobile devices.

This section provides a general overview of the empirical research on ATCs carried out by the AmILab. In doing so, the goal is to provide material for further discussion on the opportunities and challenges that this kind of research entails. Table 1 summarises these experiences in terms of target population: people with IDs, people with ASDs and people with brain injury (BI); intervention type; setting; number of participants; research methodology; type of analysis; location; and year. In Figure 6, a timeline of the projects is presented, to clearly show their connections and simultaneity.

TABLE 1. Experiences and pilots carried out by the *Ambient Intelligence Lab (AmILab)*.

Project Name	Authors	Target	Technology	Intervention	Setting	N	Methodology	Analysis	Location	Year
aQRdate	Gomez et al. [32]	BI	Smartphone	Daily life micro-prompting	Rehabilitation	1	Case study	Quantitative	CEADAC[1] (Spain)	2012
AssisT-TASK	Gomez et al. [35]	ID	Smartphone	Daily life micro-prompting	Office work training	10	Observational trial. Interviews	Quantitative	Down Syndrome Foundation [4] (Spain)	2014
AssisT-TASK	Roldán-Álvarez et al. [33]	ID	Smartphone	Daily life micro-prompting	Labour training	10	Case study	Quantitative	Alenta[2] (Spain)	2015
AssisT-TASK	Cáliz et al. [34]	ID	Smartphone	Daily life micro-prompting	Special Employment Centre	10	Observational trial	Quantitative	Prodis Foundation [3] (Spain)	2016
AssisT-OUT	Gomez and Ojala [36]	ID	Smartphone	Outdoors wayfinding	Outdoors	2	Case study	Quantitative	Volunteers (Finland)	2013
AssisT-OUT	Gomez et al. [37]	ID	Smartphone	Outdoors wayfinding	Outdoors	18	Case study	Quantitative	Down Syndrome Foundation[4] (Spain)	2014
AssisT-IN	Torrado et al. [38]	ID	Smartphone	Indoors wayfinding	Faculty building	14	Observational trial	Quantitative	UAM[5] (Spain)	2014
Taimun-Watch	Torrado et al. [40]	ASD	Smartwatch	Emotional self-regulation	Classroom	2	Case study	Quantitative	Alenta[2] (Spain)	2015
Taimun-Watch	Díaz-Escudero et al. [44]	SE teachers	Smartphone	Emotional self-regulation	Teacher office	8	Observational. Focus group	Quantitative, Qualitative	Alenta[2] (Spain)	2016
Taimun-Watch	Torrado et al. [45]	ASD	Smartwatch	Emotional self-regulation	Classroom	2	Case study	Quantitative	Juan XXIII Roncalli Foundation[6] (Spain)	2017
Taimun-Watch	Nodarse et al. [46]	ID, SE teachers	Smartwatch	Emotional self-regulation	Daycare centre	4, 2	Case study. Interviews	Quantitative, Qualitative	AMAS Foundation[7] (Spain)	2018
Leo con Lula	Gomez et al. [43]	ASD	Smartphone	Global reading skills	Special Education School	9	Case study	Quantitative	Alenta[2] (Spain)	2018

BI: people with brain injury; ID: people with intellectual disabilities; ASD: people with austism spectrum disorders; SE: special education

[1] https://ceadac.imserso.es
[2] https://www.alenta.org/
[3] https://www.fundacionprodis.org/
[4] https://downmadrid.org/
[5] https://www.uam.es
[6] https://www.fundacionjuanxxiii.org/
[7] https://www.grupoamas.org/

A. SMARTPHONE APP FOR THE MICRO-PROMPTING IN DAILY-LIFE TASKS

Autonomy is the main goal for people with any type of cognitive impairment. This motivated researchers to study how to introduce technological aids for the performance of daily life activities, both in the learning process and in the home or workplaces. Since this training already involved a new challenge for users, the use of devices with which they were already familiar was deemed less intrusive than introducing new and unknown devices into their lives. The proposal and case studies were based on mobile phones and QR Codes to assist individuals with cognitive disabilities in their labour training and integration. This proposal, named AssisT-TASK (formerly, aQRdate), was a fully functional mobile application for Android smartphones and offered step-by-step guidance, establishing a learning method through task sequencing.

The process of introducing technical aids can be divided into two steps: task selection and task execution. Since task identification can be challenging, researchers relieved users of this work by tagging their environment with QR codes. This technology is easily readable by the device, as well as affordable and widespread. Assistance was offered for task performance in the form of a prompting sequence of instructions supplemented with visual and audio cues. This way, users received the stimulus via different channels. Furthermore, because of the navigation controls, users were able to go forward and backward as they needed. A screenshot of the application is shown in Figure 1.

People with cognitive disabilities were the focus of this study. First, an initial prototype of the system was evaluated with people in the midst of rehabilitation for brain injury [32].

FIGURE 1. Screenshot of AssisT-TASK application.

After improving the prototype and discussing it with other experts in other domains (special education teachers, job insertion experts and therapists), the improved version was tested with people with IDs who were likely to be recruited for jobs [33]–[35]. These people are usually educated in labour centres, where special education teachers and labour tutors train them in several skills, adapted to their profiles. For the purposes of the present study, evaluation of the updated prototype was carried out with young adults with Down syndrome who had participated in one such labour training course.'' In this case, the communication with participants was more fluent and they provided some useful feedback about the experience, the system, and the help needed. A hybrid methodology was used which combined elements from inquiry (e.g., direct observation during the trials) and test methodologies (e.g., focus groups), which provided the research team with objective information about users' performance and knowledge acquisition.

As a result of this evaluation of the updated prototype, the influence that the type of support had on the number of errors and help requests from users trained in cognitive skills was observable. Second, task completion time was usually related to, but not the most representative of, knowledge acquisition. There was no evidence of the influence that support had on this factor of the study. Finally, solutions like AssisT-TASK were a perfect fit for users with less severe IDs, since they enable users to follow all steps of each task properly. Such solutions are nonetheless still suitable for users with more severe IDs, as they may still help users to complete tasks independently.

B. SMARTPHONE APP FOR OUTDOOR WAYFINDING

People with cognitive disabilities usually present limitations in both orientation and navigation skills. These issues directly affect their independence, limiting their autonomous movement and causing them to require supervision most of the time.

To address this problem, a mobile pedestrian navigation assistant was designed, developed, and evaluated for smartphones: AssisT-OUT [36], [37]. It adapts to the user in terms of route calculation, instructions delivery, and interface design. To do so, the system divides the calculated route into atomic instructions and uses street-level photographs at the decision points (i.e., turns). Additionally, it implements GPS tracking and an alarm system to notify the user about his or her relative position regarding the next decision point. In Figure 2, a screenshot of the application is shown. The interface is very simple and includes (from top to bottom): the direction, a red button to request help, the street level view the user has to reach, a progress bar, and two buttons to move backward and forward in the instruction set.

