Meta Principles of Technology Accessibility Design for Users with Learning Disabilities: Towards Inclusion of the Differently Enabled

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Abstract People with learning disabilities are often in isolation from the rest of society. This affects their development, their health and their full participation in society. Technologies are an indispensable answer to the problem of this marginalization and not only allows to promote their inclusion in societies but also to raise awareness of society while connecting them to the services and resources available. This paper aims at exploring guiding principles to cater for the needs for inclusive technology accessibility. We review the state of the literature and identify extant concepts in search for a set of Meta principles of technology accessibility design for users with learning disabilities.

Keywords Learning disability · Human computer interaction · User interface design · User centered design · Assistive technologies

1 Introduction

Learning disabilities (LD) are generally neurologically based processing problems. These processing problems can interfere with learning basic skills such as reading, writing and/or math. LD could also be the result of visual acuity, hearing issues, or motor handicaps; of intellectual disability; of emotional disturbance; or of environmental, cultural or economic disadvantages [1]. Children and young adults with a learning disability may struggle in society, school, and family. In adult life, LD can interfere with higher-level skills such as organization, time planning, abstract reasoning, long or short-term memory and attention, thus, influencing their life beyond academics and can have serious societal impact.

People with LD may experience barriers at the level of simple essential activities such as using traditional telephones [2], operating a digital TV [3], interfacing with

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automated teller machine, or even voting [4]. In the US, a 2017 study by the National Center for Learning Disabilities, found that 19% of students with LD drop out of high school and 46% of adults between 18 and 65 cannot enter the labor force due to LD related conditions.[1] In 2016, in the UK, a survey has shown that only 7% of people with LD have a job. They are 58 times more likely to die before the age of 50, and 4 times more likely to have a preventable cause of death due to lack of good healthcare. One in 4 people with LD spend less than one hour outside their home each day and 93% of those interviewed by the Foundation for People with LD in 2012 said they felt lonely and isolated.[2] According to the United Nations (UNDP), 80% of people with disabilities live in developing countries, where the issue gest even more critical as most schools (91%) tend to be ill equipped with technology aids to care for the needs of students with special needs.[3]

1.1 Motivation

Historically, finding accessibility solutions for LD have concerned communities [5], employers [6], policy makers [7]. Nevertheless, persons with disabilities are often underserved. Schooling can be can be discriminatory [8], often presenting parallel education systems. Once formal schooling is over, accessibility solutions for supporting adults with disabilities are still scarce [9]. Decades ago and since, most reviews of issues in LD in the non-medical literature examine use cases and obstacles, successes and failures, adoption and abandonment of related assistive technologies [10]. Human Computer Interaction (HCI) design principles were defined for ease of use and often applied using user-centered design approaches (UCD). Users began taking center stage in the needs analysis, design and testing of the application, until there was a need for more inclusive designs to improve the usability of assistive technology (AT) products [11] and broaden their application to different user groups. Technology publications boast the existence of standards and guidelines for inclusive designs without directly addressing the needs of people with LD in the depth required [12]. ***What is the state of research on accessible designs for people with LD? What principles of HCI design exist for users with disabilities? What Meta principles for accessibility of users with LD can be instantiated towards the inclusion of differently enabled users?***

[1] https://www.ncld.org/.

[2] https://www.mencap.org.uk/about-learning-disability/about-learning-disability/facts-about-learning-disability.

[3] InfoPro Survey in Lebanon 2014.

2 Approach

In line with the pivotal work of [13, 14] in HCI design, our paper seeks to underscore Meta principles (higher order guiding principles) for accessible designs for people with LD. Our aim is not to present an exhaustive set of principles, but rather to underscore essential higher order guiding principles for technology accessibility design for users with LD. Our approach consists of four basic steps:

First, we provide a background on the context of people with LD followed by an overview of related assistive technology, interfaces, and accessibility/usability concepts for the foundation of our paper's objective.

