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ORIGINAL PAPER

Accessibility, Usability, and Universal Design for Learning: Discussion of Three Key LX/UX Elements for Inclusive Learning Design

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Abstract
In this paper, we aim to provide readers with three critical concepts that can maximize inclusivity of learner experience (LX) and user experience (UX) design: accessibility, usability, and universal design for learning (UDL). Although recent K-12 and postsecondary education have experienced rapid change in its student population with the growing awareness of the equal opportunities for all, general design methods of addressing such diversity across formal and informal learning contexts are still prone to retrofitted changes to predefined instructions in favor of standardization. This is due in part to the limited interpretation of accessibility as the concept for the medical model of disabilities where learners with disabilities are not regarded as users or consumers, but as clients or patients. Moreover, LX and UX have been widely designed with the usability of dominant group in mind while trading off exclusion of those who cannot fit themselves into it. However, accessibility and usability are not mutually exclusive; rather, a truly inclusive learning design (i.e. UDL) comes from the interplay between them. Through the paper, we provide definition and description of each concept and provide practical examples of how UDL principles can be applied to inclusive learning design.

Keywords Universal Design for Learning · Learner experience · Inclusive learning design · User experience · Assistive technology

Introduction

As information technologies become increasingly integrated into our lives, there is a growing interest to consider diverse users including people with disabilities (Putnam et al., 2015). This was the same for the field of education. In fact, over the last decade or so, the concept of accessibility has become an important instructional topic for both formal and informal learning. The need for accessibility in learning environments initially emerged from legislative movements advocating equal access to general curriculum for individuals with disabilities (Rao et al., 2014). For instance, the Individuals with Disabilities Educational Act (IDEA, 2004) mandated equitable access for K-12 students with disabilities to general education while the Americans with Disabilities Act (ADA, 1990), and Sects. 504 (1973) and 508 (1998) of the Rehabilitation Act ensured these mandates at a postsecondary level (Rao et al., 2014; Roberts et al., 2011). Such legislation has contributed to the growing presence of students with disabilities in general education.

However, although recent K-12 and postsecondary education have experienced rapid change in its student population with the growing awareness of the equal opportunities for all, general design methods for addressing diversity across formal and informal learning contexts are still prone to retrofitted changes to predefined instructions in favor of standardization. This is due in part to the limited interpretation of accessibility as the concept for the medical model of disabilities where learners with disabilities are not regarded as users or consumers, but as clients or patients.

In contrast to the common perceptions of accessibility as expensive, time consuming, and overwhelming that can only benefit limited minor population (i.e., learners with disabilities), early implementations of accessibility components in learning design have proven to be cost-effective, responsive, and beneficial to not only students with disabilities, but to all students (Rose, 2000, 2002; Silver et al., 1998). However, students with disabilities are often left without appropriate

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support from instructors who are not equipped with any knowledge about how to engage them. In fact, many of the teachers still feel that they are ill-prepared to teach students with disabilities (Smith & Tyler, 2011).

The traditional perspectives to assistive technology consider accessibility as a bridge that can support learners with disabilities to overcome barriers in learning environments that are not universally designed. However, the current notion of universal design for learning (UDL) suggests that the learner population as a whole, regardless of dis/abilities, need to be considered when designing a learning environment. In this regard, the basic principle of UDL is inclusive of designing for all learners (Al-Azawei et al., 2016; Fairfax & Brown, 2019).

Given that accessibility is one of the key concepts in understanding both learner experience (LX) and user experience (UX), we aim to discuss accessibility, usability, and UDL as three key components in maximizing inclusivity of learning environments. Then, we will expand the conceptualization of accessibility in relation to usability. The two concepts, despite their distinctions, share many aspects and implications in LX and UX design processes. This paper posits that assistive technology and UDL are complementary concepts in establishing an effective learning environment for all. Moreover, this paper will discuss how UDL fosters inclusive LX through the interplay between accessibility and usability. Lastly, this will introduce how different assistive technologies support varying types of disabilities and how UDL principles can inform the design of inclusive learner experience with the assistive technologies.

