Facilitating Full-stack Accessibility of Technologies in Education: An Inclusively Designed Toolkit for Monitoring Technology Accessibility

by

Amelia Wang

Submitted to OCAD University
in partial fulfillment of the requirements for the degree of

Master of Design
in
Inclusive Design

Toronto, Ontario, Canada, April 2018

Copyright Notice

Author's Declaration

I hereby declare that I am the sole author of this MRP. This is a true copy of the MRP, including any required final revisions, as accepted by my examiners.

I authorize OCAD University to lend this MRP to other institutions or individuals for the purpose of scholarly research.

I understand that my MRP may be made electronically available to the public.

I further authorize OCAD University to reproduce this MRP by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Amelia Wang

Abstract

The United Nations has declared access to education as a fundamental human right. Educational technologies (EdTech) enable and improve access to education; yet, they could create new barriers if they are not themselves accessible.

Guided by an exploratory research approach, the use of EdTech in post-secondary education in North America was examined through literature survey, environmental scanning and expert interviews. A concept of ‘full-stack’ of EdTech, comprising technologies supporting the Platform, Process and Content in education is proposed. ‘Full-stack accessibility’ thereby becomes a desired goal for enabling and supporting education for all.

Recognizing the critical role of EdTech vendors in the path to full-stack accessibility, an Accessibility Monitoring (A11yMon) Toolkit was inclusively designed in response to their unmet needs, to support them in managing their product accessibility.

Keywords: Disability, Inclusive design, EdTech, Technical accessibility, Functional accessibility, Full-stack accessibility, Standards compliance, Accessibility monitoring toolkit.

Acknowledgment

I thank my principal advisor, Professor Jutta Treviranus, for her encouragement, guidance and kindness. I thank my committee members, David Berman and Dr. Sambhavi Chandrashekar, for their support.

I thank the Graduate Program Director, Dr. Peter Coppin, and the Graduate Office for facilitating my graduation process. I am grateful for the support from my classmates who sailed the rough seas along with me.

And to my family who always stood by me – thank you from the bottom of my heart!

Dedication

I dedicate this thesis to my beloved parents who have been a great source of support and inspiration to me.

Table of Contents

List of Tables ix
List of Figures x
Introduction 1
Problem Context and Scope 4
Conceptual Framework 7
Approach and Methods 8
Design Process and Outcomes 11
Report Roadmap 15
Technologies in Education 17
Three Layers of EdTech 17
Layer 1: Platform Technologies 18
Layer 2: Process Technologies 20
Layer 3: Content Technologies 22
Full-Stack EdTech 25
Full-Stack Accessibility 27
Technical and Functional Perspectives 31
Framing Disability and Accessibility 31
Technical Perspective 34
Functional Perspective 37
Correspondence between Technical and Functional Perspectives 39
Design Considerations 41
Needs 41
Design Choices 43
Accessibility Monitoring (A11yMon) Toolkit 45
Designing the Toolkit 45
First Design Iteration 46
Second Design Iteration 48
Developing the Checklist Tool 49
Developing the Map Tool 50
WCAG 2.0 Level AA Petals and Flower 50
Using the Checklist and Map Tools 54
Iterative testing example at WCAG 2.0 Level A 55
Testing at WCAG 2.0 Levels AA and AAA 64
Hosting the Toolkit 64
Conclusion 67

Contribution 67
Limitations and Next Steps 70
References 71
Appendices 1
A: A11yMon Toolkit — Empathy Zone 1
B: A11yMon Toolkit — Skills Zone 2
C: A11yMon Toolkit — Testing Tools 4
D: WCAG 2.0 Success Criteria Baseline Checklist 6
E: Results of WCAG 2.0 Level A Testing Round 1 15
F: Results of WCAG 2.0 Level A Testing Round 2 20
G: Results of WCAG 2.0 Level A Testing Round 3 25
H: WCAG 2.0 Level AA Petals and Flower 30
I: WCAG 2.0 Level AAA Petals and Flower 32

List of Tables

Table 1: Disability – permanent, temporary or situational..... 32

Table 3: Design Criteria and Design Choices 43

Table 4: WCAG Success Criteria summary counts at Level A..... 50

Table 5: Summary Results of Accessibility Testing Round 1 56

Table 6: Summary Results of Accessibility Testing Round 2 58

Table 7: Summary Results of Accessibility Testing Round 3 60

Table 8: WCAG 2.0 Level A Technical and Functional Criteria 6

Table 9: WCAG 2.0 Level AA Technical and Functional Criteria 10

Table 10: WCAaG 2.0 Level AAA Technical and Functional Criteria..... 12

Table 11: WCAG 2.0 Level A Test Round 1 Results 15

Table 12: WCAG 2.0 Level A Test Round 2 Results 20

Table 13: WCAG 2.0 Level A Test Round 3 Results 25

Table 14: WCAG Success Criteria summary counts at Level AA 30

Table 15: WCAG Success Criteria summary counts at Level AAA 32

List of Figures

Figure 1: Conceptual Framework 7

Figure 2: Layers of EdTech 17

Figure 3: Full-stack Developer 26

Figure 4: Full-stack Designer 26

Figure 5: Full-Stack Accessibility 30

Figure 6: WCAG 2.0 Level A Technical Accessibility Criteria Petals 51

Figure 7: WCAG 2.0 Level A Functional Accessibility Criteria Petals 52

Figure 8: WCAG 2.0 Level A A11yMon Mapping tool 53

Figure 9: A11yMon map for Accessibility Test 1 57

Figure 10: A11yMon map for Accessibility Test 1 + Test 2 59

Figure 11: A11yMon map for Accessibility Test 1 + Test 2 + Test 3 61

Figure 12: Map does not indicate severity of failed tests 63

Figure 13: WCAG 2.0 Level AA Technical Criteria Petals 30

Figure 14: WCAG 2.0 Level AA Functional Accessibility Criteria Petals 30

Figure 15: WCAG 2.0 Level AA A11yMon Mapping tool 31

Figure 16: WCAG 2.0 Level AAA Technical Criteria Petals 32

Figure 17: WCAG 2.0 Level AAA Functional Accessibility Criteria Petals 32

Figure 18: WCAG 2.0 Level AAA A11yMon Mapping tool 33

Introduction

The United Nations has declared the right to education as a fundamental human right, under Article 24 of its Convention on the Rights of Persons with Disabilities (CRPD) (UN, 2006). Of the 7.6 billion people living on this earth (Worldometers, n.d.), about 15%, or over 1.1 billion people, have some form of disability (WHO, 2018) and, of them, around 13% are students (Ready, August 29, 2016). In order for students with disabilities to enjoy their right to education, it is essential that education be accessible.

The rapid pace of development of digital technologies has resulted in their permeation into all essential life activities, including education (Tapscott & Williams, 2008). To facilitate learning, educational institutions increasingly use technologies in the form of learning platforms, virtual classrooms, and digital learning content, to name a few (Behl & Deshmukh, 2017). Educational technology (EdTech[1]) has the potential to level the playing field for students with disabilities (Hasselbring & Glaser,

[1] The term EdTech will be used in this report to refer to technologies used in education.

2000). EdTech supports students with disabilities in a variety of ways, such as:

1. Students with mobility challenges that prevent them from coming to the classroom can receive learning material at the same time as all of their classmates when learning content is provided to all students in the form of digital material.
2. Students who are blind or vision-impaired can access digital learning material similarly to their sighted classmates by using assistive technologies such as a screen reader or screen magnifier.
3. Students who are Deaf or hard of hearing can access what was spoken in lectures and discussions when they are interpreted in sign language, transcribed as text, or recorded as video with captioning.
4. Students with dexterity challenges can access digital learning systems and material and participate in the learning along with their classmates through use of alternative input technologies.

5. Students who have cognitive challenges, such as requiring more time to process content or understand, can learn at their own pace through online learning platforms.

EdTech has the potential to enhance accessibility and inclusion for both students and instructors with disabilities. However, EdTech that is not designed with accessibility in mind could introduce new barriers and hinder the learning experience, leading to exclusion rather than inclusion. In this sense, EdTech is a double-edged sword.

Accessibility happens when the design of products, devices, services, and environments takes into consideration the needs of the full range of human diversity. However, as Treviranus (2016a) emphasizes, “Accessibility is a precarious value; almost everyone agrees it is important, but often it is the first thing that is compromised when there is a time or budget crunch or when other priorities arise.” Focusing on ways to help improve the accessibility of EdTech could, therefore, afford a path to make education accessible. To that end, this Major Research Project (MRP) contributes an inclusively designed artefact to facilitate accessibility testing and monitoring by EdTech vendors.

Problem Context and Scope

Within the overarching goal of education accessibility, this MRP is focused on EdTech accessibility, given its crucial role in education accessibility. Research shows that EdTech not being fully accessible results in suboptimal accessibility of the education experience as a whole (Hersh & Leporini, 2012; Kent, 2015; McManus, Dryer & Henning, 2017). This MRP examined the processes used and challenges faced by some EdTech vendors[2] in making their products accessible. It only considered the user interface within EdTech because accessibility issues arise primarily during interactions on the user interface. This premise moved some technologies out of the scope of the study, such as cloud technologies and processing technologies, that are used in education but do not require direct student or instructor interaction. In terms of data collection, the scope was limited to EdTech used in the North American post-secondary education

[2] While 'vendor' is a general term used to describe any supplier of a good or service in a supply chain, the term is used in this report to denote a business entity that both produces and sells technology, and thereby has a role in ensuring its accessibility.

space. The findings and outcome of the study, however, could still be applicable to, and usable by other education sectors and geographic regions.

The exploratory research exposed a felt need among EdTech vendors for guidance and resources for accessibility testing and monitoring as part of product development process. Specifically, there was a need for clarity and knowledge of accessibility testing from a technical perspective, in terms of accessibility testing success criteria as specified in the Web Content Accessibility Guidelines (WCAG) 2.0, and functional perspective, in terms of physical, visual, auditory and cognitive access to use the products. The design challenge for this MRP was, therefore, chosen as the inclusive design of a toolkit[3] that equips EdTech vendors with resources for iteratively testing and monitoring the accessibility of their products. The toolkit comprises five components, of which two are based on the following innovative design ideas.

[3] A toolkit is a set of tools designed to be used together or for a particular purpose (toolkit, n.d.).

1. Providing a checklist tool that
    a. offers a baseline showing the correspondence between technical success criteria based on WCAG 2.0, and functional access modes relating to those success criteria; and
    b. provides a way to express the results of technical accessibility testing in terms of functional access.
2. Providing a visual mapping tool that shows:
    a. the correspondence between technical and functional testing perspectives in test results; and
    b. the progress in specific areas across multiple iterations of accessibility testing.

The intent of the mapping tool is merely to indicate the progressive results of the WCAG success criteria tested. It does not represent equivalent improvement in the accessibility of the product.

Given the short time frame of the MRP study, all planned components of the toolkit could not be worked upon to completion. The checklist tool and the mapping tool have been developed fully. Development of the remaining components and

hosting of the toolkit as an online resource are planned as future activities.

Conceptual Framework

To facilitate and guide the research of EdTech used in post-secondary education in North America, a conceptual framework was put together as shown in Figure 1.

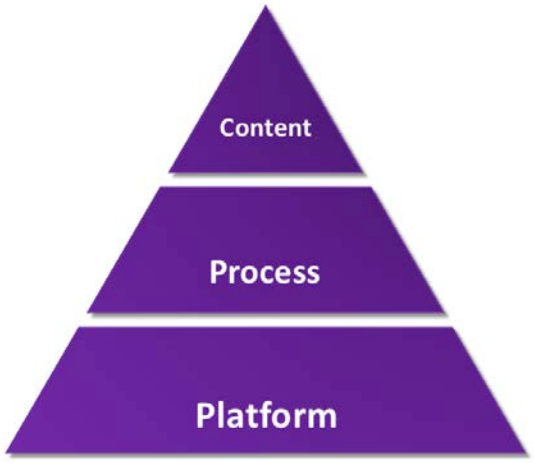

Figure 1: Conceptual Framework

The scope for use of technology in education was broadly conceptualized as falling into three layers, as enumerated below:

1. The bottom layer is the foundational platform on which all learning processes and learning content are brought together to provide the education experience.

2. The middle layer comprises processes that support education, some of which might be offered by the platform.

3. The top layer comprises digital learning content.

The three layers – platform, process and content – are rather fluid and their boundaries are fairly flexible. This framework guided data analysis in this design research. More importantly, it led to the discovery of a novel idea of ‘full-stack’ EdTech (see Figure 2 on page 17) as well as the term ‘full-stack accessibility’ (see Figure 5 on page 30), denoting accessibility of the layers of technology essential for education accessibility. Both terms are described in detail in Section 3.