Then we conduct a thorough review of the literature on suggested rules and guidelines for accessible designs for inclusion. We search for papers written in the English language and including keywords of "information technology"; "information technologies"; "human computer interaction"; "user interface design"; "user centered design"; "assistive technology"; "assistive technologies" in the context of LD. We pay attention to include all possible permutations in plural and singular form of the keywords.

Next, in an attempt to deepen the exploration on the main topic of the paper within its stated scope, we conduct a search for empirical case studies in peer reviewed journals written in English, with the keywords "case studies" AND "learning disability" AND "accessible design". No date limits were applied and no journals were excluded in the search. Case studies are investigated as they reflect an in-depth, and detailed examination of a subject of study [15]. The search on Google Scholar found only 124 articles in journals on education, assistive technology, human computer interaction and disability informatics including medico-social journals, practitioner publications and policy periodicals. The papers were read in full, checked for relevance, excluding patents and citations, removing duplicates, and restricting the review to papers relevant to our study. Consequently, 32 papers were singled out for our work as they relate directly to technology designs for people with LD or related disabilities as opposed the remaining studies that pivoted around classroom settings, landscape, environment, or access for the physically disabled. Findings from these papers are presented in Sects. 4.1 and 4.2.

Lastly, we categorize the extant case studies under themes to guide the discussion around accessibility design guiding principles for users with LD.

3 Background

Though scarce, most of the literature in the context of people with LD focus on use cases for technologies, interfaces, and present concepts of usability and guidelines for accessible designs.

3.1 Context of People with LD

The term "Learning Disabilities" is an "umbrella" term describing a number of other, more specific LD, that affect a person's ability to understand numbers and learn math facts (Dyscalculia); or a person's reading ability and related language-based processing skills (Dyslexia); or a person's handwriting ability and fine motor skills (Dysgraphia). Most people with LD (85%) have a reading disability, or dyslexia [16].

LD could derive from or induce other behavioral disorders such as ADHD (Attention Deficit, Hyperactivity Disorder), a condition that would make learning extremely challenging. Such is in the case of Visual Perceptual/Visual Motor Deficits affect the understanding of information that a person sees, or the ability to draw or copy. Other non-verbal LD, such as trouble interpreting nonverbal cues like facial expressions or body language and may have poor coordination, which may induce learning difficulties. Although not a learning disability, Dyspraxia (a developmental disorder of the brain in childhood causing difficulty in activities requiring coordination and movement) often exists along with dyslexia, dyscalculia or ADHD and affects the ability of executive functioning (processes such as planning, organization, strategizing, paying attention to and remembering details, and managing time and space). LD related physical disabilities such as Auditory Processing Disorders (APD) affect how sound that travels unimpeded through the ear is processed and interpreted by the brain may also impede learning abilities, precisely in the case of Language Processing Disorder (LPD), a specific type of (APD) that affects attaching meaning to sound groups that form words, sentences and stories.

3.2 Technologies, Interfaces, Usability and Inclusion

The notion of assistive technology (AT) refers to devices used to compensate for disabilities. The US Technology-Related Assistance Act of 1988 defines an assistive technology as "*any item, piece of equipment, or product system acquired commercially off-the-shelf, modified, or customized, that is used to increase, maintain or improve the functional capabilities of individuals with disabilities*". Persons with LD have deficits in the ways they process information. AT would then provide a means of modifying the way they receive or express information in a manner that accentuates their strengths and helps them work around their difficulties in potentially achieving job independence, satisfaction, and success to their use of technology [17]. The selection of an appropriate technology will depend on the individual's strengths and weaknesses in areas such as reading, writing, math, spelling, listening, memory, and organization as well as on the individual's prior experience with and interest in using AT [18].