Apart from the mobile application, the system integrates an authoring tool that allows caregivers to manage their users and destination points, as well as to analysing their performance in terms of time needed and the route actually followed compared to the route originally calculated.

In order to evaluate its proposal, the research team tested the system with users with diverse grades of disability in a real environment and compared it against a commercial navigation application (i.e., Google Maps). From this evaluation the team concluded that our system produced significantly better results than the commercial application in terms of the number of users who reached their destination, although they needed more time to walk the proposed routes.

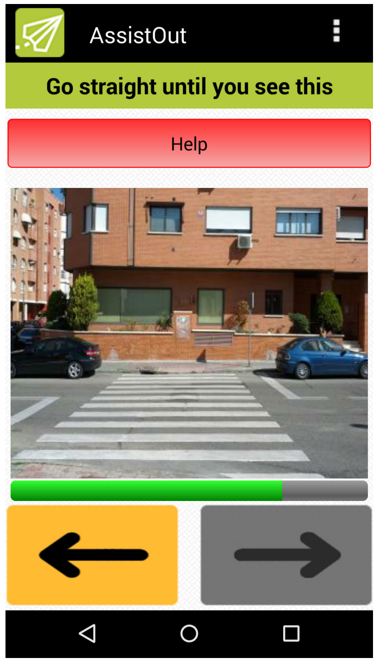

FIGURE 2. Screenshot of AssisT-OUT application.

As a result of this research it may be concluded that a dependable, scalable tool that is easy to use and understand is indispensable for providing assurance to people with cognitive disabilities in their autonomous environments, as well as to their relatives.

C. SMARTPHONE APP FOR INDOOR WAYFINDING

People with cognitive disabilities must acquire several skills in order to achieve autonomy and self-development. One of these skills is indoor navigation through new and complex environments such as their school or work centre.

This is a major challenge for these individuals when accessing a new job, for example. As they are not accustomed to the new workplace, they often need constant guidance until they have assimilated its structure and learned how to go from one place to another. Caregivers and labour trainers usually undertake this tutelage, but it is expensive and time-consuming.

A way to locate users indoors is to make them notify the system indirectly of their position within the building. The research team proposed doing this by leaving a trail of clues along the route: when users find a clue, the system knows which clue has been found and where it was placed, and therefore can pinpoint the user's location. These clues were presented as QR tags. As we mentioned above, these are inexpensive, straightforward, and easy to place throughout the workplace.

Based on the concept described above, the research team developed a system for smartphones called AssisT-IN [38]. First, the environment (i.e. builiding) has to be modelled in the tool and tagged with QR codes. Then, users begin by scanning any QR code in the environment and, from that

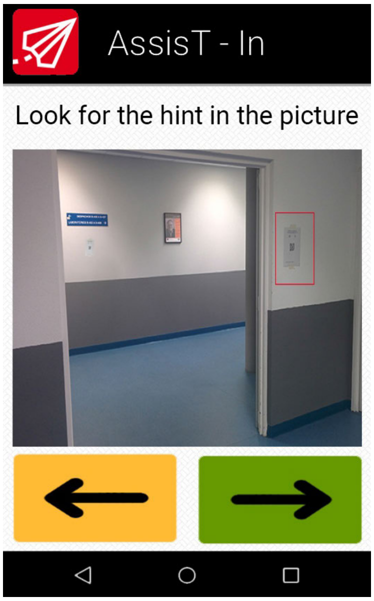

FIGURE 3. Screenshot of AssisT-IN application.

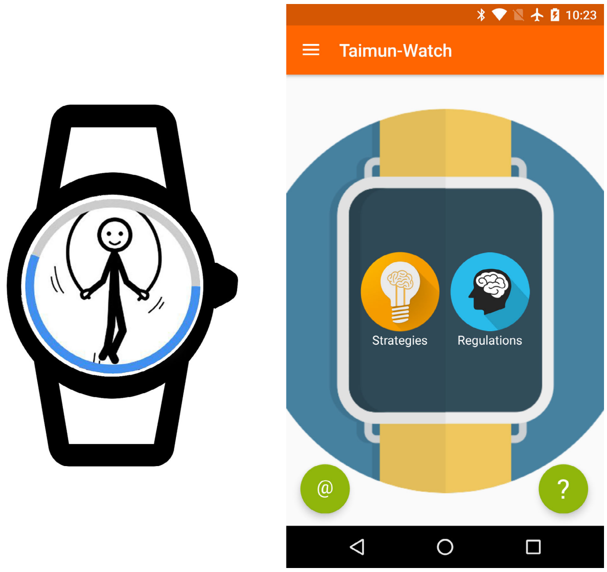

FIGURE 4. Screenshot of Taimun-Watch application. On the left, the smartwatch screen. On the right, the smartphone screen.

origin point, selecting from a list of the desired destination. These QR codes are referred to as "nodes".

The application guides the user from the initial node to the second, and then on to subsequent nodes, following a trail of nodes leading to the destination node. Arriving at a given node provides the user with information about the next one in the form of a picture of the next node as seen from the current one. A screenshot of the application is shown in Figure 3.

An evaluation was conducted in which users with several cognitive disabilities used the application to navigate an unfamiliar environment. Measurements taken confirm that the system was functional. All users successfully reached their destination point in an unfamiliar environment. Non-smartphone users also managed to use the device correctly, in an intuitive way.

All of the participants (N = 14) reached the final destination and, most of them, in a reasonable time. Only 3 of them needed extra time to finish the route (around twice the average time). Although those users who were in need of permanent support showed greater difficulties in following the trail, and to complete it within a certain timeframe, they were still able to finish the route and find the destination. These results led the team to consider the system valid for people with diverse profiles of intellectual disabilities.

D. SMARTWATCH APP FOR THE EMOTIONAL SELF-REGULATION OF INDIVIDUALS WITH AUTISM

This work researched the needs of individuals with ASD to have a pervasive, feasible and non-stigmatising form of assistance in their emotional self-regulation, in order to ease certain behavioural issues that undermine their mental health throughout their life.

A system for self-regulation of individuals with ASDs, called Taimun-Watch, was designed, developed, and tested [39]–[41]. It is composed of a smartwatch to detect the user's inner state and display self-regulation strategies, and a smartphone to create and customise such interventions. The wearable device monitors the user's heart rate and displays the intervention when that signal exceeds a configurable threshold. Smartwatches do not stigmatise the wearer, since they resemble a well-known device (regular watches), and their content is fully customisable by means of an authoring tool. In Figure 4, a screenshot of the smartwatch application is shown (left), while on the right the authoring tool (for smartphones) is shown.

An intensive experiment was conducted with individuals with ASDs who showed varied representative behavioural responses to their emotional dysregulation. Users were able to employ effective, customised emotional self-regulation strategies by means of the system, recovering from the majority of mild stress episodes and temper tantrums experienced over the course of experiment in their classroom.