Approach and Methods

Adopting an exploratory approach, this study resorted to literature survey, environmental scan and expert interviews with stakeholders (post-secondary institutions and EdTech companies) as methods to gather information about the EdTech in use in North America and to discover the needs of EdTech

vendors for monitoring the accessibility of their products. Data was gathered in the following ways:

1. Literature survey using Google Scholar with search terms such as education accessibility, technology accessibility, post-secondary education, educational technology, LMS, assistive technologies, content accessibility, and more.
2. Environmental scan using the Google search engine with search terms such as technology companies, technology accessibility, post-secondary education, educational technology, LMS, assistive technologies, content accessibility, and more.
3. Expert interviews with four educational technologists in post-secondary institutions, two from Canada (Fanshawe College and Ryerson University) and two from USA (Pellissippi State Community College and University of Colorado). Each conversation lasted between 30 and 45 minutes and was seeded by the following open-ended questions:
    a. “What are the educational technologies used in your institution?”

b. “How accessible do you find the technologies to be?”

4. Expert interviews with three EdTech companies (D2L, ReadSpeaker and Crawford Technologies), representing the Platform, Process, and Content layers from the conceptual framework. Each conversation lasted between 30 and 45 minutes and was seeded by the following open-ended questions:
    a. “What are some educational technologies used in North America?”
    b. “What is the process used by the company, and the industry in general, for ensuring accessibility of EdTech?”
    c. “What are the challenges faced by the company, and the industry in general, in testing EdTech for accessibility?”

Engaging with the post-secondary institutions first provided an idea about the kinds of EdTech in use. As well, it revealed information about the level of accessibility of EdTech that the EdTech vendors by themselves might not have been able to provide.

Design Process and Outcomes

The inclusive design challenge undertaken for the MRP involved the following steps:

- Identifying a real-world problem:
    - The problem of EdTech accessibility across the full stack of education technologies as a means to education accessibility is the real-world problem in focus for the MRP.
- Analyzing the problem with stakeholders:
    - The problem was examined using an exploratory approach through theoretical research as well as practical conversations with stakeholders from post-secondary institutions and EdTech companies.
- Deriving an idea/artefact to mitigate the problem:
    - A toolkit for EdTech vendors to help them test and monitor accessibility of their products emerged from the research as the design artefact of choice.

- Recognizing the diversity of potential users of the proposed artefact:
    - The fact that the distribution of accessibility expertise among EdTech vendors could be unequal was kept in mind while designing the resources and tools.
- Identifying their needs:
    - The business need identified was that EdTech vendors in North America have to demonstrate compliance with accessibility requirements under Section 508 of the Rehabilitation Act and the W3C Web Content Accessibility Guidelines 2.0 as part of the sale process. Other findings were: gaps in disability awareness, accessibility knowledge and testing skills; paucity of time and human resources to undertake accessibility work; and lack of user-friendly tools for interpreting accessibility test results.
- Deriving design requirements for the artefact from identified user needs:

- The toolkit is based on the W3C WCAG 2.0 guidelines, which also forms the basis for the refreshed Section 508 requirements in the USA as well as for regulations and policies in many other countries (Rogers, November 28, 2017). Resources to bridge the awareness, knowledge and skill gaps are collated and provided as part of the toolkit, particularly those that would help in understanding and using the tools. Free, automated, and open-source testing resources and tutorials are provided to address time and money constraints.

- To ensure that the checklist and map tools are user-friendly, they were co-designed with extreme users from the target group (EdTech vendors) as described below.

  - Co-design: The toolkit was designed in two iterations, getting feedback from two members from EdTech vendor companies with little knowledge about accessibility.

  - Accessibility: The toolkit and resources themselves were designed to be accessible.

- The toolkit includes

- web resources relating to disability and digital access, accessibility concepts, testing tools and tutorials;
- a checklist tool relating to technical and functional accessibility; and
- a visual mapping tool for representing accessibility test results.

- Aiming for broader beneficial impact:
  - The concept of full-stack accessibility of EdTech applies not only to post-secondary education sector but also to the K-12 sector. Hence, the toolkit could be used by EdTech vendors across education sectors.
  - The W3C WCAG guidelines form the basis for most of the policy and regulatory requirements across the globe. The toolkit could, therefore, be used by EdTech vendors not only in North America but also in other parts of the world.
  - Finally, the toolkit would be useable by vendors of any technology, not necessarily only EdTech, as it deals with the general purpose of digital accessibility testing.

This design problem, which appeared initially as a big challenge, ended up being the a very interesting design opportunity. Active use of this toolkit in the EdTech sector holds the potential of enhancing education accessibility.

Report Roadmap

This report documents the inclusive design challenge undertaken for my MRP. Following this Introductory section, which provides an overview of the study, Section 2 elaborates on the three layers in the EdTech stack and describes full-stack accessibility in relation to EdTech. Section 3 frames the concepts of disability and digital accessibility in the context of use of EdTech and reviews technical and functional perspectives of accessibility.

Section 4 examines the research data to substantiate the design goal of creating an accessibility monitoring toolkit for EdTech vendors and generates design criteria and design choices for the toolkit. Section 5 describes in detail the components of the Accessibility Monitoring (A11Mon) toolkit. Section 6 concludes the report, highlighting the unique contributions made by the MRP, identifying the limitations that bounded the scope of the work, and proposing further steps for refining the toolkit.

Technologies in Education

The focus of this MRP lies in enabling EdTech vendors to ensure better accessibility of their products. Therefore, research carried out on technology used in education was broad rather than deep or exhaustive. This section first derives the full stack of EdTech that is required for delivering an accessible educational experience and develops the concept of 'full-stack accessibility' of EdTech as a theoretical contribution.

Three Layers of EdTech

Data gathered on EdTech was classified based on the conceptual framework introduced in the previous section, resulting in three layers of EdTech as shown in Figure 2.

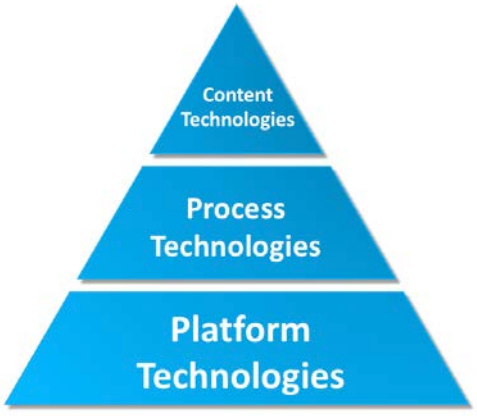

Figure 2: Layers of EdTech

Echoing the caveats of flexibility and fluidity associated with the conceptual framework, the layers of EdTech also are not separated by hard boundaries. This will be discussed further in this section.

Layer 1: Platform Technologies

Platform Technologies primarily take care of the administrative functions of an education enterprise and form the lowest layer of the EdTech stack. An example of EdTech in this layer is a Learning Management System (LMS), which is a software application that facilitates the creation, delivery and administration of educational courses or training programs (Ellis, 2009a; 2009b). Institutions offering formal education generally use an LMS to manage student enrollment, tracks student performance, interoperates with technologies supporting teaching and learning, and allows creation/import and distribution of learning content. Some popular LMS brands in use in post-secondary institutions in North America are Blackboard by Blackboard, Inc., Canvas by Instructure, Inc., Brightspace by D2L Corporation, and Moodle, an open source learning platform.

Using an LMS is the de facto order of the day. Statistics from a study conducted by Brown, Dehoney & Millichap (April 2015) in North America, show that

- Nearly 99% of institutions are running some form of LMS.
- 85% of faculty use an LMS; 56% of them use system daily.
- 83% of students use an LMS, with 56% using it in all or most courses.

Setting up instructors and students for effective teaching and learning is fundamental to the success of an LMS (Rangin, Petri, Richwine & Thompson, 2013). Providing institutions with a way to deliver teaching and learning experiences that ensure independent and successful participation for every instructor and student regardless of their abilities or learning style would make an LMS accessible.

Interoperability is another important feature of an LMS. This means providing an open platform that is able to integrate third-party tools and exchange learning content and data (Brown, Dehoney & Millichap, 2015). By leveraging open standards, an

LMS can support faculty and students with a wide variety of tools to enrich the learning process. Interoperability allows information such as course content and learning-related data to be shared across learning tools, applications, and various LMS solutions (IMSGLC, n.d.). An LMS with a high level of interoperability can offer accessibility and flexibility, which are conducive to inclusion.

An LMS could include several functions relating to the process of education, such as quizzing, assignment submission, or grading. To supplement and support the LMS, additional EdTech might be used along with the LMS, say, for processes like online proctoring. These fall into the layer called process technologies.

Layer 2: Process Technologies

These enable the *process* of imparting education and form the middle layer of the EdTech stack. The process of education is supported partly by the LMS and partly by third-party technologies. Virtual classroom (WizIQ and Electa Live) and online proctoring (Examity and Proctoru) are examples of EdTech in this layer.

Assistive technologies (AT) such as screen readers, screen magnifiers, text readers and others owned and used by individual students may not be considered as part of this layer. EdTech would have to be able to interoperate with AT. This point is discussed further under Functional Perspective on page 40.

Apart from the facilities offered by the LMS, several supporting technologies are used to enhance the overall learning experience and accessibility. Supporting technologies are programs that facilitate the process of education, such as discussions, virtual classrooms, etc. to enhance the learning experience. Some examples are:

- Capture - live session capturing tool: Enables the live webcast of lectures as well as the capture of lectures as videos for viewing later.
- YouSeeU - virtual classroom tool: Enables Virtual Classroom, an integrated web-conferencing tool to help instructors connect with their students for live discussions, online office hours, video-based training and more.

- Google Classroom is a free Google app that lets educators create classes, distribute assignments, send feedback, and see everything in one place.

Layer 3: Content Technologies

The *content technologies* layer is the third layer and is comprised of all technologies that are used to create and consume accessible learning content. Video creation technologies like Wochit and Animoto are examples in this layer.

Content is generally sourced in multiple ways. To name a few:

- by the institution through arrangements with publishers;
- by instructors from OER repositories or simply from the Web, alongside their own creations; and
- by students themselves, for self-use or for sharing.

Wherever EdTech is involved in this process, they would figure in the Content technologies space for that purpose. An example would be the online storyboard creator "Storyboard That", which would come under Content technologies. Some content technologies might be connected with the LMS through Learning

Tools Interoperability LTI) integration, but they would not be a considered a part of the LMS.

Content creation technologies help in the creation of learning content by instructors or others for use in courses through the LMS. All learning content produced and used on the LMS must be accessible. The content tools themselves must also be accessible. Some accessible content creation technologies are listed below:

- HTML editor: This tool helps in creating HTML content. The TinyMCE HTML Accessibility Checker helps check HTML pages, reports error and prompts for accessibility features to be included. For example, when an image is inserted without a text description, the tool prompts for addition of alternative text description. This tool can help instructors produce accessible HTML pages.

- Video/Audio Captioning tool: Captioning is the marking up of video and audio files with text snippets of spoken content so that those who cannot hear the audio due to permanent disability such as deafness, or temporary disability such as

ear infection, or situational disability such as sitting in the library, can understand the audio component by reading the text captions. There are free as well as paid captioning tools. Some examples of free tools are Captioning and Description Editing Tool (CADET) from National Centre for Accessible Media (NCAM); Youtube Do-It-Yourself Captioning Tool for members; and Amara Video Captioning Tool for captioning Vimeo, YouTube and html5 videos.

- Office documents tools: The process for making Word documents, Excel spreadsheets and Powerpoint slides accessible are detailed in this resource: Accessible Digital Office Documents

- PDF makers: The process for making Portable Document Format (PDF) files accessible are detailed in this resource: Accessible PDF files

There are other tools for creating educational material in alternative formats such as braille, large print, e-text, audio, accessible paper document, etc.

Full-Stack EdTech

The idea of full-stack EdTech is inspired by the prevalent concepts of full-stack developer (Liu, December 25, 2017) and full-stack designer (Liu, October 1, 2017). According to Liu, the term full-stack denotes a range of related capabilities to accomplish a definitive piece of work, such as design or development, each of which is traditionally done by a different person.

Simply put, a full-stack developer is someone who is able to work on both the front-end portion of an application (that users can see and interact with) and the back-end portion (that handles the logic, database interactions, user authentication, server configuration, etc.). Being a full-stack developer means that one is able to work on both sides and has comprehensive understanding when building an application, although this does not necessarily mean that one has mastered all required work on the front-end and back-end. Figure 3 illustrates the range of work that a full-stack developer's role could encompass.

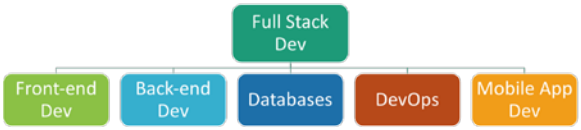

Figure 3: Full-stack Developer[4]

A full-stack designer, likewise, would be able to build a basic conception of a project, and complete the range of design and development related work such as wireframes/prototypes design, visual design, and front coding. Figure 4 presents a visualization of the capabilities of a full-stack designer.