AT for persons with LD can include, but is not limited to, recorded books, computers with speech recognition, tape recorders, readers/tablets, spellers/spellcheckers, calculators and organizers, word processors with optical character recognition (OCR) systems (as an aid for dyslexia and reading disabilities). AT tools for auditory processing disorders can include listening devices, audio recorders captions and text-to-speech apps. Software solutions include speech recognition, text-to-speech and typing tutors, ideal for those with dyslexia, dysgraphia (voice recognition software, word processing with OCR, etc.) and dyscalculia (software that assists with mathematical function using graphics, simplifications and breaking down complex functions into simpler ones [19].

In the early understanding of AT, researchers report that developers have sought ways to adapt mainstream technologies and modify them for the use of people who have disabilities [20]. However, acceptance of AT among users is impacted by its utility and usability [21]. In the last few years, technology standards have explored ways to transform AT that can result in new forms of social inclusion, transforming the thinking of technology developers to build technology for people, not disabilities [22].

Inclusive and accessible user interface standards (as opposed to assistive) are proposed as part of new implementations [23]. Technology feature and functionality standards for LD have transitioned focus from which technology to use to what interface to use for the technology. Adapting interfaces of existing platforms to include persons with LD (inclusive) instead of developing specific AT that assists persons with LD (assistive). Touch to see, tactile learning, 3D technologies bring a sense of inclusion [24], with features of haptic feedback [25]. Such features are leading this inclusion transition.

Workers with mental deficiencies have advocated tactile interaction for learning of real tasks using devices and equipment that support tactile interfaces as opposed to computer mouse or keyboard as a means of data entry [26]. Their colleagues who have no impairment could reach the same outcome, benefit equally and share the experience. Wearable computing [27], internet of things (IoT), artificial intelligence (AI), and cloud computing are becoming integrated into a trend to achieve the claim of inclusion [28].

3.3 Legislation for Accessibility of Web-Based Interfaces

International legislations (US[4] (1973 with an amendment to section 508 in 2017); AU[5] (1996); UK[6] (2012); Canada[7] (2012) and the EU[8] (2016), have precipitated to set guidelines for accessibility of web-based interfaces [12].

In summary, section 508 technical standards for features of accessibility at the interface level, software applications and operating systems discussing accessibility

[4] https://www.access-board.gov/attachments/article/1877/ict-rule.pdf.

[5] http://webguide.gov.au/accessibility-usability/accessibility/.

[6] https://www.out-law.com/page-330.

[7] Canadian Treasury Board Secretariat Standard on Web Accessibility. Tbs-sct.gc.ca. 2011-08-01.

[8] Council of the European Union Inter-institutional File: 2012/0340 (COD).

Table 1 Web content accessibility guidelines (WCAG 2.0)

Principle	Guidelines
Perceivable—ability to perceive information being presented (even if it can't be invisible to all of the users senses)	• Provide text alternatives for non-text content • Provide captions and other alternatives for multimedia • Create content presentable in different ways without losing meaning • Make it easier for users to see and hear content
Operable—Ability to operate the interface (cannot require interaction that a user cannot perform)	• Make all functionality available from touch, keyboard or mouse • Help users navigate and find content • Give users enough time to read and use content
Understandable—Ability to understand information as well as operation of the user interface	• Make text readable and understandable • Make content appear and operate in predictable ways • Help users avoid and correct mistakes
Robust—Ability to access the content as user capabilities evolve and technologies advance	• Maximize compatibility with current and future user tools

related to standardized ports, and mechanically operated controls such as keyboards and touch screens. The definition of the specification assures accessibility to web content, e.g., text description for any visuals such that users of with a disability or users that need AT such as screen readers and refreshable Braille displays, can access the content.

At a macro level, section 508 technical standards echo guidelines of Web Accessibility Initiative (WAI), developed by the World Wide Web Consortium (W3C) covering web authoring tools, content and browsers and media players, including some aspects of AT.[9] Web Content Accessibility Guidelines version 2.0 (WCAG 2.0), published by the Web Accessibility Initiative (WAI) have defined 12 guidelines for inclusion organized under four principles (websites must be perceivable, operable, understandable, and robust) (Table 1).