E. TABLET APP FOR THE TRAINING OF GLOBAL READING SKILLS IN CHILDREN WITH AUTISM

Children with ASDs show difficulties in the acquisition of reading skills following syllabic methods (used in ordinary schools), so that specific learning methodologies are needed [42].

To address this issue, Leo con Lula [43], a method of global reading learning, was developed [43]. It followed a specific methodology for people with ASD and aimed to provide a visual, personalised and error-free learning experience. Figure 5 presents a screenshot of the application, in which the user has to drag and drop the word at the bottom ("perro," meaning "dog") to the suitable picture.

This methodology focused on a global reading process, which was based on a game divided into three levels. Each

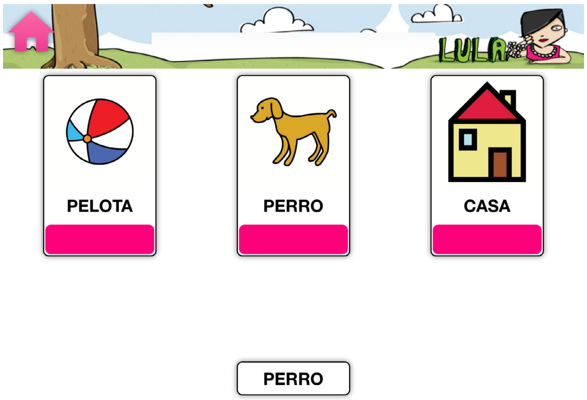

FIGURE 5. Screenshot of Leo con Lula application.

level was also divided into three sub-levels and, finally, each sub-level consisted of a (configurable) set of exercises. Additionally, the vocabulary was divided into groups of three words, so only a reduced number of words was covered at a time.

In the first level, users had to connect a word with the corresponding image. As an additional aid, the word was also written under the image. In the second level this aid was removed, so users only saw images and the word they had to link. Finally, the third level introduced the syllabic decomposition. Users had to drop each syllable in the appropriate zone (under the image) and the whole word as well.

In order to improve and refine the application, a pilot study was carried out with children with ASDs. Due to the limited time for the study, it did not focus on reading skill acquisition, as this is a process that takes longer. This pilot was based on questionnaires and direct observation to gather teachers' thoughts, discover possible limitations, and evaluate suitability as a tool for use in a class context.

The pilot provided the team with some interesting insights the adoption and suitability of Leo con Lula. First, almost all participants were motivated during all the sessions. Most of them understood the general functioning of the application quickly, but it was noted that even a minimal distraction could affect user's performance.

Despite the limited information collected, in terms of time and user variability, results suggested that Leo con Lula could be included in a special education class context, as a tool for introducing reading skills to children with ASD. Its preliminary contributions are the motivation that the game provoke in users and its potential as a method adapted to people with ASDs.

F. SYSTEM INTEGRATION

As described before, several ATCs were designed, developed, and tested. In Figure 6, the time distribution of these processes is depicted. Despite of the differences between the projects, each one addresses a particular group of people's needs, the whole process can be analyzed as a user-centred experience.

This research on ATCs started with aQRdate [32]. This project aimed to provide assistance in carrying out activities of daily living for people with brain injury. The process was expert-centred, as users had difficulties to communicate their opinions and feelings about the prototype verbally, however their therapists and families reported valuable information about the interface and interaction design. There was also another limitation: at the time the study was carried out, smartphones were not so popular among the population, and only technologists and technology enthusiasts owned an smartphone. However, experience showed that adapted interfaces and co-design with experts helped to overcome this issue.

From that experience, the research team decided to test the idea of prompting information to carry out daily life activities through smartphones with other groups that might benefit from it (people with intellectual disabilities, such as Down syndrome, ASDs and other disabilities). Thus, aQRdate was evolved into AssisT-TASK [33]–[35]. This step was supported by experts from different areas, such as labour trainers, therapists, and special education teachers. Furthermore, working with new groups and experts expanded the research to cover other needs to provide a comprehensive support, including navigating outdoors (AssisT-OUT, [36], [37]) and indoors (AssisT-IN, [38]). These two new projects were based on previous experiences and attempted to provide assistance in a similar way to AssisT-TASK, both from the interaction perspective and provision of support. Moreover, logging and register tools and files facilitated data processing and analysis for both researchers and practitioners.

Transdisciplinary experiences provide new opportunities for both researchers and practitioners. In the present case, close collaboration with practitioners and discussions allowed the team to explore other needs and scenarios for which technology could be implemented to provide efficient and effective support. Particularly, from direct observation and semi-structured interviews the team co-designed and developed a novel solution to assist in the development of emotional self-regulation skills in individuals with ASD. This was the case of Taimun-Watch. Despite the different nature of this system compared to previous experience, most of the design guidelines, methods, and provision of support could be applied and later improved in this project. Proof of this is the co-design process followed, the clean and simple interfaces, and the extensive use of pictograms to communicate and transfer the information to the final user. Moreover, some of the lessons learned from previous experiences, such as caregivers' need or easy-to-use tools of analysis, were put in practice, by integrating two levels of analytics in to the authoring tool: a simple, direct, visual level; and a more advanced level based on graphs and timelines for deeper analysis.

A final project came directly from practitioners. They developed a basic tool for electronic whiteboards to introduce reading to children with ASD through the global reading method, and the AmILab team discussed improving and providing a tablet-based version of the system in order to reach a wider population. The final app, Leo con Lula [43], used

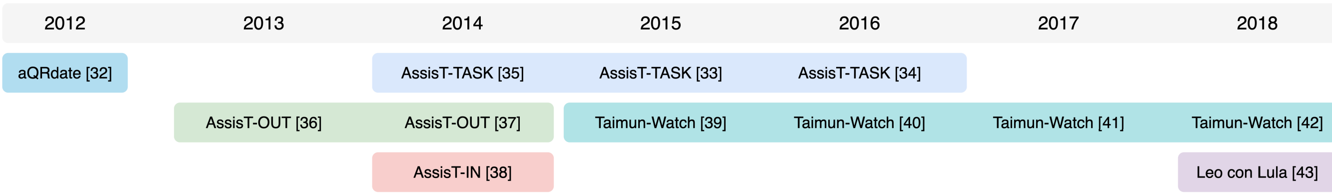

FIGURE 6. Project timeline and simultaneity.