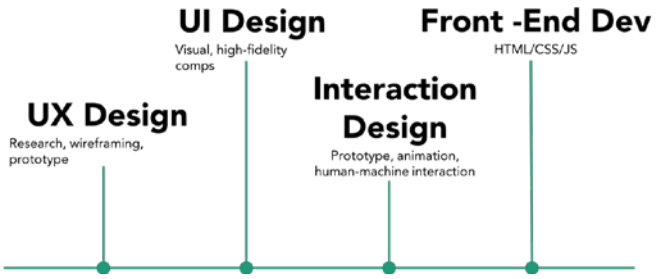

Figure 4: Full-stack Designer[5]

[4] Image adapted from https://hackernoon.com/6-essential-tips-on-how-to-become-a-full-stack-developer-1d10965aaead

[5] Image adapted from https://medium.muz.li/what-is-a-full-stack-designer-in-2017-will-you-be-one-7933a7145fb7

In large projects backed by large budgets, there would be different designers specializing in UX design, UI design and Interaction design; and different developers handling front-end vs. back-end development. The need for full-stack capabilities has arisen more out of the proliferation of smaller software products and projects that are not in a position to hire several individuals for different types of design or development work.

According to Gellert (2012), full-stack could also refer to the collection of a series of technologies needed to complete a project. In other words, referring back to the Layers of EdTech in Figure 2 on page 17, it means that together, they could constitute the EdTech stack:

1. Platform technologies
2. Process technologies
3. Content technologies

Full-Stack Accessibility

Full-stack accessibility in the context of education refers to accessibility of the complete stack of educational technologies (EdTech) that are required for delivering an accessible

educational experience. Accessibility of the technologies used in each of the stack layers to make the learning process and content accessible is important for the accessibility of the overall learning experience.

1. The LMS should primarily be accessible. If the LMS is not accessible, students with disabilities will be denied access even at the entry level.
2. A variety of support technologies such as virtual classrooms, read-aloud tools, discussion tools and more, are used or offered by the LMS to enhance the accessibility of the learning experience apart from assistive technologies and assistive devices used by individual students with disabilities. These support technologies themselves must also be accessible. If the support technologies are not accessible, students depending on those technologies for access will be denied full participation. For example, if a virtual classroom does not provide accessible chat widget, then students who are blind will not be able to contribute to or participate in the online conversation.

3. Different types of content require different technologies and techniques for making them accessible. Technologies and processes for producing as well as using learning content need to be accessible so that anyone with a disability would be able to make as well as use content. If the educational material is not accessible, then users with digital access limitations will not be able to use them.

To further illustrate the concept of full-stack accessibility, if an educational institution were to use an accessible learning platform or learner management system (LMS) and accessible technologies to support its education processes but were to use a video creation technology that does not allow an instructor with a disability to create accessible video content, then the institution would not be having full-stack accessibility because one of the layers has an inaccessible component. A point to note here is that the reference here is to the accessibility of the content creation technology, which in turn allows instructors and students of all abilities to create content that is accessible. The focus is on the fact that people with disabilities are not only consumers but also creators of content. Therefore, even the

technology that is used to create accessible content must be accessible.

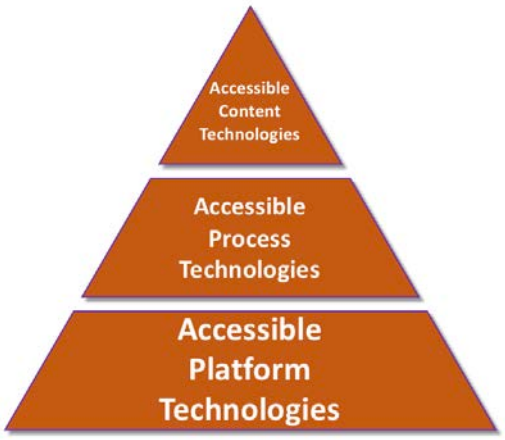

Figure 5: Full-Stack Accessibility

Full-stack accessibility occurs when technologies in each of the three layers of Platform, Process and Content are accessible and work together to produce an accessible learning experience (Figure 5). The next section presents two perspectives of accessibility – technical and functional.

Technical and Functional Perspectives

This section opens with a brief review of the concepts of disability and accessibility and then proceeds to examine technical and functional perspectives of accessibility. Technology must be accessible, both from technical and functional perspectives. The former views accessibility in terms of conformance of the technology to technical accessibility standards and the latter views accessibility from the perspective of usability by users with digital access challenges.

Framing Disability and Accessibility

The Inclusive Design Research Centre (IDRC) reframes disability within the design context as a “mismatch between the needs of the individual and the design of the product, system or service rather than a personal characteristic or a binary state of disabled vs. non-disabled.” With this framing, disability is socially constructed, and anyone excluded by the design could experience disability. (IDRC, n.d.)

Digital interaction primarily involves three processes: perceiving the interface elements; operating the controls; and

understanding the content. These are not distinct and sequential processes but help in making sense of digital interactions. Disability happens when any of these processes is challenged. Disability could be permanent, temporary or situational (Microsoft, 2016), as illustrated in Table 1 in the three cases of perceiving the interface elements, operating the controls, and understanding the content on a computer screen.

Table 1: Disability – permanent, temporary or situational

Action	Permanent	Temporary	Situational
Perceive	Blindness	Cataract surgery	Driving
Operate	Quadriplegia	Sprained hand	Baby in arms
Understand	Cognitive impairment	Concussion	Lack of sleep

The inability to visually perceive the content on the computer screen could be a permanent feature in the case of a blind user, a temporary one when a user undergoes an eye surgery, and situational one while driving. Likewise, operating the keyboard using both hands could pose a permanent challenge to a quadriplegic user, a temporary challenge to a user with a sprained hand, and a situational challenge to a mother with a

baby in her arms. These challenges amount to a lack of accessibility.

Treviranus (2016a) frames accessibility as the “ability of the environment, service or product to match the needs of the individual, in a given context, for a given goal.” Both disability and accessibility are seen as relative. Rather than viewing accessibility as a means to fix, or somehow accommodate, somebody’s individual disability or medical condition, it must be viewed as an artefact of the interaction of the person with the digital system. Anyone can experience a disability when working with digital systems, like trying to watch a video in a library environment with the sound muted. Access to captions or transcript of the audio would meet the need of accessing the dialogue in the video.

To promote digital accessibility, world bodies such as the World Wide Web Consortium (W3C) have developed guidelines such as Web Content Accessibility Guidelines (WCAG) 2.0, Authoring Tools Accessibility Guidelines (ATAG) 2.0, and User Agent Accessibility Guidelines (UAAG) 2.0. Of these, this section provides a brief review of (WCAG) 2.0**,** which is now regarded as

the global ICT content accessibility standard. WCAG 2.0 forms the basis for content accessibility regulation or policy in at least 18 countries around the world (Rogers, November 28, 2017).

Technical Perspective

The WCAG 2.0 Guidelines provide a technical perspective to digital access and accessibility in that these guidelines can be tested through programmatic and heuristic methods without involving users. These guidelines provide ways to make content accessible by laying out guidelines, which are divided at the highest level into four principles: Perceivable, Operable, Understandable, and Robust. Broadly, these could be thought of as referring to perceivable interface, operable controls, understandable content, and robust system

Distributed under these four principles are 12 guidelines and 66 success criteria classified into three levels A, AA and AAA in increasing order of rigor as listed below:

1. Perceivable
    1.1 Text Alternatives
        1.1.1 Non-text Content A
    1.2 Time-based Media
        1.2.1 Audio-only and Video-only (Prerecorded) A

1.2.2 Captions (Prerecorded) A
1.2.3 Audio Description or Media Alternative (Prerecorded) A
1.2.4 Captions (Live) AA
1.2.5 Audio Description (Prerecorded) AA
1.2.6 Sign Language (Prerecorded) AAA
1.2.7 Extended Audio Description (Prerecorded) AAA
1.2.8 Media Alternative (Prerecorded) AAA
1.2.9 Audio-only (Live) AAA

1.3 Adaptable
1.3.1 Info and Relationships A
1.3.2 Meaningful Sequence A
1.3.3 Sensory Characteristics A

1.4 Distinguishable
1.4.1 Use of Color A
1.4.2 Audio Control A
1.4.3 Contrast (Minimum) AA
1.4.4 Resize Text AA
1.4.5 Images of Text AA
1.4.6 Contrast (Enhanced) AAA
1.4.7 Low or No Background Audio AAA
1.4.8 Visual Presentation AAA
1.4.9 Images of Text (No Exception) AAA

2. Operable

2.1 Keyboard Accessible
2.1.1 Keyboard A
2.1.2 No Keyboard Trap A
2.1.3 Keyboard (No Exception) AAA

2.2 Enough Time
2.2.1 Timing Adjustable A
2.2.2 Pause, Stop, Hide A
2.2.3 No Timing AAA
2.2.4 Interruptions AAA

2.3 Seizures
2.3.1 Three Flashes or Below Threshold A

- 2.3.2 Three Flashes AAA
- 2.4 Navigable
  - 2.4.1 Bypass Blocks A
  - 2.4.2 Page Titled A
  - 2.4.3 Focus Order A
  - 2.4.4 Link Purpose (In Context) A
  - 2.4.5 Multiple Ways AA
  - 2.4.6 Headings and Labels AA
  - 2.4.7 Focus Visible AA
  - 2.4.8 Location AAA
  - 2.4.9 Link Purpose (Link Only) AAA
  - 2.4.10 Section Headings AAA
- 3. Understandable
  - 3.1 Readable
    - 3.1.1 Language of Page A
    - 3.1.2 Language of Parts AA
    - 3.1.3 Unusual Words AAA
    - 3.1.4 Abbreviations AAA
    - 3.1.5 Reading Level AAA
    - 3.1.6 Pronunciation AAA
  - 3.2 Predictable
    - 3.2.1 On Focus A
    - 3.2.2 On Input A
    - 3.2.3 Consistent Navigation AA
    - 3.2.4 Consistent Identification AA
    - 3.2.5 Change on Request AAA
  - 3.3 Input Assistance
    - 3.3.1 Error Identification A
    - 3.3.2 Labels or Instructions A
    - 3.3.3 Error Suggestion AA
    - 3.3.4 Error Prevention (Legal, Financial, Data) AA
    - 3.3.5 Help AAA
    - 3.3.6 Error Prevention (All) AAA
- 4. Robust
  - 4.1 Compatible

4.1.1 Parsing A
4.1.2 Name, Role, Value A

Building interfaces that are compliant with standards specified by the Web Content Accessibility Guidelines (WCAG) 2.0 Level AA ensures accessibility from a technical perspective.

Functional Perspective

Many people with disabilities are dependent on alternative or augmented access systems to use a computer. Assistive technologies (AT), which could be in the form of software or hardware device, provide alternative or augmented ways for perceiving and operating technology interfaces. Some forms of assistive technologies are:

- Screen reader software such as JAWS, NVDA, VoiceOver and Talkback, which can convert the contents of a computer or mobile screen into audio. Users who are blind generally use this AT.

- Screen readers can also direct their output to a refreshable braille display, which is an AT device. Users who are deafblind generally use this software and device.

- Screen magnifier software such as ZoomText and Magic can enlarge the display on the screen and also provide audio output if required. These are generally used by persons who have low vision.

- Speech recognition software such as Dragon Naturally Speaking can convert audio commands into operations on the computer. These are generally used by persons who cannot operate devices with their hands but can talk.

- Switch devices such as sip-n-puff systems and eye tracking systems can enable operation of the computer using simplified physical movements when users have very severe physical limitations such as quadriplegia, with added speech limitations.

- Text Reading software such as Kurtzweil 3000 read out text loud and also highlight the paragraph being read out and every word as it is being read. This is useful to persons with low vision or learning disability.

It is important that EdTech interoperates with AT used by students and instructors. Applications that interoperate with AT

are said to be “access system friendly” (Treviranus & Petty, 2001). Compliance with the WCAG 2.0 guidelines improves the interoperability of EdTech with AT. From a testing viewpoint, it is useful to understand the access need from a functional perspective for each of the 66 success criteria listed under technical perspectives above.

Correspondence between Technical and Functional Perspectives

An illustration of the technical and functional perspectives based on one of the success criteria (SC) from WCAG 2.0 is given below:

SC 2.1.1 – Keyboard navigation: Every control in a web page must be accessible using only keyboard (without using a mouse).

Technical perspective: This requirement can be tested programmatically.

Functional perspective: Keyboard (or keyboard emulator) access is needed for a user who is unable to point and click a mouse by seeing the screen (through visual access) and user who is unable to hold or click a mouse (through physical access).