Conceptual Foundations

Learner Experience (LX) and User Experience (UX)

The notion of learner experience (LX), sometimes referred to as learning experience, stemmed from the need to design learning environments more holistically (Ahn, 2018). There has been a paradigm shift when conceptualizing learning due to the emergence of diverse learning contexts that ranges from classrooms to informal learning environments such as libraries and museums, home, workplaces, as well as online and virtual environments. As a result, the role of learning designers has been expanding to encompass both formal and informal learning environments in designing learning environments that are situated in diverse learning contexts (Ahn, 2018).

In order to accommodate such transition, Ahn (2018) suggests that the notion of user experience (UX) could shed light in exploring LX. Originally discussed in technological sectors, UX draws from diverse fields to understand how a user interacts with technologies. There are three inspirations from UX that can potentially help designing LX: a) techniques that explore and recognize human experiences; (b) empathizing with users; and c) an emphasis on usability. On a similar note, Earnshaw et al., (2017) suggests that the field of instructional design could benefit from focusing on human–computer interaction (HCI) and user-centered design (UCD) and that there is a need to consider these constructs in facilitating learning through the design of technology. In other words, the ever-changing technological atmosphere surrounding learning design calls for new ways to understand learners, and already established conceptual notion of UX can be used to understand what LX is. Such perspective also aligns with previous tradition of applying UCD approach to the field to accommodate technological needs in the educational context (e.g. Jackson et al., 1996; Krajcik et al., 1998; Soloway et al., 1994). The UCD approach recognized the power of technologies to support learners and professionals gain their expertise (Soloway et al., 1994). The notion of LX and the tradition of learner-centered design are similar in nature in terms of implementation of HCI's methodologies and approach for learners and learning environments, yet LX focuses more on complexity of today's learning environments.

While both UX and LX share the notion of exploring experiences of "peoples", there are distinctions that separate them from each other. The distinction stems from LX's specific focus on learning and learners. Bergin (2018) distinguishes LX and UX by listing ten critical differences (see Table 1).

While these notions are more of a practical guideline on distinguishing LX and UX, it recognizes that LX is more specific in terms of its purpose, which specifically focuses on learners and their learning processes. Hence, while UX encompasses all aspects of user's interaction with products, LX is more specific in a way that it involves deeper understanding about learning goals and learning environments. Therefore, it is important to note that understanding UX is not sufficient to fully comprehend what LX is. In order to fully understand LX, notions of learning design such as learning theories, pedagogies, and knowledge about teaching and learning are critical.

Accessibility

Before going further into exploring UX and LX in terms of accessibility, it is imperative to operationally define what accessibility is and what other concepts are closely related to accessibility. There are many available definitions for accessibility. Due to its multifaceted nature, accessibility has been discussed in multiple fields such as environment and planning architecture, technology, etc. (Iwarsson & Ståhl, 2003). In their discussion of web accessibility, Petrie et al. (2015)

Table 1 Differences between LX and UX (Bergin, 2018)

Differences	Interpretations
It's difficult to overcome our own biases (p. 18)	LX designers have often have more educational trainings than their target learners. Hence, it is important to acknowledge the differences and avoid bias through research findings
Targeting struggling students is a struggle (p. 18)	Student struggles can vary greatly, and it is important to address multiple levels of learner difficulties
The LX is (often) prescriptive and not elective (p. 17)	The prescribed nature of LX requires both instructor and student experiences
Learning science and human centered design can be in conflict (p. 17)	There may be contradictions between the two fields
Data is difficult to gather and analyze (p. 17)	The scattered nature and complexity of learner data can be a hindrance
Timelines are based on the academic calendar (p. 17)	LX is often school based, so it requires careful planning for execution
Iterative testing raises ethical concerns (p. 17)	Because the intervention impacts the student learning, research needs to be designed in a way that does not penalize students
Research requires additional rigor (p. 16)	On top of UX research requirements, LX requires foundational learning sciences research and learner outcome research
The context is variable (p. 16)	The complex nature of LX makes it impossible to isolate certain variables
The experience is driven by standards, objectives, and outcomes (p. 16)	Unlike UX, LX has certain standards to follow

felt the need to come up with a unified definition. In order to achieve this goal, they have gone through an extensive literature review of 50 available definitions on web accessibility and came up with common concepts that reside within the definition dealing with web accessibility. The concepts were a) "groups of users, characteristics, needs of users"; b) "what users should be able to do"; c) "technologies used"; d) "characteristics of the website"; e) "design and development of the website"; and f) "characteristics of the situations of use" (p.2). Based on these concepts, following definition has been created:

> *All people, particularly disabled and older people, can use websites in a range of contexts of use, including mainstream and assistive technologies; to achieve this, websites need to be designed and developed to support usability across these contexts* (p.1).