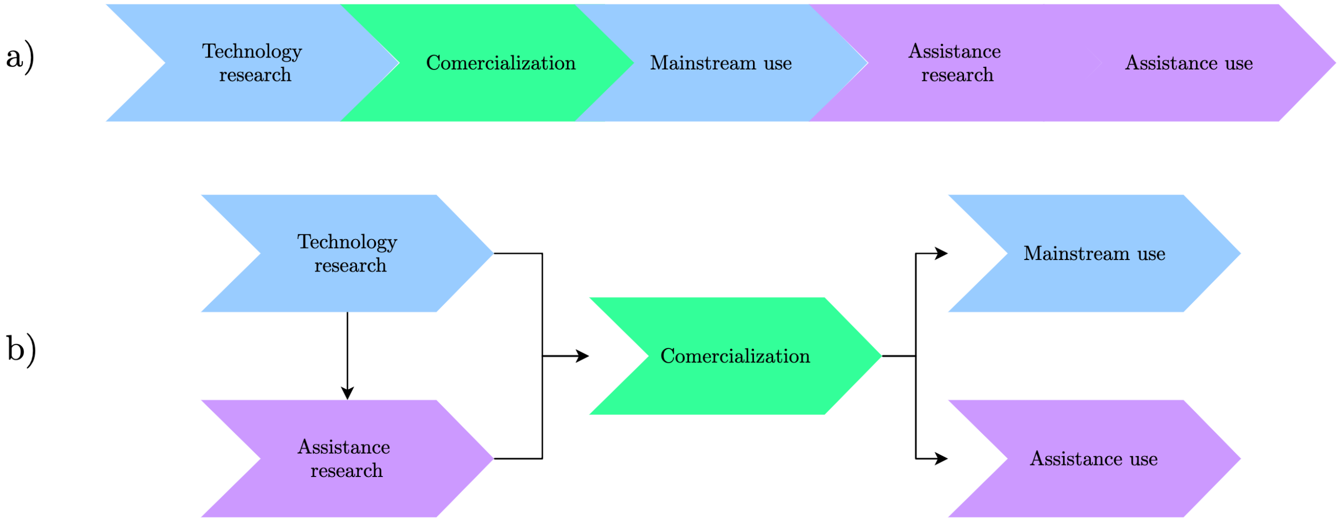

FIGURE 7. Assistive technologies incorporation to mainstream diagram.

pictograms extensively and provided a high level of adaptation. It was not only co-designed between researchers and practitioners, but practitioners were also invited to participate in the research method design and dissemination.

IV. OPPORTUNITIES

In this section the opportunities highlighted by empirical research on ATCs for people with intellectual disabilities are described.

A. UNIVERSAL DESIGN ADVOCACY

Traditionally, the apps and assistive systems market draws inspiration from the research community, either from the academic sphere or from R&D departments [47], [48]. Therefore, when researchers express concern over and focus on certain topics, it is more likely that the market, either via entrepreneurship, collaboration, or other means of knowledge transfer, has flagged such concerns in their designs and products. Even some research paradigms include these expectations. Hayes [49] states that Action Research in the field of human-computer interaction seeks societal benefit as a main result, arguing that any improvement or particular solution provided for a specific social issue is a contribution per se.

Consequently, the very act of performing and disseminating empirical research on the development of ATCs for people with IDs represents a contribution from a societal point of view. This is sustained by the mainstream interest on cognitive accessibility and the knowledge transfer that occurs frequently between industry and research in this regard: a representative example of this is the evolution of cognitive accessibility to the Web in recent years [50]. Additionally, the number of accessibility options in the release version of many software and hardware items has grown significantly [51], whereas most of AmILab's research experience has been acquired through the development new software because either the commercial one was not cognitively accessible. For example, AssisT-OUT is an alternative to the map view-based interface of commercial apps, AssisT-IN is a cheaper and easier to deploy alternative to those based on beacons, and Leo con Lula is an alternative to the mainstream global reading apps). In experiments for AssisT-Task and Taimun-Watch, no mainstream solutions even existed for the issues in question. Figure 7 shows two ways in which assistive technology is incorporated into the mainstream. The diagram in Figure 7.a represents the way the AmILab research team adapted pre-existent technologies to the needs of individuals with intellectual disabilities (or other special needs), which involves initial design, development, and distribution of devices and apps among standard users, followed by the appearance in the market of adaptation from academia, educative environments, or as a result of the good will of stakeholders. However, the advocative nature of this research points towards the idea shown in Figure 7.b, which means that these adaptations are included in release version of apps and systems that people with intellectual disabilities might want to use. In other words, we advocate for a simultaneous research and design targeting the mainstream and the user with special needs, in order to have a universally usable system at release. This idea is also in keeping with Article 9.2 of the Conference of Persons with Disabilities (see Introduction). This is called Universal Design in learning vocabulary [52]. Given the inspiration that the industry has drawn from research in digital inclusion and human-centered ICTs [47], [48], we argue that performing research that proves the efficacy of ICTs to help solve issues of certain social groups contributes directly to the advocacy for Universal Design in the industry and other technology developers such as entrepreneurs.

B. STUDENT RECRUITMENT

Evidence shows that the interest that students have for careers in engineering goes beyond technical challenges [53] and that it has shifted towards social justice issues [54], [55], even more so as these fields are becoming more and more inclusive [56], [57]. All of the experiences and pilots listed in Table 1 involved one or more students either in the development or testing of ATCs as research assistants (15 students in total). The number of students has been growing yearly and their motivation was based more on the social benefit of participating on the project rather than the technical challenge involved. These students reported that these projects were well regarded among them, and that they were different than the other proposed for student participation or final thesis, precisely because of their social nature. The students also reported that knowing about the existence of these projects enhances and broadens their expectations about computer science, software engineering and product design as career choices. This was because students with genuine interest in social innovation thought that these careers were purely technical and disconnected from human aspects.

For those students who seek an academic career, AmI-Lab's projects were an eye-opening example of alternative options for research topics within engineering fields: action research, ethnographic research, and cooperation with NGOs and organisations focused on vulnerable populations such as individuals with intellectual disabilities. Therefore, involving students in the testing and development of ATCs contributes to increase awareness of the application of ICTs to help solve issues related with social justice, under-representation, and inclusion.

Additionally, there is evidence for the educational benefits of involving students in academic testing, as the study from Carver *et al.* [58] shows, however, researchers and instructors should mind the balance between logistic benefits for the research and pedagogical benefits for the student. In the team's experience, and following the conclusions of Carver *et al.*, involving students in research concerning ATCs might entail:

- **Education on the topic of ATCs.** The students obtain knowledge on state-of-the-art devices, software, and computer-based aids for individuals with special needs.
- **Hands-on practice.** Students participate directly in the steps that make up an empirical study, obtaining knowledge that would be otherwise restricted to the theoretical classroom. They also face real-life, practical problems caused by the involvement of varied profiles such as practitioners, individuals with IDs, and learn how to navigate and overcome these difficulties during research sessions.
- **Third-party assessment.** By witnessing ethical, responsible, and methodological empirical studies targeting vulnerable populations, students overcome the fear of becoming a subject of experimentation in human-computer interaction and other computer science fields.