Technical and functional perspectives to accessibility are, thus, complementary to one another. Adding the functional perspective helps the tester understand user needs better for any given success criterion. Together, the two concepts provide the necessary background for making better sense of accessibility testing; and form the basis for the design artefact created for this MRP.

Design Considerations

As part of the design research, the processes used by some EdTech vendors and the challenges faced by them in making their products accessible were examined in the North American post-secondary education space. By and large, the research pointed to a gap in resources for guidance in accessibility testing and monitoring as part of their product development process. This section presents the needs of EdTech vendors to manage the accessibility of their products, and for doing that effectively. Based on these, the design criteria and design choices for the artefact being designed are derived in this section.

Needs

EdTech vendors uniformly expressed the need of having to demonstrate compliance with accessibility requirements under Section 508 of the Rehabilitation Act and the W3C Web Content Accessibility Guidelines 2.0 as part of the sale process in North America. To be able to sell their product in the USA, they need to be able to produce a Voluntary Product Accessibility Template (VPAT), which is based on the WCAG 2.0 checklist, showing their

compliance with the required accessibility standards to the specified level. They also felt the need for, or the lack of, user-friendly tools that would demystify and easily interpret for them the results of accessibility testing.

This need of EdTech vendors prompted the choice of the Accessibility Monitoring Toolkit as the design artefact for this MRP. Through some innovative design thinking, two tools (checklist tool and map tool) were developed as part of the toolkit. These tools are described in detail in the next section.

Surprisingly, the EdTech vendors who participated in the research and design exercise, when asked about persons accessing their products said that they did not consciously think that:

a. All users might not see colours in the same way.
b. All users might not read the text as displayed.
c. All users might not see their screen.
d. All users might not use a mouse.
e. All users might not be able to hear.
f. All users might not understand easily.

Research data revealed a need for:

1. Greater awareness about disabilities and related access requirements.
2. Greater knowledge about disability and digital accessibility.
3. More skills to test for accessibility.
4. Free or inexpensive testing tools, due to paucity of economic resources for investing in them.
5. Easily understandable tools, due to paucity of time to learn and use complicated accessibility testing tools

Design Choices

Knowledge gathered about end-user needs, as above, shaped the design choices that determined the content and form of the design artefact. The data is presented in Table 3.

Table 2: Design Criteria and Design Choices

St. no.	Design Criteria	Design Choices
1	Increase awareness about disabilities and related access requirements	Include a section in the toolkit with video resources that demonstrate how people with different disabilities access the computer and the web

2	Provide knowledge about digital accessibility	Include online resources that expand understanding about digital accessibility
3	Provide resources for required skills to test for accessibility	Include verbal protocols for conducting automated and manual accessibility testing, as well as user testing
4	Provide information about low-cost/free testing tools	Include links to free, open source resources for automated testing, manual testing, colour contrast checking, readability checking, etc.
5	Help reduce the time to conduct testing	Develop an accessibility checklist that simplifies the testing process and helps keep track of test results
6	Provide tools to monitor accessibility	Create an inclusive mapping tool and tutorial that guides and keep track of progress in accessibility

Design and development of the toolkit is described in the next section.

Accessibility Monitoring (A11yMon) Toolkit

This section presents the process of designing and developing a toolkit for EdTech vendors containing tools they could use for testing the accessibility of their products and monitoring progress of accessibility across tests. The design choices indicated in Table 3 on pages 43 and 44 were used as the first step in the design of the toolkit components.

Designing the Toolkit

The Accessibility Monitoring (A11yMon) toolkit was co-designed with the EdTech participants through two iterations. As they were not too familiar with accessibility and did not know about WCAG, they can be considered as extreme users[6].

[6] Extreme user is a user whose needs are different from most users. They might "need/want less or more of something to solve their problems." (Strachan, October 19, 2017, n.p.)

First Design Iteration

Based on the research results, the toolkit was initially designed with the following seven pages.

The proposed content as indicated under each was presented to the users.

1. **Launching Page**: A brief introduction to the background and context, followed by links to the other pages and links to downloads of the toolkit in other formats for offline use.
2. **Awareness Page**: Small write-ups, video resources that demonstrate how people with different disabilities access the computer and the web, and links to other important resources on the topic.
3. **Knowledge Page**: Online resources that expand understanding about digital accessibility.
4. **Test Protocols Page**: Verbal protocols for conducting automated and manual accessibility testing, as well as user testing.

5. **Testing Tools Page**: Links (with annotations) to free, open source resources for automated testing, manual testing, colour contrast checking, readability checking, etc.
6. **Accessibility Checklist Page**: An accessibility checklist that simplifies the testing process and helps keep track of test results.
7. **Accessibility Monitoring Tool Page**: This page hosts the inclusive mapping tool resources and tutorial that guide and keep track of progress in accessibility testing.

The first round of discussion was around asking them about their overall vision and what they would like to get done through the tool, are these the pages they want, where would they like to land, what would they like to be able to do, whether the navigation path provided makes sense to them, etc. Based on the feedback, the number of pages was reduced from seven to four to make it simpler and more relevant to the needs as given under Second Design Iteration.

Second Design Iteration

1. **Empathy Zone**: Small write-ups, video resources that demonstrate how people with different disabilities access the computer and the web, and links to other important resources on the topic. (See Appendix A)
2. **Skills Zone**: Online resources about designing and developing for digital accessibility (See Appendix B).
3. **Testing Tools**: Links (with annotations) to free, open source resources for automated testing, manual testing, colour contrast checking, readability checking, etc. (See Appendix C).
4. **Monitoring Tools**: An accessibility checklist tool and a visual monitoring map that simplifies the testing process and helps keep track of progress across tests. The checklist and mapping tool will be provided in the online toolkit space along with a tutorial about how they should be used. Users can download and use both tools.

Of the above, the first three components of the toolkit are intended to be refined later. The checklist and map tools were developed first. Their development and use are explained below:

Developing the Checklist Tool

Success criteria associated with Level A, Level AA and Level AAA under the 4 WCAG principles: PERCEIVABLE, OPERABLE, UNDERSTANDABLE and ROBUST (POUR) are provided in an Excel file named 'WCAG 2.0 Success Criteria Baseline.xlsx' for marking test results. Even though Level AAA criteria testing is not mandatory under current compliance regulations such as AODA in Ontario, Canada or Section 508 in the USA, those success criteria are also included in the Excel file.

Appendix D shows an extract of the Baseline checklist sheet in the Excel workbook that contains three tables, one each for success criteria at Level A, Level AA and Level AAA. Each table has one column marked Technical. A numerical value of 1 is marked in this column for each success criterion. The total for each of the four POUR sections gets computed automatically for both levels by applying the Excel Autosum formula. The Baseline sheet also has four columns under Functional – PHYSICAL, VISUAL, AUDITORY AND COGNITIVE (PVAC). The functional access impacted by each of the success criteria is marked with 1. The correspondence was discovered by referring to online

resources such as Understanding WCAG 2.0, aXe ruleset and Deque University. Totals for each of the four types of functional access (PVAC) are computed automatically for Level A.

The success criteria for Level A under each of the four principles are given in Table 4.

Table 3: WCAG Success Criteria summary counts at Level A

WCAG Principle Technical	**Level A Success Criteria**
Perceivable	25
Operable	12
Understandable	7
Robust	7
Functional Access	**Level A Success Criteria**
Physical	16
Visual	45
Auditory	5
Cognitive	21

Developing the Map Tool

This comprised two steps:

- creating the petals (as in Figures 6 & 7; and
- assembling the flower (as in Figure 8).

WCAG 2.0 Level AA Petals and Flower

First, four petals were created for WCAG Level A as shown in Figure 6, one for each technical WCAG principle—PERCEIVABLE,

OPERABLE, UNDERSTANDABLE AND ROBUST. Each petal was calibrated with a radial line representing the number of Level A success criteria under that principle.

Likewise, radial lines were drawn in each of the other two petals, which were calibrated as per the number of Level A success criteria for UNDERSTANDABLE and ROBUST. Figure 6 shows the four calibrated Level A 'Technical petals'.

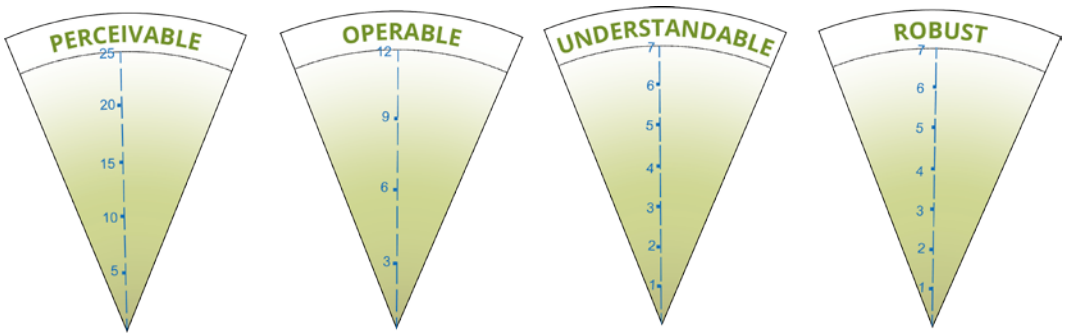

Figure 6: WCAG 2.0 Level A Technical Accessibility Criteria Petals

The functional criteria petals (Figure 7) were marked after the 4 broad access criteria: PHYSICAL, VISUAL, AUDITORY and COGNITIVE (PVAC).

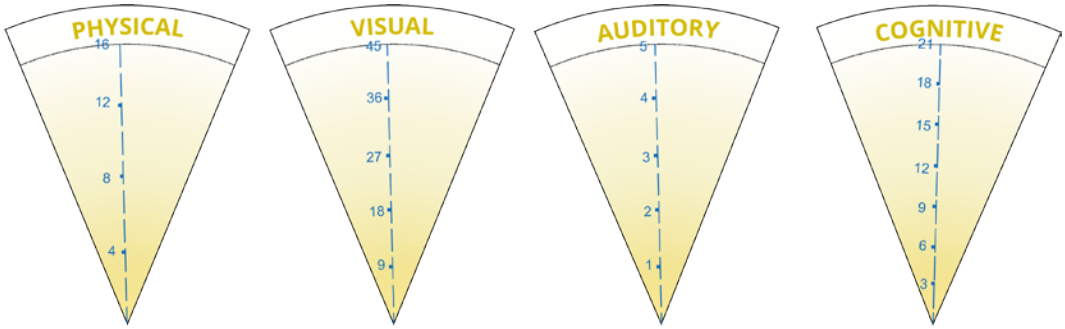

Figure 7: WCAG 2.0 Level A Functional Accessibility Criteria Petals

These were marked with one radial line each from 0 to n from centre to edge, where n represents the total number of success criteria that impact each of physical, visual, auditory or cognitive interaction respectively. These four numbers are derived from a detailed checklist (at Appendix D) and presented in Table 4 on page 50. The checklist indicates which access criteria are associated with every success criterion. One success criterion might impact more than one functionality; for example, being able to operate controls with keyboard alone (success criterion 2.1.1) is applicable to users with visual challenges as well as users with physical challenges.

The calibrated green and yellow petals were assembled into a flower as shown in Figure 8. This is the mapping tool for marking

the outcomes of accessibility tests and getting cues about areas requiring improvement.