4 Findings and Discussion

4.1 Principles and Guidelines for Accessible Designs

Principles of HCI Design for Users with Disabilities. Though scarce, research has recognized the value of accessible web design [29] and identified principles for HCI design for users with disabilities. Our literature review reveals a wide consensus that

[9] https://www.w3.org/WAI/intro/components.php.

Table 2 HCI Design for users with disabilities[a]

Focus	Guidance
Layout	• Use bigger graphic elements i.e. fonts, buttons, icons etc. • Use very few colors, clearly distinct from one another • Use sound (sparingly) to reinforce the visual information
Content	• Avoid lengthy written information • Minimize information that must be remembered from one screen to the next • Use familiarity and imagery for what must be remembered • Reduce the normally suggested number of maximum elements on a screen
Navigation aids	• Direct users' attention by structuring and grouping elements • Avoid simultaneous tasks • Offer a narrow and shallow decision structure with few choices for options • Avoid situations when the user feels 'trapped' in a screen—triggering severe frustration
Motor & Sensory Aids	• Find alternatives to using the mouse or part of the keyboard. Minimize the number of gross motor movements e.g. back and forth between mouse and keyboard and transitions between gross and fine motor movements

[a]Consolidation from the literature [20, 21, 24, 25, 30–37]

an approach of principles for simplicity (in layout, navigation and content) that has produced a positive outcome for target user groups in different contexts, cultures and social settings based on user centered design practices (Table 2).

4.2 State of the Research on Accessible Designs for People with LD

We have found that research on this subject has focused on advocating the Web Accessibility initiative, noting the lack of awareness about the needs of the disabled and addressing suggestions to improve the quality of services.

"Accessibility *in learning shouldn't be viewed as a compliance activity, rather it should be embraced as a means of ensuring good design*" [38; p. 62]. The state of the art in web accessibility research, development and practice shows timid progress in this domain [39, 40]. Empirical investigation exploring the use of accessibility standards for people with LD is scarce. Our literature search has identified four main directions of research. The first direction presents case studies that advocate the use of Web Accessibility Standards [41–44], identify shortcomings [45] and suggest ways to refine the related guidelines [46].

Another stream of studies recommends approaches to promote awareness on the need for diversity [47], identifies accessibility needs, requirements, and preferences

[48, 49], and provides guidance to develop accessible e-learning practice [50]. In a third direction, empirical studies have concluded strong support for extending user centered design principles [51] that engage persons with disabilities in all the phases of the technology design [52]. Finally, we have identified a recent trend in the literature promoting inclusion for differently enabled users especially in quality of services for learning [40, 42, 53–55].

Table 3 summarizes these findings into four suggested Meta principles of Technology accessibility design for users with LD.

4.3 Accessibility Design Principles for Users with LD

Refining Web Accessibility Principles and Guidelines. Colwell et al. [40] describe the need for a diverse solution for access to laboratory work for students unable to attend conventional lab setting due to visually, physical or hearing impairment [40]. This brings up the conversation that different people can have different but related views of accessibility [41]. Case studies in distance learning for students and teachers with general disabilities have recognized positive experience enhancements in the adoption of universal design and universal access principles [46] with the implementation of web accessibility standards [42]. Most studies found advocate the use of reference principles from the Web Accessibility Initiative in a general context [42–44]. Shortcomings are related to evaluation benchmarks and indicators [45], lack of policies required, integration tools available and additional tools needed [42].

Building Awareness on the Need for Diversity. Awareness at the policy making level has been set for more than a decade [56]. Yet, case studies still find significant obstacles. Addressing accessibility needs for secondary adolescent with disabilities, Savi et al. [48] evaluate acceptable use outcomes for a website that adhere to accessibility standards. Library programs and service providers lack awareness about the needs of the disabled among the leaders and trainers in the library profession [47], giving rise to case studies offering suggestions to improve the quality of library services for students with disabilities [55]. Studies involving people with cognitive disabilities [44] confirm the scale of diversity in the need for accessibility with specific requirements and preferences. For individuals with LD, synchronous discussion is not very conducive as it is synonymous with the rapid delivery and execution of thoughts and ideas. Pedagogical approaches must be aware of these specific disabilities to be able to plan for an alternate method of communication [54].