C. TRANSDISCIPLINARITY

Boger *et al.* [59] argue that the challenges that the development of assistive technologies entails must be addressed from a transdiciplinary perspective. Although multidisciplinarity, interdisciplinarity, and transdisciplinarity are often used interchangeably, the authors differentiate them as follows:

- Multidisciplinarity refers to a collaboration of specialists from one or more relevant fields in a convergent and unidirectional for the purposes of a single specialist's knowledge and specific goal.
- Interdisciplinarity refers to a collaboration of specialists from one or more relevant fields in a bidireccional way.
- Transdisciplinarity refers to a synergy that goes beyond mere collaboration, it is a common place in which the involved specialists share goals, methods, and unite their knowledge to develop new joint approaches to a problem that is relevant to all of them.

According to Boger *et al.*, issues like the design of assistive technologies by people with intellectual disabilities entails such a number of eventualities and is so sensitive to individual needs that only a transdiciplinary approach is able to provide robust and valid solutions. Therefore, assembling a transdisciplinary team in order to solve a problem concerning ATCs for people with intellectual disabilities is an opportunity instead of a challenge, since its goal transcends the initial reason for conforming it and allows to create a dynamic in which the subteams work closely in order to continue addressing other issues, providing solutions and building an approach to tackle relevant problems across several experiments.

This is the case with the experiments carried out in the AmILab. As Table 1 shows, the team has collaborated closely with different centres like Alenta, a special education school and day centre in Madrid (Spain), from the very beginning of the ATCs design process. Figure 8 shows the composition of the transdisciplinary team that produced the software and continued working across further experiments and other pieces of software like Leo con Lula. After some experiments, new approaches stemmed from the meetings, design routines solidified, and the stakeholders ended up developing acting protocols for addressing new problems that they were observing in the children with intellectual disabilities in terms of education, capabilities, behaviour, and well-being. This transdisciplinary team also served as a space in which all parties tried different ways of involving end users in the process: sometimes children were invited to give their opinion on a particular design or idea, and in many occasions they participated in pilots, for example. In a transdisciplinary approach, it is not only the people and the direction of the knowledge transfer what make the work successful, but also the spaces they occupy, the time they devote for common understandings, and the communication they end up building in the process.

D. REQUIREMENTS ELICITATION

Designing and performing empirical studies on ATCs for people with intellectual disabilities require the early involvement of a transdisciplinary team in the process. As the requirements elicitation is the first step of the traditional design process of ICTs, this particular stage of the development process entails an opportunity to set up productive and symbiotic synergies that benefit both practitioners and researchers. When ATCs are designed, requirements arise from everyday issues of special education teachers, families, and therapists. Consequently, the requirements elicitation becomes a moment in which research and practice have to find a common ground [60]. Transdisciplinarity makes divergent fields converge. The requirements identified in clinical profiles concerning intellectual disabilities would address the clinical validity of the study, whereas the requirements from educators would address educative aspects, and those from parents and caregivers are more likely to be associated with the daily use of ATCs and avoidance of stigmatisation [61].

In the team's research, requirements elicitation sessions were, in most cases, carried out in special education schools. In fact, in the Taimun-Watch and Leo con Lula projects, the fundamental idea behind the designed systems came from special education teachers and caregivers. Assembling a transdisciplinary team in the very stage of requirements elicitation reduces the need for iteration over the design process. Additionally, allowing flexibility when formal software engineering process models, such as user-centered design, are applied thoroughly to the requirements elicitation stage (and other stages of the project) benefits the interaction between stakeholders in terms of mutual trust and availability. Researchers who involve individuals with intellectual disabilities in the process should also note that classic inspection techniques of user-centred models and usability studies such as card-sorting [62], think aloud [63], or cognitive walkthrough [64] might be too intellectually demanding or not even feasible for them. Replacing these activities by others based on caregivers or parent-proxy, or adapting the design activities to their needs through multimedia proved to be efficient solutions for the successful involvement of individuals with intellectual disabilities in the research process [65]–[68].

E. PARTICIPATION OF INDIVIDUALS WITH INTELLECTUAL DISABILITIES

The involvement of individuals with intellectual disabilities in research does not usually extend the evaluation stage, during which they participate as subjects of an experiment. Their input in the requirement elicitation, analysis, design, and implementation of ATCs has not been studied and used thoroughly, since traditional participatory design techniques are too cognitively demanding for some individuals (see Subsection V-A). However, every ATC development with a research approach offers an excellent opportunity when it comes to investigating innovative ways of involving individuals with IDs in the process, which constitutes a novelty in terms of software engineering, participatory design, and action research.

Two kinds of novel co-design approaches that would benefit from research on ATCs, as follows: a) adaptations of traditional or mainstream techniques to the cognitive needs of people with IDs, and b) creation of new techniques that are specifically tailored for them. The former has much to do with the philosophy behind Universal Design, since it pursues the goal of including everyone as a target of technology, anticipating all the adaptations that might be needed in a digital solution, hence targeting a *universal population* (see Section IV-A). The latter, on the contrary, indicates the need to shape a set of software engineering-related techniques from scratch that are not built upon certain assumptions limited to the mainstream populations targeted in participatory design. However, this approach requires a holistic, disability-centered approach to co-design necessitating work that has yet to be done, but it is rather unrealistic to tackle for researchers who just want to validate a certain tool or evaluate a particular piece of ATC. Moreover, it is possible that applying adapted traditional design and evaluation techniques to experiments with individuals with intellectual disabilities might bring added value to the research. For example, self-reports, which are utilized as a way to elicite the users' opinions about a certain piece of ATC such as Assist-Out, AssisT-Task, and Taimun-Watch provided the team with valuable information about their capacity to evaluate their own performance, which is considered a very much needed skill in their development as autonomous individuals.

F. SOCIAL INNOVATION

The term ''social innovation'' was coined by Phills *et al.* [69] and can be defined as: ''A novel solution to a social problem that is more effective, efficient, sustainable, or just than existing solutions and for which the value created accrues primarily to society as a whole rather than private individuals.'' AT research, by nature, is strongly related to social innovation, as its goal is to solve some of the problems that a particular part of society (i.e. people with IDs) experiences in daily life. Therefore, research on ATCs opens a new door for social innovators to explore.