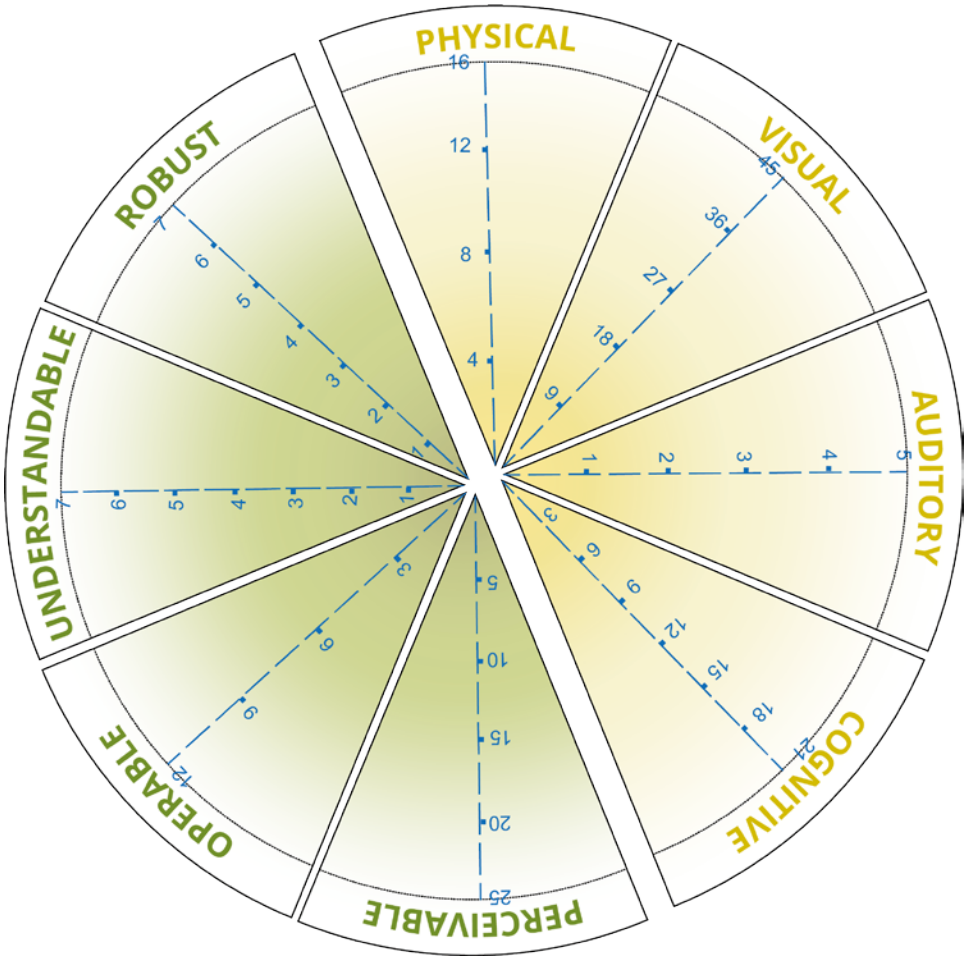

Figure 8: WCAG 2.0 Level A A11yMon Mapping tool

The semi-circles representing the technical (POUR) criteria on the left side, and the functional (PVAC) criteria on the right side, reflect different views of the same set of WCAG Level A success criteria. They are visually separated to indicate that the two are

not independent of each other; rather, they represent different ways of grouping the success criteria.

Using the Checklist and Map Tools

The exercise is about stretching and reaching: to include as many accessibility criteria as possible till we reach the edges. It is also about balance and flexibility in dealing with the technical and functional aspects of accessibility tests, knowing how they play together.

At the start of a testing session, a copy of the Baseline file is made for marking test results. The results of one round of technical testing can be marked into the Excel worksheet tool to generate the functional equivalence of the successes and failures in that round of testing. The value is changed from 1 to 0 for tests that fail. Totals get automatically calculated in the Excel worksheet to reflect the total value for each technical and functional segment. These values are marked on the map for each test.

When both technical and functional results of that round of testing are marked on the circle, we get a map that shows us

visually how far away from the edges the product is in terms of achieving full testing success. More importantly, it shows visually how the technical testing successes and failures translate in terms of functional access of the product. The map also indicates which functionalities need to be focused on for improving the product before doing the next round of testing. Repeated testing after attempting improvements would indicate how the map expands and moves closer to the edges towards greater test success.

Iterative testing example at WCAG 2.0 Level A

When a round of accessibility testing (automated and manual) is completed, the results are marked on a copy of the Baseline sheet in the Excel workbook and marked as Test 1 sheet. For every criterion passed, the value of 1 in the cell will be retained. For every criterion that failed, the value will be changed to 0. Appendix B gives a snapshot of the Test 1 results sheet. The total count for Perceivable, Operable, Understandable and Robust under Technical for Level A and Level AA will give the number of passed tests under each of these technical WCAG principles. These 4 numbers are marked as points on the map on

each of the green POUR petals to show how many success criteria were met. The counts of '1's under each functional criterion (Physical, Visual, Auditory and Cognitive) will give numbers for marking the points on the map on each of the yellow PVAC petals to show how many success criteria met each functional requirement. Detailed results of WCAG 2.0 Level A Accessibility Testing Round 1 are given in Appendix B of which Table 5 provides the summary.

Let us illustrate the above with an example data set Test 1 as shown in Table 5, which gives the technical results count of the tests that passed at Level A along with the extrapolated functional values.

Table 4: Summary Results of Accessibility Testing Round 1

Technical Requirements	**Level A Success Criteria**
Perceivable	17
Operable	12
Understandable	3
Robust	7
Functional Requirements	**Level A Success Criteria**
Physical	16
Visual	33
Auditory	5
Cognitive	17

Figure 9 shows the corresponding map, which provides a visual indication that visual and cognitive access, where the map dips below the edge of the circle need further attention.

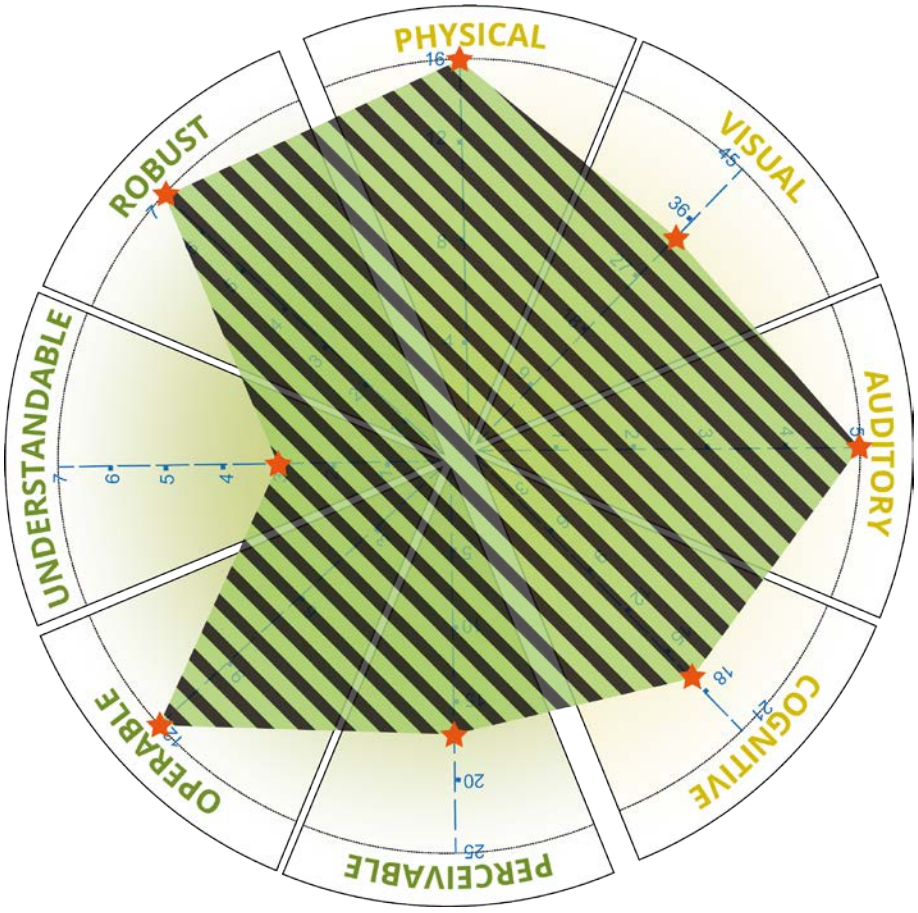

Figure 9: A11yMon map for Accessibility Test 1

Note: This map is only a progress indicator and cannot be considered a publishable "score" of the accessibility of the product without either full usability testing or having been reviewed by a certified expert who would be able to anticipate the result of user testing.

A cautionary note as above will be added to every map produced. Functional implications of each failed test will be made available as notes accompanying the checklist. Product improvements are then attempted based on cues provided by the notes.

From the functional points marked in this manner, we can infer which functional areas are well served and which require further work towards becoming accessible. This will also help EdTech companies judiciously plan their round of user testing.

Test round 2: Another round of testing is done, where some more tests pass, resulting in the Test 2 data set as in Table 6.

Table 5: Summary Results of Accessibility Testing Round 2

Technical Requirements	**Level A Success Criteria**
Perceivable	25
Operable	12
Understandable	3
Robust	7
Functional Requirements	**Level A Success Criteria**
Physical	16
Visual	41
Auditory	5
Cognitive	17

Figure 10 shows the corresponding map, which visually indicates areas of further success in tests over the first test results. The map is also seen to move closer to the edges.

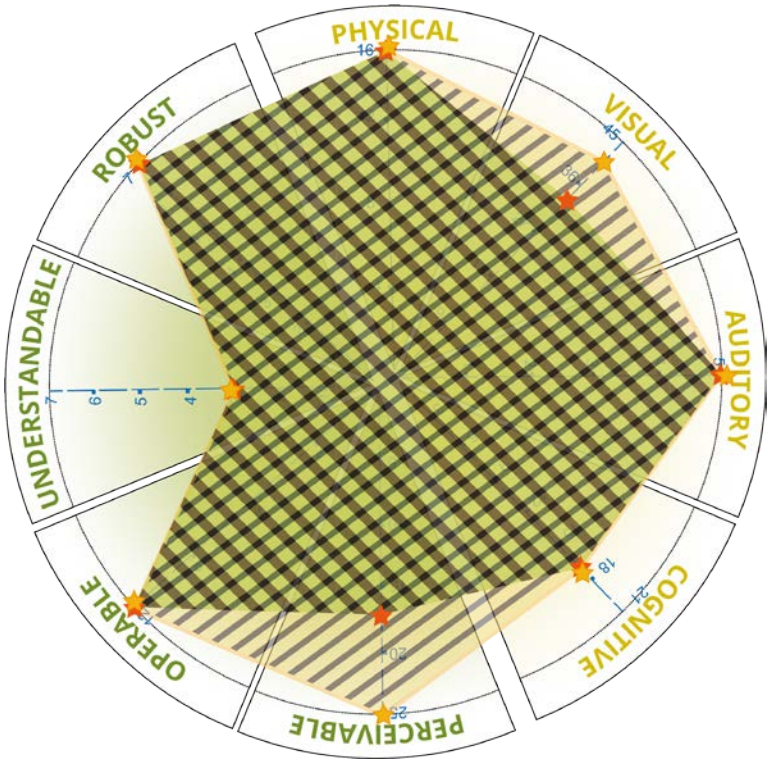

Figure 10: A11yMon map for Accessibility Test 1 + Test 2

Note: This map is only a progress indicator and cannot be considered a publishable "score" of the accessibility of the product without either full usability testing or having been reviewed by a certified expert who would be able to anticipate the result of user testing.

Once a round of remediation is completed and retesting is done, the results are mapped on the same map with a different colour. Detailed results of WCAG 2.0 Level A Accessibility Test Round 2 are given in Appendix F of which Table 6 provides the summary.

The overlap between the two maps, as seen in Figure 11, shows the shift in testing success in the second test round. The new map now showa areas where further remediation and refinements are necessary, which appears to be the COGNITIVE functional area.

Test Round 3: Product improvements are then attempted based on cues gathered from the notes accompanying the checklist. After further improvements, one more round of accessibility testing is done. Detailed results of WCAG 2.0 Level A Accessibility Testing Round 3 are given in Appendix G of which Table 7 provides the summary count of the tests that passed at Level A along with the extrapolated functional values.

Table 6: Summary Results of Accessibility Testing Round 3

Technical Requirements	**Level A Success Criteria**
Perceivable	25
Operable	12
Understandable	7
Robust	7
Functional Requirements	**Level A Success Criteria**
Physical	16
Visual	45
Auditory	5
Cognitive	21

The results marked on the A11yMon map in blue stripes as in Figure 11 show that test success has now extended to the edges, under COGNITIVE on the functional side and UNDERSTANDABLE on the technical side.