The definition was intended specifically for the web; however, it still works for other contexts since the definition covers the essence of what accessibility would mean in the context of technology. Websites could easily be substituted with other products or services. Per definition, accessibility allows people to freely access and perform intended tasks while using a product. Another definition worth looking at is by IMS Accessibility SIG. It is the system's ability to accommodate the needs for all learners. This definition focuses on the learning system or learning resources' flexibility to accommodate needs for all learners (Cooper et al., 2007; IMS Global Learning Consortium, 2002). Also, accessibility can be interpreted in terms of its characteristics. Web Accessibility Initiative (2008) suggests four principles for accessibility which are: a) perceivable; b) operable; c) understandable; and d) robust. According to these principles, the information needs to be presented in a way that is perceivable by learners. Also, learners should be able to navigate and operate user interface elements and be able to understand the information itself and how to operate user interface. Lastly, the content should remain accessible as the technologies delivering the content evolve.

Usability

Usability can be defined as a system's degree of effectiveness in achieving the intended goal through the usage of a system (Cooper et al., 2007; Karat, 1997). More formalized definition is provided by ISO 9241–11 (ISO, 2018), which defines usability as "the extent to which a product can be used by specified goals with effectiveness, efficiency and satisfaction in a specified context of use." In this definition, effectiveness is the degree of success in achieving the goal of the users, efficiency refers to the degree of resources used to achieve the goal, and satisfaction refers to positive attitude derived from using the product. Other concepts that are related to the notion of usability include flexibility, learnability, memorability, and safety (Petrie & Bevan, 2009). To reiterate, usability refers to how much a user is successful in accomplishing the intended task, and success can be measured by different constructs such effectiveness, efficiency, and so on. In other words, if a product is usable, it means that a user can use it easily in order to accomplish the intended task.

The Relationship Between Accessibility and Usability

The relationship between accessibility and usability have been discussed in multiple literature (e.g. Cooper et al., 2007; Iwarsson & Ståhl, 2003; Petrie & Bevan, 2009). Accessibility and usability are closely linked to each other because low accessibility for certain individuals is bound to affect the usability. Both accessibility and usability of a learning system can impact learners. Although something inaccessible is not necessarily entirely unusable, poor accessibility does lead to poor usability. Learners might still manage to complete tasks, but they will likely face greater difficulty or frustration in doing so. Conversely, if the accessibility of a product increases, the usability would increase as well (Cooper et al., 2007). Accessibility and usability are similar in terms of how they are measured. Both concepts are often measured by observed task performances meaning that both accessibility and usability of a product is determined by whether or not a user was successful in completing the task with the product. (Iwarsson & Ståhl, 2003). However, these two concepts cannot be used interchangeably. Because in nature, they are referring to two concepts that are inherently different. Accessibility is more about the relationship between a person and an environment. It is the "encounter between the person's or group's functional capacity and the design and demands of the physical environment" (p. 61). In other words, there are standards and requirements that need to be met for a product to be called accessible for a certain group of people. On the other hand, usability is more of a personal term. In order for a product to be called usable, the product does not have to meet all the standards. Perception and satisfaction of a user is a key criterion. Hence, while they are closely related, something is usable does not necessarily mean that it is accessible.