This concept has been put into practice in different contexts and approaches. For instance, Pappas *et al.* [70] targeted a

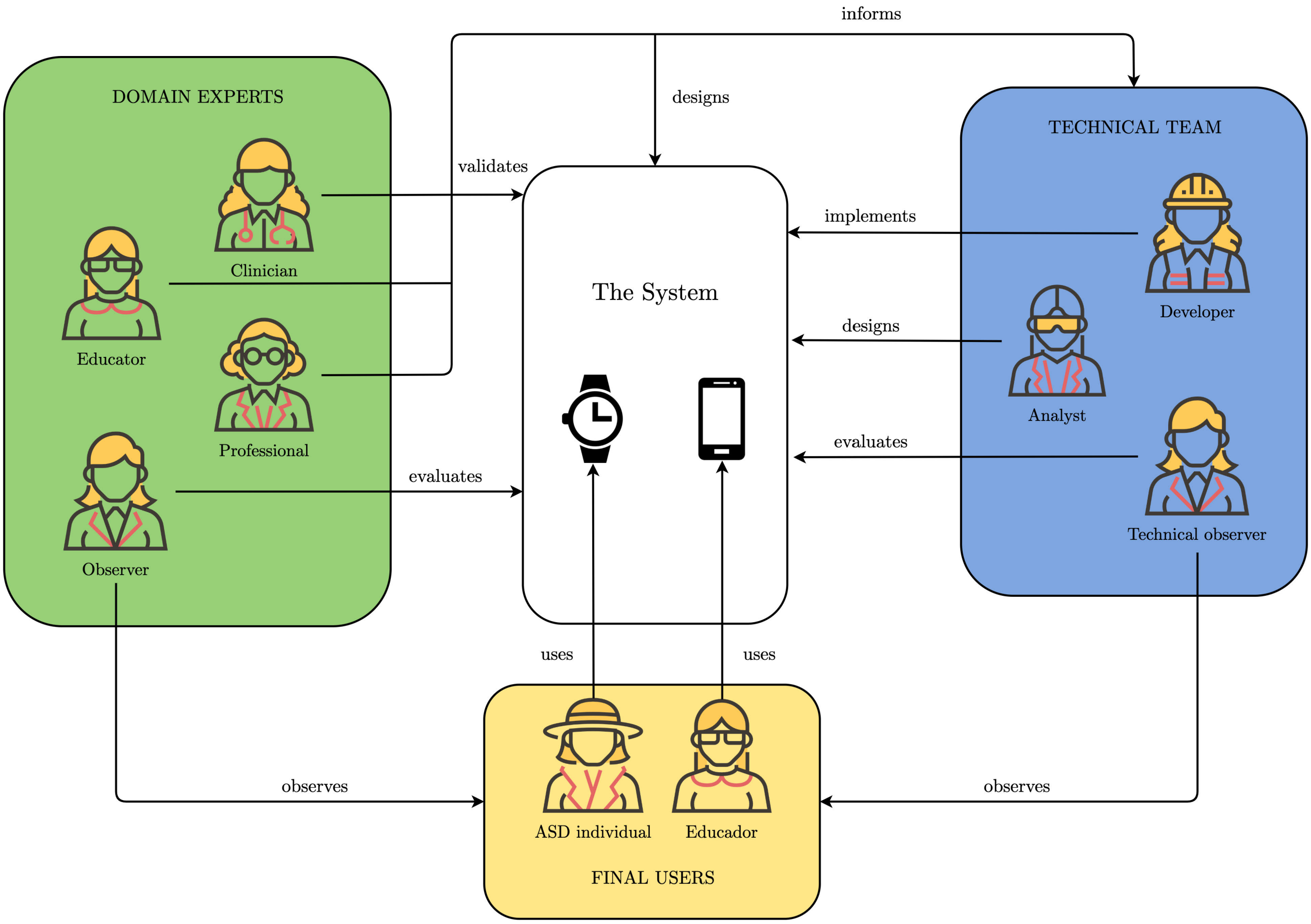

FIGURE 8. **Transdisciplinary work example from Taimun-Watch.**

social innovation course towards the design and development of ATCs for people with ASD, with very positive results.

This can be taken a step further by basing AT research on social innovation. Its success relies on the different stakeholders, policy makers, and funding entities. Particularly, most of the research projects carried out by the team have been funded by social innovation entities and foundations. Not only do these entities provide the necessary funds to carry out the research (purchase of equipment, hiring developers, cover student grants and dissemination costs, for example) but also their expertise, network of contacts, brand visibility, and business environment complements the research and endows projects with an added value that is rarely found in other research areas.

V. CHALLENGES

This section describes the challenges that traditionally appear during research on ATCs for people with intellectual disabilities, along with the team's approaches to overcoming them during some of the experiences listed in Table 1.

A. SUBJECT RECRUITMENT

Despite the benefits of including users in the research process at every stage: problem identification, ideation, requirements elicitation, design, development, testing of the proposed solution, and reflection on the process. Recruiting and keeping users involved is complicated when doing research in ATCs. Moreover, as reported in literature, carrying out random control trials is nearly impossible since the method itself requires a high number of (homogeneous) participants. On the other hand, long-term studies require the user to be available for long periods of time, which has a high risk of failure due to high drop-out rates reported in literature [21]. Finally, participation itself may provoke feelings of rejection, as users may not be accustomed to taking part in research/formal evaluations.

The main reasons for subject recruitment being one of the most difficult parts of the research process were:

- **Unique needs and capabilities**. Researchers seek results that can be generalised. However, due to the unique needs of users, either it was necessary to include an unattainable number of participants or to narrow the target population to those with a very particular need and context. However, when narrowing the target population, the type of users and the abilities being addressed by the research must be specified. For example, in some cases (such as in the AssisT-Out pilot) the user needed to know how to read and to be able to go out, either on their own or accompanied by a helping companion. Thus, the population would be limited.

- **Time availability**. On many occasions, users attended courses in special education centres or labour training centres, or were otherwise subject to a number of rehabilitation sessions. In special education centres, sometimes users leave for shorter or longer periods of time to do an internship in a company or, eventually, to start a job. For those that were receiving a more traditional form of training (i.e. spending the day at the centre, participating in different activities and classes), time availability was also limited, as they had to follow a routine and curricula. In the case of rehabilitation, the inconsistency in terms of user availability is even higher, as their routine was dependent on many factors, including health issues and personal decisions (in the case of adults).
- **Permission to participate**. Although this was a less common issue, some families were still reluctant to technology and, even more, to participate in research studies in which technologies were (usually) not so mature.
- **Potential rejection to the solution**. The success of an ATC products depends entirely on the acceptance of the final user. An unpleasant experience (due to a connectivity issue while testing an app, for example) may provoke a feeling of rejection that might stop a user from participating, which could indicate that the abandonment rate of the product is high.

B. ETHICS

There are several guidelines, policies, and considerations that highlight the ethical implications of involving users with intellectual disabilities as subjects in empirical studies.

McDonald and Kidney [71] collected peer-reviewed studies that included individuals with intellectual disabilities in order to analyse common ethical practices. Although they found that there is a lack of clear consensus and divergent values among practitioners, common practice shows that studying contextual ways of obtaining valid consent and providing educational payoff might be the way towards ethical integrity. The ethical guidelines of Dalton and McVilly [72] aimed to facilitate research involving individuals with IDs and they were endorsed by the International Association for the Scientific Study of Intellectual Disabilities. These guidelines highlight the importance of taking into account the cultural diversity that exists in different groups of individuals with these disabilities, especially when the studies are carried out in developing countries. They also remark on the need for proper dissemination of the work, so not only do researchers benefit from the experiments, but so do practitioners, relatives, advocates, and individuals through the introduction of new intervention strategies, training methodologies, software, and hardware.