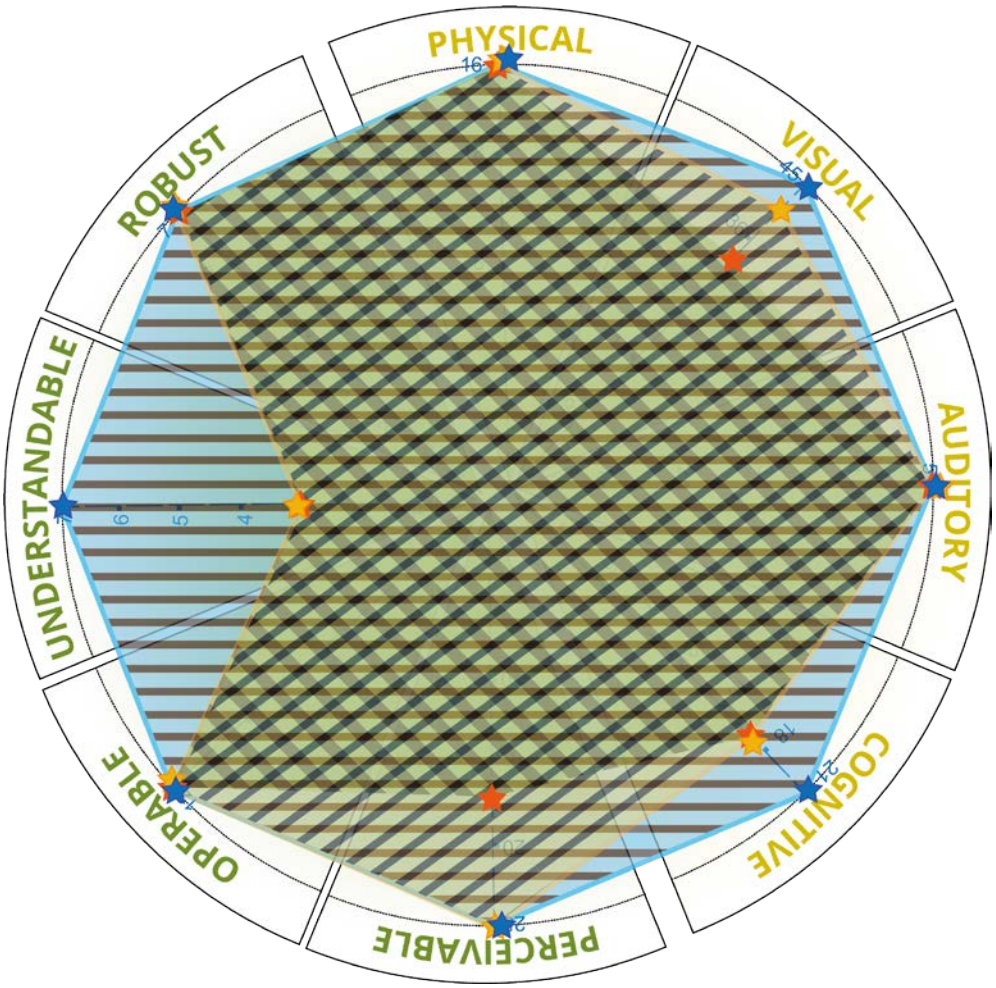

Figure 11: A11yMon map for Accessibility Test 1 + Test 2 + Test 3

Note: This map is only a progress indicator and cannot be considered a publishable "score" of the accessibility of the product without either full usability testing or having been reviewed by a certified expert who would be able to anticipate the result of user testing.

This is a hypothetical example fashioned to explain how the mapping system works. The A11yMon tool visually shows testers where they stand in the current round of accessibility testing as compared to where they stood in the previous round of testing, giving them a visual way to observe how the coverage of the success criteria tested changes across the tests. It also breaks that view up into how they have improved in terms of the WCAG POUR technical criteria, as well as what that means with respect to meeting the functional access needs of users.

It is important to remember that the visual map indicates coverage of the accessibility tests and does not indicate the level of accessibility of the product. This is explained below with an example.

Consider the case where all tests except one are successful, as illustrated in Figure 12. The failed test pertains to success criterion 2.1.1, which states that “All functionality of the content is operable through a keyboard interface.” This is a highly severe accessibility requirement. If the controls require the use of a point-and-click device such as a mouse and are not reachable and operable using only a keyboard or keyboard emulator, users

who are blind and users who cannot effectively use their hands will not be able to use the product at all. This example illustrates the fact that even though the map covers almost all of the area, it only shows that almost all of the success criteria have been tested successfully and does not indicate that the product is accessible to that degree.

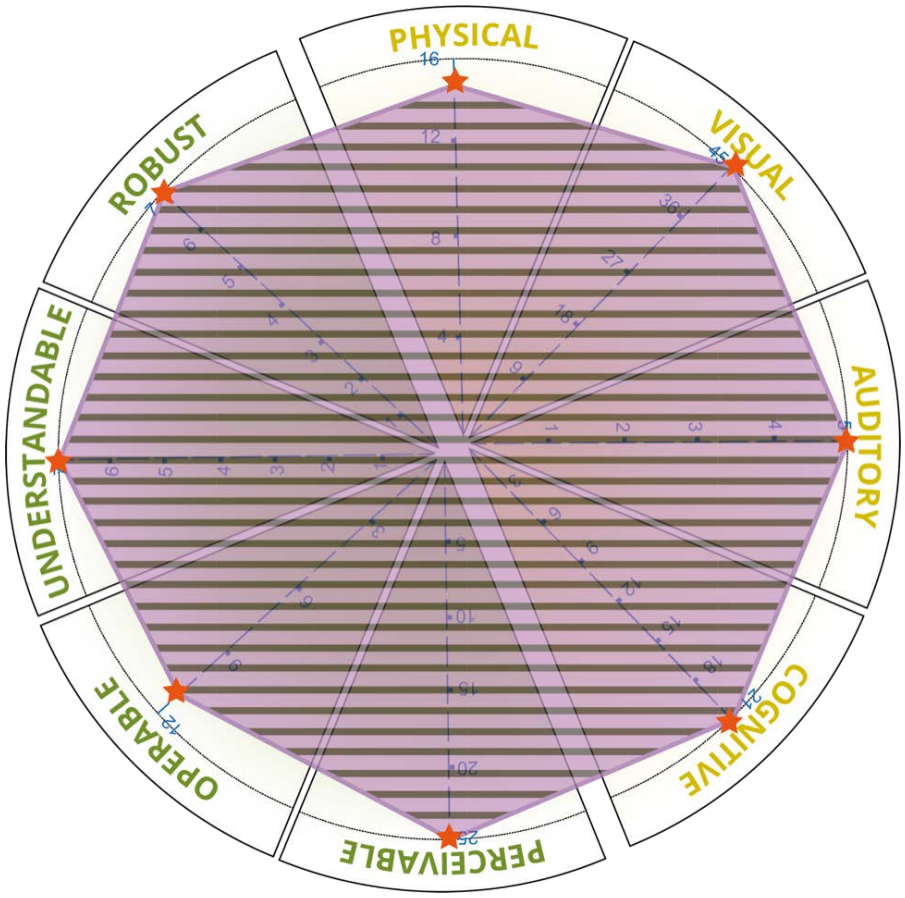

Figure 12: Map does not indicate severity of failed tests

Therefore, the intent of the mapping tool is only to indicate the progressive results of the WCAG success criteria tested. The map does not factor in the severity of tests that failed. Therefore, it does not represent equivalent improvement in the accessibility of the product.

Testing at WCAG 2.0 Levels AA and AAA

The petals and flower for Level AA and Level AAA are given in Appendix H and Appendix I respectively. They are to be used for monitoring testing done at the AA and AAA levels. Users can choose the appropriate inclusive design mapping circle (WCAG Level A or AA or AAA) based on the level of testing they are required to do. These will be available as downloadable and printable pdf files.

Hosting the Toolkit

With regard to the presentation, the toolkit is envisioned as an online resource hosted on a server at the Inclusive Design

Research Centre, Toronto[7], with a launching page that leads to four pages containing resources as detailed below:

1. **Empathy Zone**: Small write-ups, video resources that demonstrate how people with different disabilities access the computer and the web, and links to other important resources on the topic. (See Appendix A)
2. **Skills Zone**: Online resources about designing and developing for digital accessibility (See Appendix B).
3. **Testing Tools**: Links (with annotations) to free, open source resources for automated testing, manual testing, colour contrast checking, readability checking, etc. (See Appendix C).
4. **Monitoring Tools**: An accessibility checklist tool and a visual monitoring map that simplifies the testing process and helps keep track of progress across tests. The checklist tool shows the correspondence between technical and functional perspectives for each of the WCAG success criteria, and the map tool helps monitor the accessibility

[7] https://idrc.ocadu.ca/ last accessed on February 4, 2018.

improvements across tests as testers iteratively work on their product's accessibility.

The toolkit is designed as a set of accessible web pages with downloadable versions in alternative formats. The checklist and mapping tool will be provided in the online toolkit space along with a tutorial about how they should be used. Users can download and use the mapping tool.

Downloadable resources will be provided on each page. A Contact Us page will be provided for users to submit their feedback, based on which further refinements could be made to the content or presentation.

The toolkit will be published online as an accessible web page created using HTML5. The entire content will be transformed into the following formats and made available on the launching page for download to work offline:

- accessible PDF file
- accessible Word file
- accessible Excel workbook

A captioned video tutorial will also be created.

Conclusion

Among those enrolled in a 4-year program in public institutions in North America, only 33% of students with disabilities complete a bachelor's degree, compared with 48% of students without disabilities (NCES, 2000). One possible reason for the drop outs could be issues of accessibility. Technologies used in education (EdTech) enable and improve access to education; yet, if not inclusively designed, they could create new barriers.

Since the turn of the century, there has been a proliferation of technologies aimed at the education sector. A recent industry report projects an estimated value of $252 billion for the global EdTech industry by 2020 (Morrison, 2017). EdTech and its accessibility rightly deserves attention. This report presents the results of an exploratory research around accessibility of EdTech in post-secondary education in North America.

Contribution

Full-stack accessibility or accessibility of the 3 layers of EdTech (Platform, Process, Content) was proposed as a concept and a theoretical framework for optimizing education accessibility.

Based on this framework and responding to the needs of EdTech vendors as identified through research, a toolkit was designed using inclusive design principles to help EdTech vendors monitor product accessibility.

The Accessibility Monitoring (A11yMon) toolkit supports and facilitates how EdTech vendors could work towards improving accessibility of their products through testing, remediation and retesting as part of their design and production process. It provides resources to support their testing process.

The toolkit contains A11yMon checklist tool, an Excel checklist for marking the results of WCAG 2.0 testing at one of three levels that automatically converts the technical testing results into a functional access perspective. It also contains A11yMon map, a visual mapping tool for marking the results of accessibility tests. The map helps in visualizing and understanding the technical and functional components covered. It enables visual monitoring of the improvements in test results across different tests, the goal being to cover more and more success criteria and reach the edge.

The map tool is based on IDRC's inclusive design mapping tool[8]. IDRC's mapping tool is intended for co-design of artefacts with people with diverse needs, and the A11yMon map tool is designed for monitoring the improvements in the results of iterative accessibility testing. The intent of the mapping tool is merely to indicate the progressive results of the WCAG success criteria tested. It does not represent equivalent improvement in the accessibility of the product.

This tool is an innovatively variant use of IDRC's mapping tool. The tool is intended to be generically useful and understandable. From a functional perspective, the stretching of the map towards the edges across testing iterations denotes the stretching of the design to cover a wider range of user needs. From a technical perspective, it shows the expansion in the compliance or success achieved in tests, to encompass more of the WCAG 2.0 success criteria.

[8] https://guide.inclusivedesign.ca/activities/InclusiveDesignMapping.html and https://wiki.fluidproject.org/pages/viewpage.action?pageId=80674818 (last accessed on February 4, 2018).

The toolkit would help EdTech go beyond technical compliance and engage with users meaningfully for improving the accessibility of their products. They would then gain the 'diversity bonus,' as Scott Page calls it[9].

Limitations and Next Steps

Due to the short duration of the MRP study, all planned components of the toolkit could not be completed. Of the five components, two (checklist tool and mapping tool) were developed fully and the remaining will be taken up in future.

In conclusion, digital technology should never limit learning opportunities. As stated by Jutta Treviranus, Director of the Inclusive Design Research Centre, Toronto,

"… in this digitally transformed reality that we live and work in—where consumption does not consume, and space has no limits—there is no downside to inclusion and it is possible to make room for us all."

[9] https://press.princeton.edu/titles/11077.html (last accessed on May 4, 2018).

References

Behl, G., & Deshmukh, U. M. (2017). Use of Technology and Innovations in Education Sector: A conceptual study. International Journal of Advanced Educational Research Vol 2(6). pp. 326-327.

Brown, M., Dehoney, J., & Millichap, N. (2015). The next generation digital learning environment. *A Report on Research. ELI Paper. Louisville, CO: Educause April*.

Ellis, R. K. (2009a). Learning Management Systems. *Alexandria, VI: American Society for Training & Development (ASTD)*.

Ellis, R. K. (2009b). Field guide to learning management systems. *ASTD Learning Circuits*, 1-8.

Gellert, L. (2012). What is a Full Stack developer. *Laurence Gellert's Blog* https://www.laurencegellert.com/2012/08/what-is-a-full-stack-developer/.

Hasselbring, T. S., & Glaser, C. H. W. (2000). Use of computer technology to help students with special needs. *The Future of Children*, 102-122.

Hersh, M. & Leporini, B. (2012). Accessibility and usability of educational gaming environments for disabled students. IEEE International Conference on Advanced Learning Technologies, 2012 pp. 752-753.

IMSGLC. (n.d.). Seamless, Rapid Integration of Innovative Learning Applications and Tools. LAT. IMS Global Learning Consortium

Inc, n.d. Web. https://www.imsglobal.org/.

Kent, M. (2015). Disability and eLearning: Opportunities and barriers. Disability Studies Quarterly, vol. 35(1).