Universal Design for Learning (UDL) and Assistive Technology (AT)

The concept of accessibility varies between individuals and groups with disabilities. Because of this variability, it is extremely difficult to address all the issues regarding disabilities. Then how can accessibility be improved? This is where UDL comes in (Edyburn, 2005). Unlike traditional design philosophies, which often presuppose a 'standard' population and subsequently create 'bridges' for those who do not fit this presumed norm, UDL adopts a more inclusive stance. It does not perceive the population as segmented into 'general public' and 'others' Instead, the notion of universal design and UDL acknowledges the entire spectrum of human diversity as a single, heterogeneous population. This approach eliminates the need for 'bridges' by designing environments and products from the outset to be accessible and usable by all people, regardless of ability, thereby promoting equity and inclusivity (Edyburn, 2005; Iwarsson & Ståhl, 2003).

Rose et al.'s (2005) work provides a good framework for understanding accessibility and UDL. Recent advancement of technology enabled us to address diverse yet specific needs of individual learners with disabilities with AT. There are numerous AT that are currently available (e.g. screen readers; voice recognition; Braille displays; captioning; switches), and each has specific purpose and goals. AT follows the traditional view of accessibility. AT are analogical bridges. There are learning materials and curriculum for a population without disabilities, and AT helps those with disabilities engage with learning environments that are tailored for people without disabilities.

UDL approach is different. As previously mentioned, the whole notion of UDL posits that a design needs to serve all populations regardless of their dis/abilities (Edyburn, 2005). According to this philosophy, the population with disabilities are not people with additional needs. They are people with different needs, and their needs are just as natural as people without disabilities. UDL is an educational framework that guides the design of learning goals, materials, methods, and assessments to optimize teaching and learning for all students. Based on neuroscience research, UDL aims to improve and optimize learning for all people by fulfilling the three core principles (Center for Applied Special Technology, 2011; Jones et al., 2011; Rogers-Shaw et al., 2018). The three core principles of UDL are: 1) ensuring multiple means of representation to present content in different ways, 2) allowing multiple means of action and expression to differentiate how students can demonstrate their knowledge, and 3) providing multiple means of engagement to stimulate motivation and interest in learning. By applying these principles, educators can proactively design flexible learning experiences that reduce barriers and give all students equal opportunities to learn and succeed (Center for Applied Special Technology, 2011).

UDL encompasses technologies, pedagogies, interactions, etc. It is about creating an environment and atmosphere that welcomes everyone. AT and UDL philosophies are indeed different yet complementary. Even if UDL is successfully implemented, it is extremely difficult to adapt to individual learner needs. In such cases, AT could fill in the gap and help learners with needs (Rose et al., 2005). In understanding the interplay between AT and UDL, the following diagram could be useful (Fig. 1). In serving the whole population of people with and without dis/abilities, UDL perspective provides purpose for the environment:

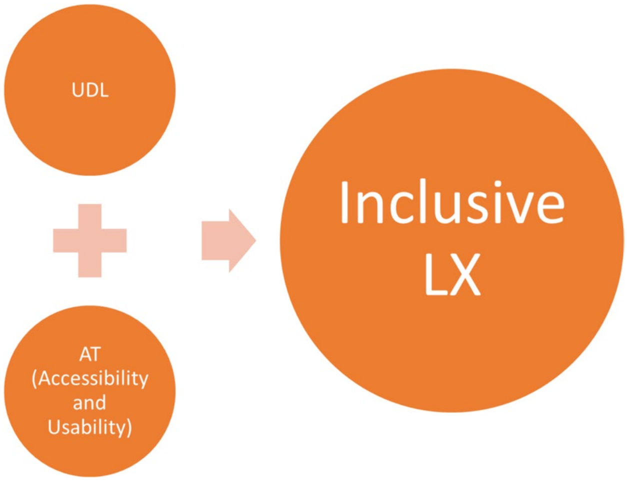

Fig. 1 UDL, AT, and Inclusive LX

that is supporting learning for all. AT, which comprises accessibility and usability, support UX of the population. The interplay between the two creates inclusive LX.