Extending the Application of User Centered Design Principles. Deep awareness is required in order to develop accessible e-learning practice that would provide an inclusive accessibility for a large scope of individuals with LD. For instance, accessibility features in technology may not be sufficient in the case of the visually impaired demanding a certain dependence on support by a seeing person for their learning experience [51]. In their case study, Kennedy and Leung [52] have advocated user centered design principles that considering the needs of intellectually disabled communities might be beneficial for effective digital experience design. The diver-

Table 3 Meta Principles of Technology Accessibility Design for Users with LD

Meta principles	Study findings [Ref]	Use case (Related disability)
Refining web accessibility principles and guidelines	Advocate the web accessibility initiative in a general context [41]	Access to laboratory work for students unable to attend conventional setting (visual/physical/hearing)
	Recognize the value of web accessibility designs [42]	Distance learning (students and teachers with general disabilities)
	Web accessibility design standards—shortcomings: evaluation benchmarks, policies, tools [45]	Distance learning (students and teachers with general disabilities)
	Suggested accessibility indicators for distance learning [46]	Distance learning (students and teachers with general disabilities)
	Advocate the Web Accessibility initiative in a general context [43]	Evaluate outcome for website that adhere to accessibility standards (Secondary adolescent)
	Advocate the web accessibility initiative in a general context [44]	Using accessible web 2.0 (students with disabilities)
Building awareness on the need for diversity	Lack of awareness about the needs of the disabled [47]	Access to library programs and services (general disabilities)
	Deep awareness is required in order to develop accessible e-learning practice [50]	Different people can have different but related views of accessibility (general disabilities)
	Confirms diversity of the accessibility needs, requirements, and preferences [48]	Synthesize measures for accessibility to electronic communication (people with cognitive disabilities)
	Awareness of disabilities is needed to plan for an alternate method of communication [49]	Synchronous discussion is not very conducive to this type of learning (learning disability)
Extending user centered design principles	Advocate extending user centered design principles [51]	Needs identification considered beneficial to digital experience designers (intellectual disability)
	Framework for assessing the potential effectiveness of emerging experiential media platforms [52]	Including persons with disabilities in building media prototypes… (differently enabled users)

(continued)

Table 3 (continued)

Meta principles	Study findings [Ref]	Use case (Related disability)
Inclusion of differently enabled users—quality of services	Suggestions to improve quality of library services for students with disabilities [53]	Library programs and services (general disabilities)
	Accessibility is not sufficient—dependence on support by a seeing person [54]	Accessible education for blind learners (visually impaired/Blind)
	Universal design and universal access in distance learning [40]	Distance learning (students and teachers with general disabilities)
	Lack of governmental governance for equally accessible systems for education [55]	Serious discrimination persists in some societies (general disabilities)
	Recommendation to use graphical content to counteract the negative impact of dyslexia [42]	Accessibility study of dyslexia and information retrieval (learning disability/dyslexia)

sity of LD challenges the usability (fit for use) and accessibility (fit for purpose) of devices by multiple user groups, generating a need for complex customizations [57]. Increasingly, developers of application for people with LD have found better success by integrating user centered design (UCD) processes to improve accessibility and usability (visibility, legibility and language) of systems by users with impaired functions [58]. Users with special needs [59], perceptual impairments [34], visual impairments [60], cognitive impairments [61], and reading disabilities [32] participate in defining, testing and adjusting application interface and functionalities to inform inclusive designs [62].