McManus, D., Dryer, R. & Henning, M. (2017). Barriers to learning

online experienced by students with a mental health disability. Distance Education, vol. 38(3), pp. 336-352.

Liu, T. (October 1, 2017). What is full-stack designer. *Medium.* https://medium.muz.li/what-is-a-full-stack-designer-in-2017-will-you-be-one-7933a7145fb7.

Liu, T. (December 25, 2017). Six essential tips on how to become a full-stack developer. *Hackermoon*. https://hackernoon.com/6-essential-tips-on-how-to-become-a-full-stack-developer-1d10965aaead.

Microsoft. (2016). Inclusive Design Toolkit. Web. *https://www.microsoft.com/en-us/design/inclusive*

Morrison, N. (2017). “Google Leapfrogs Rivals to Be Classroom King.” Forbes, May 9. https://www.forbes.com/sites/nickmorrison/2017/05/09/google-leapfrogs-rivals-to-be-classroomking/#32966ae927a6.

NCES. (2000). National Centre for Educational Statistics. Post Secondary Students with Disabilities. https://nces.ed.gov/surveys/peqis/publications/2000092/.

Rangin, H., Petri, K., Richwine, B., & Thompson, M. (2013). A

comparison of learning management system accessibility. University of Illinois Disability Resources and Educational Services. Retrieved from presentations. cita. illinois. edu/2011-03-csun-lms.

Ready, S. (August 29, 2016). Accessibility in education: How is it defined? Blog. http://blog.blackboard.com/accessibility-in-education-how-defined/ last accessed on February 3, 2018.

Rogers, M. (November 28, 2017). Government Accessibility Standards and WCAG 2. Powermapper. Blog. https://www.powermapper.com/blog/government-accessibility-standards/

Strachan, J, (October 19, 2017). Why use extreme users? Web. https://uxplanet.org/why-use-extreme-users-345e97719e52.

Statscan. (2006). Statistics Canada. Prevalence of Disability 2006. http://www.statcan.gc.ca/pub/89-628-x/2007002/4125019-eng.htm.

toolkit. (n.d.). *Collins English Dictionary - Complete & Unabridged 10th Edition*. Retrieved April 17, 2018 from Dictionary.com website http://www.dictionary.com/browse/toolkit.

Treviranus, J. (2016a). Life-long learning on the inclusive web. In *Proceedings of the 13th Web for All Conference* (p. 1). ACM.

Treviranus, J. (2016b). The Future Challenge of the ADA: Shaping Humanity's Transformation. *Inclusion*, *4*(1), 30-38.

Treviranus, J., Petty, L., 2001, Computer Access, in *Manual of Assistive Technology*. Mosby, Chicago.

UN. (2006). United Nations Division for Social Policy and Development – Disability. Convention on the Rights of Persons with

Disabilities (CRPD). https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html.

US Census. (2000). United States Census Bureau. Census Gateway 2000. https://www.census.gov/main/www/cen2000.html

IDRC (n.d.). What is Inclusive Design. Retrieved from https://idrc.ocadu.ca/resources/idrc-online/49-articles-and-papers/443-whatisinclusivedesign.

Worldometers. (n.d.) World Population. Website. http://www.worldometers.info/world-population/

Appendices

A: A11yMon Toolkit — Empathy Zone

Small write-ups, video resources that demonstrate how people with different disabilities access the computer and the web, and links to other important resources on the topic.

Inclusive Design 24 (#ID24)

YouTube – Google's A11yCast videos playlist by Rob Dodson

Webaim students with disabilities video

JAWS screen reader demo

Voiceover screen reader demo

Sip-and-Puff demo

Eye Tracking demo

Push Switch demo

Sign language technology

NoCoffee Visual Simulator for Chrome

Sim Daltonism Colour blindness simulator for iOS and MacOS

B: A11yMon Toolkit — Skills Zone

Online resources about designing and developing for digital accessibility.

Humber College – Media Accessibility Course

Udacity – Web Accessibility course by Google

Web Accessibility Tutorial

W3C BAD demo site

W3C Tips on Developing for Web Accessibility

W3C Tips on Designing for Web Accessibility

WebAIM Web Accessibility Tips for Designers

W3C Tips on Writing for Web Accessibility

NCSU Accessibility Handbook

Material Design Accessibility Guidelines for Designers

Google Web Fundamentals for Developers, Accessibility

WebAIM Screen Reader User Surveys

Ryerson – Web Accessibility MOOC – Professional Web

Accessibility Audit made Easy

Google – Introduction to Web Accessibility

C: A11yMon Toolkit — Testing Tools

Links (with annotations) to free, open source resources for automated testing, manual testing, colour contrast checking, readability checking, etc.

aXe 3.0 Rules

Web Accessibility Evaluation Tools List

Easy Accessibility Testing with aXe

Wave from WebAIM

Tenon from Tenon.io

aChecker from IDRC

aXe browser extension for Firefox and Chrome

Wave browser extension for Firefox and Chrome

How to use NVDA – Video by Deque

AllyCasts Screenreader Basics – NVDA

Keyboard Shortcuts for NVDA

AllyCasts Screenreader Basics – Voiceover

Online Colour Picker – ImageColourPicker

Online Contrast checker

Online Colour Codes

WebAIM Colour Contrast Checker

Youtube – DIY Video Captioning tool for members

Amara – DIY Video Captioning tool

D: WCAG 2.0 Success Criteria Baseline Checklist

WCAG 2.0 Level A Technical Success Criteria mapped to Functional Access Criteria

Table 7: WCAG 2.0 Level A Technical and Functional Criteria

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Perceivable					
A 1.1.1.a Alternative Text (Active Images)	1		1		
A 1.1.1.b Alt Text (Informative Images)	1		1		
A 1.1.1.c Alternative Text (Complex Images)	1		1		
A 1.1.1.d Alt Text (Decorative Images)	1		1		
A 1.1.1.e Alternative Text (CSS Images)	1		1		
A 1.1.1.f Alt Text (Input Type Images)	1		1		
A 1.1.1.g Alternative Text (Captcha)	1		1		
A 1.1.1.h Alternative Text (Audio or Video)	1		1		

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.2.1.a Text Transcript (Prerec Audio)	1			1	
A 1.2.1.b Text or Audio Desc (No Dialog)	1		1		
A 1.2.2.a Captions (Prerecorded)	1			1	
A 1.2.3.a Text or Audio Desc (with Dialog)	1		1		
A 1.3.1.a Semantics	1		1		
A 1.3.1.b Data Tables	1		1		
A 1.3.1.c Programmatic Labels	1		1		
A 1.3.1.d Group Related Form Elements	1		1		
A 1.3.1.e Headings	1		1		
A 1.3.1.f Lists	1		1		
A 1.3.2.a Reading Order	1		1		
A 1.3.2.b Finding Added Content	1		1		
A 1.3.3.a Visual Cues	1		1		
A 1.3.3.b Sound Cues	1			1	

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.4.1.a Color as Information	1		1		
A 1.4.1.b Link Color Contrast	1		1		
A 1.4.2.a Audio Control	1			1	
Total for Perceivable Level A	25				
Operable					
A 2.1.1.a Keyboard Navigation	1	1	1		
A 2.1.1.b Shortcut Keys	1	1	1		
A 2.1.2.a Keyboard Trap	1	1	1		
A 2.2.1.a Timing Adjustable	1	1	1		1
A 2.2.2.a Pause, Stop, or Hide Content	1	1	1		1
A 2.2.2.b Automatically Updating Content	1	1	1		1
A 2.3.1.a Flashing Content	1				1
A 2.4.1.a Avoid Repetitive Elements	1	1	1		
A 2.4.1.b Titles on Frames	1		1		1

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 2.4.2.a Titles on Pages	1		1		1
A 2.4.3.a Focus Order	1	1	1		1
A 2.4.4.a Link Purpose	1	1	1		1
Total for Operable Level A	12				
Understandable					
A 3.1.1.a Default Page Language	1		1		
A 3.2.1.a Context Changes (on Focus)	1		1		1
A 3.2.2.a Context Changes (on Input)	1		1		1
A 3.3.1.b Errors Identification	1		1		1
A 3.3.2.a Visible Labels	1				1
A 3.3.2.b Missing Instructions	1		1		1
A 3.3.2.c Required Form Fields	1		1		1
Total for Understandable Level A	7				
Robust					
A 4.1.1.a Formatting Errors	1	1	1		1

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 4.1.1.b Well Formed	1	1	1		1
A 4.1.1.c Duplicate Attributes	1	1	1		1
A 4.1.1.d Unique IDs	1	1	1		1
A 4.1.2.a Name, Role, Value	1	1	1		1
A 4.1.2.b Custom Controls	1	1	1		1
A 4.1.2.c Compatibility	1	1	1	1	1
Total for Robust Level A	7				
Totals for Functional Level A		16	45	5	21

WCAG 2.0 Level AA Technical Success Criteria mapped to Functional Access Criteria

Table 8: WCAG 2.0 Level AA Technical and Functional Criteria

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AA	Physical	Visual	Auditory	Cognitive
Perceivable					
AA 1.2.4.a Captions (Live)	1			1	
AA 1.2.5.a Audio Descriptions (Prerecorded)	1		1		

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AA	Physical	Visual	Auditory	Cognitive
AA 1.4.3.a Color Contrast (regular text)	1		1		
AA 1.4.3.b Color Contrast (large text)	1		1		
AA 1.4.4.a Resize (200%)	1		1		
AA 1.4.5.a Images of Text	1		1		
Total for Perceivable Level AA	6				
Operable					
AA 2.4.5.a Multiple Ways	1	1	1		1
AA 2.4.6.a Descriptive Headings	1	1	1		1
AA 2.4.6.b Descriptive Labels	1	1	1		1
AA 2.4.7.a Focus Visible	1	1			1
Total for Operable Level AA	4				
Understandable					
AA 3.1.2.a Language of Parts	1		1		
AA 3.2.3.a Consistent Navigation Patterns	1		1		1
AA 3.2.4.a Consistent Identification	1		1		1

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AA	Physical	Visual	Auditory	Cognitive
AA 3.3.3.a Error Suggestion	1		1		1
AA 3.3.4.a Error Prevention	1		1		1
Total for Understandable Level AA	5				
Robust					
No assigned success criteria					
Total for Robust Level AA	0				
Totals for Functional Level AA		4	13	1	8

WCAG 2.0 Level AAA Technical Success Criteria mapped to Functional Access Criteria

Table 9: WCAaG 2.0 Level AAA Technical and Functional Criteria

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AAA	Physical	Visual	Auditory	Cognitive
Perceivable					
AAA 1.2.6 Sign Language (Pre-recorded)	1			1	
AAA 1.2.7 Extended Audio Desc (Pre-recorded)	1		1		

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AAA	Physical	Visual	Auditory	Cognitive
AAA 1.2.8 Media Alternative (Pre-recorded)	1		1	1	
AAA 1.2.9 Audio-only (Live)	1			1	
AAA 1.4.6 Contrast (Enhanced)	1		1		
AAA 1.4.7 Low or No Background Audio	1		1		1
AAA 1.4.8 Visual Presentation	1		1		1
AAA 1.4.9 Images of Text (No Exception)	1		1		
Total for Perceivable Level AAA	8				
Operable					
AAA 2.1.3 Keyboard (No Exception)	1	1	1		
AAA 2.2.3 No Timing	1	1	1		1
AAA 2.2.4 Interruptions	1	1	1		1
AAA 2.3.2 Three Flashes	1				1
AAA 2.4.8 Location	1		1		1
AAA 2.4.9 Link Purpose (Link Only)	1		1		1

WCAG 2.0 Success Criteria	Technical	Functional			
	LEVEL AAA	Physical	Visual	Auditory	Cognitive
AAA 2.4.10 Section Headings	1		1		1
Total for Operable Level AAA	7				
Understandable					
AAA 3.1.3 Unusual Words	1				1
AAA 3.1.4 Abbreviations	1				1
AAA 3.1.5 Reading Level	1				1
AAA 3.1.6 Pronunciation	1				1
AAA 3.2.5 Change on Request	1				1
AAA 3.3.5 Help	1	1			1
AAA 3.3.6 Error Prevention (All)	1	1	1		1
Total for Understandable Level AAA	7				
Robust					
No assigned success criteria					
Total for Robust Level AAA	0				
Totals for Functional Level AAA		5	13	3	15

E: Results of WCAG 2.0 Level A Testing Round 1

Table 10: WCAG 2.0 Level A Test Round 1 Results

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Perceivable					
A 1.1.1.a Alternative Text (Active Images)	0		0		
A 1.1.1.b Alt Text (Informative Images)	0		0		
A 1.1.1.c Alternative Text (Complex Images)	0		0		
A 1.1.1.d Alt Text (Decorative Images)	0		0		
A 1.1.1.e Alternative Text (CSS Images)	0		0		
A 1.1.1.f Alt Text (Input Type Images)	0		0		
A 1.1.1.g Alternative Text (Captcha)	0		0		
A 1.1.1.h Alternative Text (Audio or Video)	0		0		
A 1.2.1.a Text Transcript (Prerec Audio)	1			1	