However, ethical considerations go beyond the issues of consent and mutual benefits. Designers must analyse ethical aspects of the use of the piece of ATC they are designing. Some users might be concerned a decrease in self-governance or autonomy when relying on reminders, micro-prompters, and planners, for example. Others might argue that users might feel coerced to use ATCs in special education schools or their homes. In their study, Perry *et al.* [73] gave an overview of the main ethical practices of the use of ATCs and telecare for people with intellectual disabilities. Some of these points have been selected and adapted to the general case of empirical studies on ATCs:

- **Obtain regularly reviewed consent.** When ATCs are going to be used for long periods of time, practitioners must ensure that people with disabilities or their proxies provide periodic consent. Researchers and other stakeholders tend to think that life circumstances of people with intellectual disabilities are constant and their will unchanging, but they should have the right to retire their consent unconditionally. Therefore, researchers and practitioners are ethically responsible for reviewing the status of the consent periodically.
- **Mind the right to privacy.** Some ATCs work using personal data of individuals with disabilities. This data is highly sensitive, since it is difficult to make these users aware of the implications of sharing personal data and their vulnerability [25]. Sometimes, it is also difficult to explain to their proxies. The common practice in research is to achieve as much transparency as possible, trying to make the information about their data easy to understand and accessible. Again, researchers and practitioners are responsible to the end users and their proxies gaining full awareness of the status of their personal data, either by following directives from national or international level and obtaining approval from authorised entities that supervise research with human subjects.
- **Avoid stigma.** ATC engineers and software designers tend to prioritise efficacy above other aspects of technology. For example, in Taimun-Watch, the engineer's perspective would focus on a custom hardware design that is able to achieve the most precise detection of the emotional state of the user. However, efficacy, precision, or performance disregard the social implications of the technology employed. Some devices that might have been more precise on performing such detection would have been wired helmets or chest bands. Researchers ought to consider the practical use of the ATCs in the daily life of the user in terms of normalisation and acceptance [74]. For Taimun-Watch, the team focused on regular, commercial smartwatches, even though their performance in terms of detection and sensor precision is not as effective as others with higher risks of stigmatisation or lower acceptance by the end users and their relatives. Additionally, the selection of hardware contributes to the users' acceptance in terms of costs and availability: efficacy and precision tend to be more expensive, intrusive, and more difficult to access. Balancing technical efficacy and realistic use should be a

priority that is better discussed at the early stages of the ATC development. Table 1 indicates, we indicate the technology selected for each app and experiment. The AmILab has always made a deliberate selection of commercial and widespread technology in order to increase the adherence of the ATC it develops

- **Mind common dissonances between proxies and individuals with IDs.** Researchers must actively seek for consonance between the interests of people with intellectual disabilities and their proxies, and not take it for granted. Sometimes, parents and close caregivers state that individuals with intellectual disabilities have certain needs that are, in fact, their own needs as well, which have to be taken into consideration, unless there is some conflict. Thus, researchers have the responsibility to make the consent and the information process as transparent and accessible as possible so that individuals with intellectual disabilities are able to express their own will as much as possible in terms of ATC use, experiment conditions, and personal data.
- **Return of results**: The relation and trust between researchers and stakeholders has to be bidirectional. Both parties need to perceive a return of investment (ROI), which is different for each party. While stakeholders might be interested in early access to technologies or skills development, researchers might look for access to users' and experts' opinions, spaces in which to evaluate their idea,s and valuable research data. The next Subsection (See Subsection V-C) further explores this concept of trust among stakeholders.

Ethical solutions to this issue are not straightforward. As the reader might have noticed, the path towards ethical integrity when using individuals with intellectual disabilities as subjects has to be navigated based in two principles: a) transparency and b) communication with stakeholders. However, more research should be done on this topic, and official ethical committees should invest more effort in providing tools and solutions to researchers in order to carry out comprehensive and reliable studies in terms of ethics.

C. TRUST AMONG STAKEHOLDERS

The trust among researchers and stakeholders can be interpreted as being two-fold:

First, stakeholders must not feel like ''guinea pigs'' [28]. In order to establish a fair and trusted relationship, stakeholders have to perceive their contribution and a ROI. This ROI can be a free use of technology (for which they have participated in the design and development), access to technology or funds (through contracts or project grants), or even participation in innovative projects. This ROI can also be reflected in intangible things, such as experiences for users with IDs, opportunities to develop new skills, and increased reputation (thanks to the collaboration with top-research centres and universities). As an example of an intangible ROI, the evaluation of AssisT-In consisted of a visit to the university in which participants were invited to attend a class, visit teaching and research labs and, finally, take part in the experiment while using the technology. At the end of the day, all the stakeholders (users with IDs and their teachers) were invited to a light refreshment and snacks at the ambient intelligence lab (in which they also explored ambient intelligence technologies). The design of this experiment benefited the participants as they lived ''one day as university student'', explored new spaces, met professors, and experienced new technologies. It also provided them with the development of a transverse skill: the use of ICTs. For the researchers, they had the opportunity to test a new AT development in a real and optimal setting.

Second, this ROI has to come back to researchers as well, by means of high quality and formal data. In order to avoid possible biases, direct and naturalistic observation and experiment notes are frequently delegated to teachers or caregivers. Although this can sometimes be risky, as they are not researchers, quality data is essential to the research. In order to ensure this, communication and provision of appropriate tools are mandatory. The former involves a detailed explanation of the research: pursued objectives, methodology, experimental design, expected results, and the type of data needed for the analysis. The latter involves providing teachers with pre-formated notebooks to take notes, examples of valuable information to be recorded, and support. The combination of both factors and a trusted relationship produces a better understanding of the process and, therefore, higher-impact research.

In the case of the Taimun-Watch project, including assistants to make naturalistic observations and notes during the experiments, yielded to poor data collection from research point of view. Therefore, the analysis was very limited and the team could hardly scratch the surface of the in-depth implications of the use of technology, rather than describing the experience and learned lessons.

D. COMMUNICATION

Fluent communication is basic to the success of every collaboration. This is even more important in the case of transdisciplinary teams, in which the different components may speak different languages but also use different methods, work styles, and epistemologies [75]. Furthermore, in the case of working directly with people with IDs, communication is frequently a barrier and alternative communication channels are needed [76].