Technological Examples

It is important to note that there is not a single technology that can accommodate all the types of disabilities. There exists a wide range of AT that enables learners with disabilities to be better engaged during learning, and these technologies vary depending on the disabilities. Because the need for AT is different for each disability type, it is important to understand each disability type. In their discussion of web accessibility, Brophy and Craven (2007) list groups that can benefit from accessible design which can be applicable in learning context as well:

> *People who are blind (either totally blind or with no useful sight) who need to use screen reading technology or refreshable Braille to access the web;*
> *People with a visual impairment who need to use screen magnification or screen enlargements/adjustments;*
> *People with a learning difficulty such as dyslexia who need to adjust the screen or text or who use screen reading aids*
> *People who have a hearing impairment and need to have any audio or sound captioned or described in text; and*
> *People who have a physical impairment that does not allow them to use a mouse, or who need to use assistive technologies such as joysticks, switches, or speech input to access the web* (p. 951–952).

Other literature have similar categorization schemes for disabilities (e.g. Duhaney & Duhaney, 2000; Laabidi et al., 2014).

As described, different types of disabilities require different types of AT to accommodate the needs. In the subsequent subsections, we discuss how different AT support aforementioned disabilities and how UDL principles can guide the design of inclusive learner experience with these technologies. For visual and hearing disabilities, the essence is providing an alternative way to perceive information. Technologies ranging from screen readers to automated captioning tools enable learners to perceive alternate modes of information delivery. Information intended for a certain sensory system is being substituted via change in modality. On the other hand, for physical disabilities, the essence is providing an alternative way to input information. For learning disabilities, the needs could arise from both output and input needs. Lastly, mobile devices from the perspective of AT and UDL will be discussed.

Assistive Technologies for Learners with Visual Impairments

Disabilities related to human vision range from mild visual impairment to blindness. Many of the learning materials include visual information either in the form of image or text, and it is critical for learners with visual disabilities to have other means to access such information. Therefore, many of the AT focus on providing alternative ways to reading resources. The UDL guidelines provide a framework for developing accessible learning environments and materials. The guideline "Provide Multiple Means of Representation" (Center for Applied Special Technology, 2011, p. 13) is particularly relevant for learners with visual impairments, as it emphasizes the importance of presenting information in different ways, such as through auditory and tactile means. One of the key AT for learners with visual impairments is screen reader that use text-to-speech synthesizer and refreshable braille display (e.g. Bigham et al., 2008; Southwell & Slater, 2012). The software converts visual information into audible and tactile signals. The most popular commercial screen reader is JAWS (Job Access with Speech: https://www.freedomscientific.com/products/software/jaws/). It supports speech and Braille output for Windows applications such as web browsers, word processors, email clients, and other Windows standard user interfaces. However, it costs approximately $1,000 USD; thus, another open-source screen reader called NVDA (Non-Visual Desktop Access: https://www.nvaccess.org/) has attracted interest of those seeking alternative solutions. While NVDA is relatively a new product, it has been chasing JAWS rapidly (WebAIM, 2017). These screen readers align with the UDL guideline

"Provide Multiple Means of Action and Expression" (Center for Applied Special Technology, 2011, p. 21) by allowing learners to interact with digital content using alternative methods, such as keyboard navigation and voice commands, rather than relying solely on visual cues and mouse input. Another technology to note would be a magnifier software for learners with low vision: color contrast, zooming features, etc. (Theofanos & Redish, 2005). Although each operating system has their own magnifier, ZoomText (https://www.freedomscientific.com/products/software/zoomtext/) has been recognized for the most widely used one among people with low vision (Moore, 2016). ZoomText Magnifier enlarges and enhances any element on computer screen, and echoes users' typing in text-to-speech synthesizer for low-vision individuals. Magnifier software supports the UDL guideline "Provide Multiple Means of Representation" (Center for Applied Special Technology, 2011, p. 13) by allowing learners to customize the visual display of digital content to meet their individual needs and preferences, such as adjusting text size, contrast, and color.

Assistive technologies for learners with visual impairments effectively blend UX and LX principles. Screen readers like JAWS and NVDA illustrate this synergy by offering auditory and tactile access to digital content. These tools adhere to UX accessibility standards and enable learners to consume educational materials in formats that suit their needs, thereby enhancing comprehension and engagement. Similarly, magnifier software such as ZoomText integrates both UX and LX principles. It follows accessibility guidelines by allowing users to personalize visual displays based on individual preferences, such as text size and contrast. This customization directly influences the learning experience by adapting it to personal needs, promoting better engagement, comprehension, and overall learning outcomes.