Towards the Inclusion of Differently Enabled Users. Since more than a decade, closer to the practitioner's circle, inclusive design guidelines have stipulated adequate design principles of user interfaces that have a high impact on the social lives of users with disabilities [63]. The intention is to inform design thinking in the context of providing a comparable experience for all, suitably in different situations, to people regardless of their circumstances [ibidem]. Designers have looked at ways to provide information, tools, services and structures that is readable, understandable and usable for the biggest possible user group [23]. In their study on accessibility study related to information retrieval, Dyslexia had a negative effect on search performance in systems with a low tolerance for errors [53]. Berget et al. [53] recommend using graphical content to counteract the negative impact of dyslexia. Emerging experiential media platforms, using augmented and virtual reality. These platforms advance accessible AT in the direction of inclusion of differently enabled users [43].

5 Conclusion

The paper explores the present LD literature to outline the principles capable to support the present transition from assistive technologies to inclusive technologies (i.e. that can be used both by impaired and non-impaired people). We have reviewed guidance indicated for HCI for users with disabilities (with a special attention to LD), user centered design approaches recommended for enhancing the usability of AT and interfaces, legislations driving the need for accessible designs at the policy level and inclusive design guidelines used by practitioners. Following these guidelines, and associated techniques, the World Wide Web Consortium (W3C) claims to make content accessible to a wider range of people with disabilities, including blindness and low vision, deafness and hearing loss, learning disabilities, cognitive limitations, limited movement, speech disabilities, photosensitivity and combinations of these.

From our review, it is evident that interest in the subject of this paper is growing. With less than 10 papers found dating prior to the turn of the millennium, we found a steady increase in publications since. The period between 2001 and 2016 has seen an average of 5–6 papers published per year, whereas our search shows twice as many (12 papers) in 2017 alone. These publications address obstacles and shortcomings [42, 44, 47, 54], sometimes provide suggestions for improvements [43, 45, 53, 55] and largely advocate the use of web accessibility standards and UCD [40, 42, 46, 48, 50, 52].

That said, we recognize that there has been a clear focus on improved reading capabilities for people with cognitive disabilities in the case of WCAG 2.0. However, adherence to accessibility guidelines is weak as concluded by Jaeger and Xie [64], possibly induced by the constant change of technology platforms and implementations [65].

Extant contributions from the literature postulate how to make content accessible ubiquitously, interfaces usable to all user agents, primarily for people with disabilities. Nevertheless, a consensus is yet to be reached in areas of access to technology for people with cognitive difficulties [66].

We have not yet found a formalized set of principles that can be essential in the complete usability experience of people with learning disabilities! For instance, internet access technologies for individuals with deaf-blindness are still in the early stages of development and are targeted towards specific functions of the internet. This signals that inclusive design principles have not yet reached the breadth required for effective inclusion [37]. Therefore, we conclude that research has yet a significant challenge ahead to provide a more pragmatic evidence for theory and practice in the direction of inclusive AT.

The authors are aware that a set of design principles for inclusion may be costly and arduous to implement but still helpful to orient practitioners' work and further development. Awareness of ethical-technical implications of IT/IS design is increasing so that writing and conversation and elaboration of these concepts are of importance. Furthermore, learning disabilities also affect the elderly, a part of the world population which is steadily increasing and looking for support through the development of inclusive ITs.

In closing, we borrow from MacIver [67; p. 1708) and reckon that "*Inclusion is influenced by the physical environment, attitudes, expectations and opportunities, in addition to a learner's skills and abilities*". Through this paper we encourage broader and deeper studies on inclusion for people with LD in order to enrich the literature and heighten the awareness on the subject. Requirements for inclusion could be costly and complicated hindering its realization in contexts where accessibility to information is mostly necessary [68].

Still, "it is necessary to move beyond guidelines that focus on one-way transfer of information and to develop guidelines for multidirectional communication" [69; p. 55). Practitioners and technology developers are invited to use this paper to hone their approaches towards inclusive platforms. Platforms that combine HCI simplicity principles discussed in the paper, refine guidance from WCAG 2.0 with benchmarks and indicators, broaden the application of UCD principles with clear awareness for the need for diversity, serving the sustainable agenda,[10] towards the inclusion of differently enabled users in the digital ecosystem.

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