In the first case, in which researchers and domain experts, such as caregivers, teachers, and families collaborate, information should be as clear as possible: research goals, methods, requirements, implications, etc. must be explained to them using precise but understandable language. For instance, to explain the testing method that would be used (AB testing, for example) to a researcher, just stating the method name would be enough. In contrast, in order to provide the necessary information to understand the goals and possible risk when explaining the method to the families, a more detailed description is needed. Apart from this, this description has to be simple to be understood and, if possible, based on examples. This way, stakeholders would get the same picture of the research. Useful tools for this are leaflets, diagrams, slide shows or videos explaining all the steps, implications, and tasks.

The second case is even more complex and, in many cases, limits the methods and researchers have to do a workaround. For example, in order to collect the opinion of users in a classic usability study, USE [77] or SUS [78] questionnaires are very popular, validated and accepted in the field. However, they are composed of a set of questions that can be difficult to understand. Moreover, if the user does not read, an assistant is required to help him or her. And the same happens when using interviews in order to collect users' opinions and reflections. If the user cannot communicate verbally, these interviews are less appropriate or the information collected can be very limited. In both cases, a popular workaround is designing experiments to be expert-centred instead of user-centred. Using domain experts as proxies provides more reliable and complete information, as they understand and interpret the users and their feelings.

Despite limitations to users' ability to communicate, interacting with them is desirable. Meeting them prior to the pilot sessions, introducing yourselves, and knowing them in advance makes them feel less observed, in a safe and comfortable environment and, in the end, participate actively in the research.

E. VALIDITY

As reported in literature, validity of ATCs, understood as the statistical evidence of positive impact of an AT-based intervention on the user, is very low compared to other HCI areas. This issue comes from the reduced number of users participating in the evaluations and lacking homogeneity [21], [29]. However, other authors, such as Hayes *et al.* [49], state that the validity of ATCs relies on any improvement for a specific issue.

From the experience presented in this paper, besides the statistical analysis, when possible, we consider that qualitative data provides even more interesting results. Moreover, the validation of an AT for a particular case should be contrasted with the domain experts, and put their expertise and reflections in value. Examples of this are AssisT-Task and Taimun-Watch projects, which are still in use in Alenta. Some users, identified by the domain experts as key users (those who are more prone to use technology and need the support), use these ATCs in their daily life, as any other support available.

Another source of validity flaw might come from the fact that many users tend to bias their opinion (positively) when asked about the tested technology [79]. Either because they think that is the result researchers ''need'' or a high level of excitement, these answers bias the results.

Finally, one last limitation is related to the trust among stakeholders. In some occasions, data collection relies on domain experts annotations and observations and, unfortunately, sometimes this data is incomplete or the value for research is weak.

VI. CONCLUSIONS

This paper aims to serve as a compilation of findings and ideas derived from the long experience of the *Ambient Intelligence Lab (AmILab)* carrying out empirical studies that test the efficacy of ATCs for individuals with cognitive disabilities in several aspects of their lives: outdoor and indoor wayfinding, reading skills training, daily life task guiding, and emotional self-regulation. These studies include numerous tasks: planning the experiments, knowing and interacting with the individuals and their stakeholders, and employing different design approaches according to the specific needs of each group, centre and project. Handling so many factors while performing rigorous research with these users entails certain challenges related to the validity of the results and ethical responsibilities of the researcher, while maintaining the trust among stakeholders and fruitful communication with all the involved. Based on the literature and on the team's experience, the theoretical basis of these challenges are presented, along with common, evidence-based strategies to overcome them.

Regarding subject recruitment, the main factors that hinder gathering big and representative samples are analysed, namely: a) individuals with IDs have unique sets of abilities and needs that jeopardise generalisation for research, b) their educative schedules are tight and have little time available throughout the year and within the day, c) obtaining consent from them or their relatives can be a challenge, d) rigorous research requires representative samples with baseline capabilities that are difficult to find within one single centre, and e) even if the sample is representative and large, the subjects still might reject the proposed solution based on an unpleasant experience during the study. In the present case, a flexible planning of the testing sessions and keeping healthy, continuous, and proactive communication with the special education schools were the strategies that helped to overcame these challenges to some extent, but more research should be done regarding methodological frameworks and team composition in order to alleviate this issue.

Furthermore, the fact that the team needed to involve individuals with intellectual disabilities as research subjects and collecting data from them led to imperative reflection on the ethical integrity of the team's research. Although this has been discussed by several authors, more research and debate ought to be done addressing this issue. In this regard, some advisable practices have been identified, supported by the literature and our transdisciplinary work with expert stakeholders with different backgrounds. In the first place, obtaining consent in a regular and periodical way is recommended, given that life circumstances and preferences of individuals with cognitive disabilities and their proxies are likely to change over time for multiple reasons. Acknowledging users' right to privacy by making all information clear and accessible is advisable, as is making every process transparent, so they and their proxies can be as aware as possible and keep their right to withdraw and decide over their data. Researchers should also keep in mind that technology adherence is strongly related to the lack of stigma: if the end user or their relatives do not accept the practical or social implications of using a certain piece of ATC, its efficacy will become irrelevant because it will be easily abandoned. However, this proxy-based relationship might contain dissonances, of which the researcher has the ethical responsibility to look after.

Difficulties associated with the participatory nature of this kind of research must also be acknowledged. Trust among stakeholders is to be maintained by ensuring a return of investment for every part involved: rigorous and valuable data for researchers and educational or tangible benefits for the subjects and the stakeholders. This paper has described some practical cases of the experiments carried out by the *Ambient Intelligence Lab (AmILab)* that ensured the return of investment and trust among stakeholders in different ways. Clearly, communication plays a major role in this issue, especially when there are language or cognitive barriers. Comprehensive and accessible communication channels (for instance, including alternative and augmentative communication strategies) might contribute to bringing diverse profiles together in a transdisciplinary team that leads to successful and fruitful research.

Nevertheless, some opportunities arise from the research on ATCs for individuals with intellectual disabilities. Research contributions represent advances that are received by advocates, representatives, and educators as innovative possibilities to improve current practice and reach more individuals with special needs. As a matter of fact, this very paper is intended as a way to encourage researchers to work on this topic. Opportunities arising from this kind of research in terms of creating fruitful, transdisciplinary work teams that lead to the development of novel methodological approaches and real change in the lives of individuals with cognitive disabilities are also highlighted.. Additionally, we describe the benefits of involving students in these studies in their education and fostering science as a career with a strong social component, as an alternative for those who are not so interested in purely technical fields.

Although these opportunities and challenges take their roots in the literature and the experience of the *Ambient Intelligence Lab (AmILab)* carrying out empirical studies of ATCs for people with cognitive disabilities, limitations have been acknowledged. More experiments are needed in order to add more validity to the conclusions, since they are locally restricted to a single country in space and to the last 10 years in time. Additionally, the range of technologies explored is limited: smartphones, smartwatches and tablets were tested. Despite having selected these technologies for ATCs based on acceptance and inclusion arguments, carrying out experiments with other technologies might shed some light on the challenges and opportunities elicited above.

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