Assistive Technologies for Learners with Hearing Impairments

Hearing impairment is another disability type that needs attention. Because we are living in a 'sound-oriented' society where the majority of information is communicated through interactions mediated by acoustic information. Much learning happens by hearing, especially during early childhood. Hence, hearing loss does not merely mean inability to hear. "A hearing loss of any degree or type" would impact such interactions between individuals "which in turn adversely affect language, academic, social, emotional, and career development" (Hart & Risley, 1995, 2003; Luckner et al., 2012, p. 59). In fact, it has been reported that a significant portion of school-age students with hearing disabilities experience learning disabilities as well (Luckner & Carter, 2001). The UDL principle "Provide Multiple Means of Representation" (Center for Applied Special Technology, 2011, p. 13) is crucial for learners with hearing impairments, as it emphasizes presenting information in different formats, such as visual and tactile, to ensure accessibility. By providing alternatives to auditory information, educators can create a more inclusive learning environment that caters to the needs of all students. List of "byproducts of a hearing loss" that impact student learning include: "a) language, vocabulary, and literacy delays; b) gaps in background and domain knowledge; c) inadequate knowledge and use of learning strategies; d) social skills deficits; and e) reliance on assistive technology" (Luckner et al., 2012, p. 59). AT for hearing impairments mainly deal with enabling learners to hear better. Therefore, traditional AT include "cochlear implants, programmable digital hearing aids, bone-anchored hearing aids (BAHA), contralateral routing of signal (CROS) hearing aids, tactile communication devices, personal-worn frequency modulated (FM) amplification systems, and classroom amplification systems" (Luckner et al., 2012, pp. 63–64). These assistive technologies support the UDL guideline "Provide Options for Perception" (Center for Applied Special Technology, 2011, p. 13) by offering learners various ways to access auditory information. For example, teachers can use FM systems in the classroom to transmit their voice directly to students' hearing aids or cochlear implants, ensuring that they can hear the lesson clearly. While these technologies mainly focused on improving hearing itself, other types of technologies emerged to help people with hearing impairments in a different way. Technological advancements in communication technologies brought new needs as well as new ways to communicate. Tele-typewriters were invented in lieu of telephones until emails, instant messaging, and text messaging replaced them. Then video communications emerged in the form of video phones and vlogs which could afford communication via sign languages (Cavender & Ladner, 2008). Video communication tools align with the UDL guideline "Provide Options for Language, Mathematical Expressions, and Symbols" (Center for Applied Special Technology, 2011, p. 15) by offering learners alternative means of communication, such as sign language. Educators can leverage these technologies to facilitate group projects and discussions, ensuring that all students can participate and contribute effectively. Video captioning is another set of technologies that needs attention (Cavender & Ladner, 2008; Hong et al., 2010; Kent et al., 2018). Captioning enables learners to understand, enjoy, and learn from videos. Captioning technology is evolving; for instance, Kent et al. (2018)'s dynamic captioning project enables captioning with character-mapping. Other examples would be automated captioning afforded by web services such as YouTube. Captioning supports the UDL guideline "Provide Options for Perception" (Center for Applied Special Technology, 2011, p. 13) by presenting information in both auditory and visual formats. Teachers can incorporate captioned videos into their lessons and assignments, making the content more accessible to learners with hearing impairments and benefiting all students by providing multiple means of representation.

The impact of these assistive technologies on LX and UX is substantial. For instance, FM systems allow teachers' voices to be transmitted directly to students' hearing aids or cochlear implants, ensuring clear and direct communication. This significantly enhances the learning experience by reducing background noise and ensuring that auditory information is accessible, which is crucial for understanding and retaining lessons. Video communication tools and captioning technologies provide further examples. Video phones and vlogs allow students who use sign language to engage in visual communication, facilitating their participation in class discussions and group projects. This use of video tools aligns with the UDL principle of providing multiple means of representation and communication, ensuring that all students can express themselves and comprehend the material. Captioning technologies, especially those that offer dynamic captioning with character-mapping, make videos accessible to students with hearing impairments. By displaying text that maps to the spoken dialogue, these tools ensure that learners can follow along with the audio-visual content. Automated captioning services on platforms like YouTube also enable educators to provide accessible video content effortlessly. These tools not only improve accessibility but also enhance the overall user experience by making learning materials more inclusive and easier to navigate.

Assistive Technologies for Learning Disabilities

Learning disabilities can be defined as “a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, that may manifest itself in an imperfect ability to listen, think speak, read, write, spell, or to do mathematical calculations, including conditions such as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia” (Edyburn, 2006, p. 18). Basically, it consists of minor disabilities that inhibit learners from fully engaging in learning activities. Language skills (i.e. reading and writing) are often the main problems. The UDL principle "Provide Multiple Means of Representation" (Center for Applied Special Technology, 2011, p. 13) is particularly relevant for learners with learning disabilities, as it emphasizes presenting information in various formats to ensure accessibility. By offering text, audio, and visual representations of content, educators can support learners with different processing strengths and challenges. Different AT such as text- and graphics-base software that supports writing, speech synthesis (text-to-speech) that help learners read the text, and organizational software that help learners organize thoughts systematically, and voice recognition software (speech-to-text) are available (Duhaney & Duhaney, 2000; Forgrave, 2002). These assistive technologies align with the UDL guideline "Provide Options for Expression and Communication" (Center for Applied Special Technology, 2011, p. 22) by offering learners alternative ways to demonstrate their knowledge and skills. For example, a student with dysgraphia may struggle with handwritten assignments but can effectively express their ideas using speech-to-text software. By providing these options, teachers can create a more inclusive learning environment that supports the diverse needs of all students. Furthermore, the UDL guideline "Provide Options for Executive Functions" (Center for Applied Special Technology, 2011, p. 24) can be supported by organizational software that helps learners with learning disabilities manage their thoughts and ideas systematically. These tools can assist students in planning, goal setting, and progress monitoring, enabling them to develop essential self-regulation skills. By incorporating these technologies into their teaching practice, educators can empower learners with learning disabilities to become more independent and self-directed in their learning.

By explicitly integrating the principles of LX and UX, these assistive technologies provide concrete examples of how they enhance both learning and user interactions. For instance, speech-to-text software allows students with dysgraphia to articulate their thoughts verbally, transforming them into written text. This not only aids in completing assignments but also enhances the student's confidence and engagement with the material. Similarly, text-to-speech tools enable learners with reading difficulties to listen to written content, making it easier for them to comprehend and retain information. This multimodal approach directly supports the UDL principle by catering to diverse learning styles and needs. Organizational software helps students with learning disabilities visually map out their ideas, create outlines, and structure their thoughts. These tools enhance executive functions by providing a clear, visual representation of complex information, making it easier for students to plan, set goals, and monitor their progress. By offering these tailored technological solutions, educators not only improve the usability of educational content but also create a more inclusive and supportive learning environment that aligns with the core principles of LX and UX. This demonstrates a compelling and practical application of UDL guidelines, ensuring that all learners can achieve their full potential.

Assistive Technologies for Physical Impairments

Physical impairments mainly concern with people's mobility that impact "the ability to move, to manipulate objects, and to interact with the physical world" (Laabidi et al., 2014, p. 30). Hence, unlike AT for other disabilities that focus more on providing alternative ways to present information, AT for physical impairment concerns more about providing alternative ways to input information to the system (Fernández-López et al., 2013; Murchland & Parkyn, 2010). The UDL principle "Provide Multiple Means of Action and Expression" (Center for Applied Special Technology, 2011, p. 21) is relevant for learners with physical impairments, as it emphasizes offering various ways for students to interact with learning materials and demonstrate their knowledge. By providing alternative input methods, educators can ensure that all learners have equal opportunities to participate in learning activities. Examples would be moth sticks, larger keyboards, speech recognition systems, touch screens, keyguard that can stabilize users' movements, and keylatchers (Duhaney & Duhaney, 2000; Ray & Warden, 1995). These assistive technologies support the UDL guideline "Provide Options for Physical Action" (Center for Applied Special Technology, 2011, p. 21) by offering learners alternative ways to interact with digital content and physical learning materials. For instance, a student with limited hand mobility may struggle with traditional keyboard and mouse input but can effectively use speech recognition software to navigate digital resources and complete assignments. By incorporating these technologies into their teaching practice, educators can create a more inclusive learning environment that accommodates the diverse physical needs of all students.

These technologies have a profound practical impact on both LX and UX. For instance, a student with quadriplegia using speech recognition software can control their computer entirely through voice commands, enabling them to write essays, conduct research, and participate in online discussions without the need for physical input. This not only makes the content accessible but also empowers the student by providing a seamless and efficient way to interact with educational materials. Another example is the use of keyguards, which allow students with fine motor control difficulties to type accurately on a keyboard. These guards help prevent accidental key presses, making typing more manageable and reducing frustration. This directly enhances UX by making the interface more user-friendly and supports LX by ensuring the student can engage with digital learning activities effectively. Touch screens with customized interfaces can be used by students with various physical impairments to interact with educational apps and tools. For example, a tablet set up with large, easy-to-press buttons, and voice feedback can enable a student with limited hand strength to navigate and use educational software independently.

Assistive Technologies and Mobile Devices

While mobile devices themselves are not specifically designed for learners with certain disabilities, recent advancement in mobile technologies – having high-powered computing capacity, different modes of input and output, and portability for ubiquitous computing – support learners with disabilities in various ways.

In fact, Both iOS (Fernández-López et al., 2013; Maich & Hall, 2016; Morris & Mueller, 2014) and Android (Morris & Mueller, 2014) have accessibility settings that can universally accommodate needs of learners with different types of disabilities. For instance, iOS setting menus located within the directory "Settings—> General—> Accessibility" provides diverse configurations for people with disabilities (e.g., VoiceOver, Auto-Captioning, Assistive Gestures, etc.), and their interface guidelines and policies dictate universal design principles to address the user needs (see Apple Developer's pages on Accessibility and Accessibility features). In a similar manner, Android provides functionalities such as TalkBack/BraileBack for VI people and captioning (see Google's Android Accessibility Overview page and App Developer's Accessibility Guide). While these technologies are not directly UDL, they support diverse input methods (e.g., speech, alternative gestures) as well as output methods (e.g., text-to-speech synthesizers, Braille, speech-to-text captioning, various haptic patterns), which align with UDL's three principles (i.e., multiple means of engagement, representation, and action and expression). Apps and mobile websites follow these protocols that accommodate different accessible capabilities afforded by mobile devices, and having standardized protocols is the key to creating UDL-inspired learning environments.

Conclusion

Drawing upon "universal design for learning" guideline (Center for Applied Special Technology, 2011), which suggest that anyone regardless of dis/abilities can be included as a centric participant in learning ecology, we argue that considering accessibility during the design process is more than merely meeting minimum requirements and adding additional functionality for learners with disabilities. With this in mind, first we argued how the field of instructional design can benefit from implementing the notion of UX. Following the footsteps of scholars in 1990s who integrated LCD in designing technologies for learning (e.g. Jackson et al., 1996; Krajcik et al., 1998; Soloway et al., 1994). Moreover, drawing from the arguments of Ahn (2018), Earnshaw et al. (2017), and Bergin (2018), we argued that utilizing UX concepts yet still considering learners and their learning process is critical in fully understanding LX. Second, we defined accessibility and usability and how those two terms are interrelated to each other in terms of impacting UX and LX and yet distinctive due to accessibility's focus on objective task completion and usability's focus subjective perception. Third, we aimed to discuss UDL approach can be complemented with AT to create an inclusive LX. Through AT examples, we illustrated and discussed how AT can afford to support LX and UX to address learner needs.

There are a few implications for this work. We aimed to align the concepts of accessibility, usability, and universal design with UX and LX with the framework presented by Rose et al. (2005). Just as LX can be designed through the interplay between UX and LD, inclusive LX can be fostered through the interplay between AT and UDL. This paper also provides categorization for types of disabilities and provides examples of AT for each disability type as well as standardized protocol that can support UDL environment in mobile platforms.

Declarations The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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