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.2.1.b Text or Audio Desc (No Dialogue)	1		1		
A 1.2.2.a Captions (Prerecorded)	1			1	
A 1.2.3.a Text or Audio Desc (with Dialogue)	1		1		
A 1.3.1.a Semantics	1		1		
A 1.3.1.b Data Tables	1		1		
A 1.3.1.c Programmatic Labels	1		1		
A 1.3.1.d Group Related Form Elements	1		1		
A 1.3.1.e Headings	1		1		
A 1.3.1.f Lists	1		1		
A 1.3.2.a Reading Order	1		1		
A 1.3.2.b Finding Added Content	1		1		
A 1.3.3.a Visual Cues	1		1		
A 1.3.3.b Sound Cues	1			1	
A 1.4.1.a Color as Information	1		1		
A 1.4.1.b Link Color Contrast	1		1		

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.4.2.a Audio Control	1			1	
Total for Perceivable Level A	17				
Operable					
A 2.1.1.a Keyboard Navigation	1	1	1		
A 2.1.1.b Shortcut Keys	1	1	1		
A 2.1.2.a Keyboard Trap	1	1	1		
A 2.2.1.a Timing Adjustable	1	1	1		1
A 2.2.2.a Pause, Stop, or Hide Content	1	1	1		1
A 2.2.2.b Automatically Updating Content	1	1	1		1
A 2.3.1.a Flashing Content	1				1
A 2.4.1.a Avoid Repetitive Elements	1	1	1		
A 2.4.1.b Titles on Frames	1		1		1
A 2.4.2.a Titles on Pages	1		1		1
A 2.4.3.a Focus Order	1	1	1		1
A 2.4.4.a Link Purpose	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Total for Operable Level A	12				
Understandable					
A 3.1.1.a Default Page Language	1		1		
A 3.2.1.a Context Changes (on Focus)	0		0		0
A 3.2.2.a Context Changes (on Input)	0		0		0
A 3.3.1.b Errors Identification	0		0		0
A 3.3.2.a Visible Labels	1				1
A 3.3.2.b Missing Instructions	1		1		1
A 3.3.2.c Required Form Fields	0		0		0
Total for Understandable Level A	3				
Robust					
A 4.1.1.a Formatting Errors	1	1	1		1
A 4.1.1.b Well Formed	1	1	1		1
A 4.1.1.c Duplicate Attributes	1	1	1		1
A 4.1.1.d Unique IDs	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 4.1.2.a Name, Role, Value	1	1	1		1
A 4.1.2.b Custom Controls	1	1	1		1
A 4.1.2.c Compatibility	1	1	1	1	1
Total for Robust Level A	7				
Total for Functional Level A		16	33	5	17

F: Results of WCAG 2.0 Level A Testing Round 2

Table 11: WCAG 2.0 Level A Test Round 2 Results

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Perceivable					
A 1.1.1.a Alternative Text (Active Images)	1		1		
A 1.1.1.b Alt Text (Informative Images)	1		1		
A 1.1.1.c Alternative Text (Complex Images)	1		1		
A 1.1.1.d Alt Text (Decorative Images)	1		1		
A 1.1.1.e Alternative Text (CSS Images)	1		1		
A 1.1.1.f Alt Text (Input Type Images)	1		1		
A 1.1.1.g Alternative Text (Captcha)	1		1		
A 1.1.1.h Alternative Text (Audio or Video)	1		1		
A 1.2.1.a Text Transcript (Pre-recorded Audio)	1			1	

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.2.1.b Text or Audio Desc (No Dialogue)	1		1		
A 1.2.2.a Captions (Pre-recorded)	1			1	
A 1.2.3.a Text or Audio Desc (with Dialogue)	1		1		
A 1.3.1.a Semantics	1		1		
A 1.3.1.b Data Tables	1		1		
A 1.3.1.c Programmatic Labels	1		1		
A 1.3.1.d Group Related Form Elements	1		1		
A 1.3.1.e Headings	1		1		
A 1.3.1.f Lists	1		1		
A 1.3.2.a Reading Order	1		1		
A 1.3.2.b Finding Added Content	1		1		
A 1.3.3.a Visual Cues	1		1		
A 1.3.3.b Sound Cues	1			1	
A 1.4.1.a Color as Information	1		1		
A 1.4.1.b Link Color Contrast	1		1		

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.4.2.a Audio Control	1			1	
Total for Perceivable Level A	25				
Operable					
A 2.1.1.a Keyboard Navigation	1	1	1		
A 2.1.1.b Shortcut Keys	1	1	1		
A 2.1.2.a Keyboard Trap	1	1	1		
A 2.2.1.a Timing Adjustable	1	1	1		1
A 2.2.2.a Pause, Stop, or Hide Content	1	1	1		1
A 2.2.2.b Automatically Updating Content	1	1	1		1
A 2.3.1.a Flashing Content	1				1
A 2.4.1.a Avoid Repetitive Elements	1	1	1		
A 2.4.1.b Titles on Frames	1		1		1
A 2.4.2.a Titles on Pages	1		1		1
A 2.4.3.a Focus Order	1	1	1		1
A 2.4.4.a Link Purpose	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Total for Operable Level A	12				
Understandable					
A 3.1.1.a Default Page Language	1		1		
A 3.2.1.a Context Changes (on Focus)	0		0		0
A 3.2.2.a Context Changes (on Input)	0		0		0
A 3.3.1.b Errors Identification	0		0		0
A 3.3.2.a Visible Labels	1				1
A 3.3.2.b Missing Instructions	1		1		1
A 3.3.2.c Required Form Fields	0		0		0
Total for Understandable Level A	3				
Robust					
A 4.1.1.a Formatting Errors	1	1	1		1
A 4.1.1.b Well Formed	1	1	1		1
A 4.1.1.c Duplicate Attributes	1	1	1		1
A 4.1.1.d Unique IDs	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 4.1.2.a Name, Role, Value	1	1	1		1
A 4.1.2.b Custom Controls	1	1	1		1
A 4.1.2.c Compatibility	1	1	1	1	1
Total for Robust Level A	7				
Total for Functional Level A		16	41	5	17

G: Results of WCAG 2.0 Level A Testing Round 3

Table 12: WCAG 2.0 Level A Test Round 3 Results

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Perceivable					
A 1.1.1.a Alternative Text (Active Images)	1		1		
A 1.1.1.b Alt Text (Informative Images)	1		1		
A 1.1.1.c Alternative Text (Complex Images)	1		1		
A 1.1.1.d Alt Text (Decorative Images)	1		1		
A 1.1.1.e Alternative Text (CSS Images)	1		1		
A 1.1.1.f Alt Text (Input Type Images)	1		1		
A 1.1.1.g Alternative Text (Captcha)	1		1		
A 1.1.1.h Alternative Text (Audio or Video)	1		1		
A 1.2.1.a Text Transcript (Pre-recorded Audio)	1			1	

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.2.1.b Text or Audio Description (No Dialogue)	1		1		
A 1.2.2.a Captions (Pre-recorded)	1			1	
A 1.2.3.a Text or Audio Description (with Dialogue)	1		1		
A 1.3.1.a Semantics	1		1		
A 1.3.1.b Data Tables	1		1		
A 1.3.1.c Programmatic Labels	1		1		
A 1.3.1.d Group Related Form Elements	1		1		
A 1.3.1.e Headings	1		1		
A 1.3.1.f Lists	1		1		
A 1.3.2.a Reading Order	1		1		
A 1.3.2.b Finding Added Content	1		1		
A 1.3.3.a Visual Cues	1		1		
A 1.3.3.b Sound Cues	1			1	
A 1.4.1.a Color as Information	1		1		
A 1.4.1.b Link Color Contrast	1		1		

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 1.4.2.a Audio Control	1			1	
Total for Perceivable Level A	25				
Operable					
A 2.1.1.a Keyboard Navigation	1	1	1		
A 2.1.1.b Shortcut Keys	1	1	1		
A 2.1.2.a Keyboard Trap	1	1	1		
A 2.2.1.a Timing Adjustable	1	1	1		1
A 2.2.2.a Pause, Stop, or Hide Content	1	1	1		1
A 2.2.2.b Automatically Updating Content	1	1	1		1
A 2.3.1.a Flashing Content	1				1
A 2.4.1.a Avoid Repetitive Elements	1	1	1		
A 2.4.1.b Titles on Frames	1		1		1
A 2.4.2.a Titles on Pages	1		1		1
A 2.4.3.a Focus Order	1	1	1		1
A 2.4.4.a Link Purpose	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
Total for Operable Level A	12				
Understandable					
A 3.1.1.a Default Page Language	1		1		
A 3.2.1.a Context Changes (on Focus)	1		1		1
A 3.2.2.a Context Changes (on Input)	1		1		1
A 3.3.1.b Errors Identification	1		1		1
A 3.3.2.a Visible Labels	1				1
A 3.3.2.b Missing Instructions	1		1		1
A 3.3.2.c Required Form Fields	1		1		1
Total for Understandable Level A	7				
Robust					
A 4.1.1.a Formatting Errors	1	1	1		1
A 4.1.1.b Well Formed	1	1	1		1
A 4.1.1.c Duplicate Attributes	1	1	1		1

WCAG 2.0 LEVEL A Success Criteria	Technical	Functional			
	LEVEL A	Physical	Visual	Auditory	Cognitive
A 4.1.1.d Unique IDs	1	1	1		1
A 4.1.2.a Name, Role, Value	1	1	1		1
A 4.1.2.b Custom Controls	1	1	1		1
A 4.1.2.c Compatibility	1	1	1	1	1
Total for Robust Level A	7				
Total for Functional Level A		16	45	5	21

H: WCAG 2.0 Level AA Petals and Flower

Table 13: WCAG Success Criteria summary counts at Level AA

WCAG Principle Technical	**Level AA Success Criteria**
Perceivable	6
Operable	4
Understandable	5
Robust	0
Functional Requirements	**Level AA Success Criteria**
Physical	4
Visual	13
Auditory	1
Cognitive	8

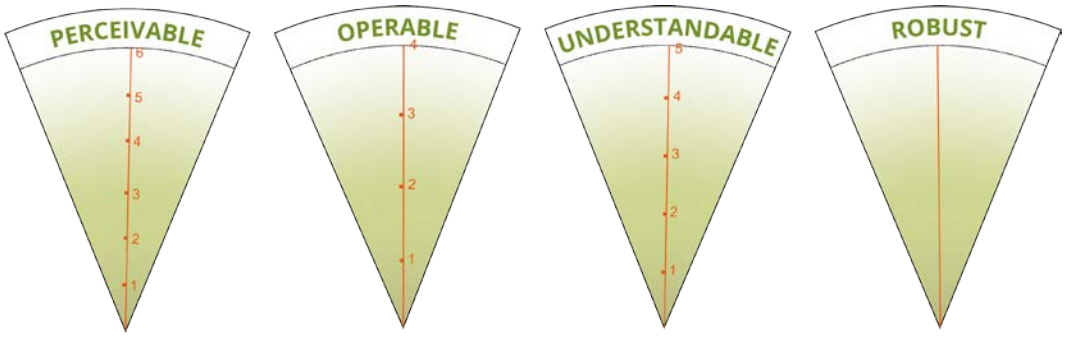

Figure 13: WCAG 2.0 Level AA Technical Criteria Petals

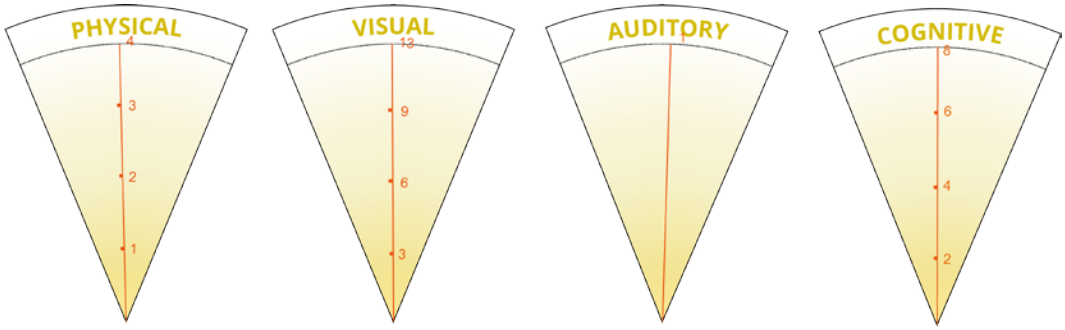

Figure 14: WCAG 2.0 Level AA Functional Accessibility Criteria Petals

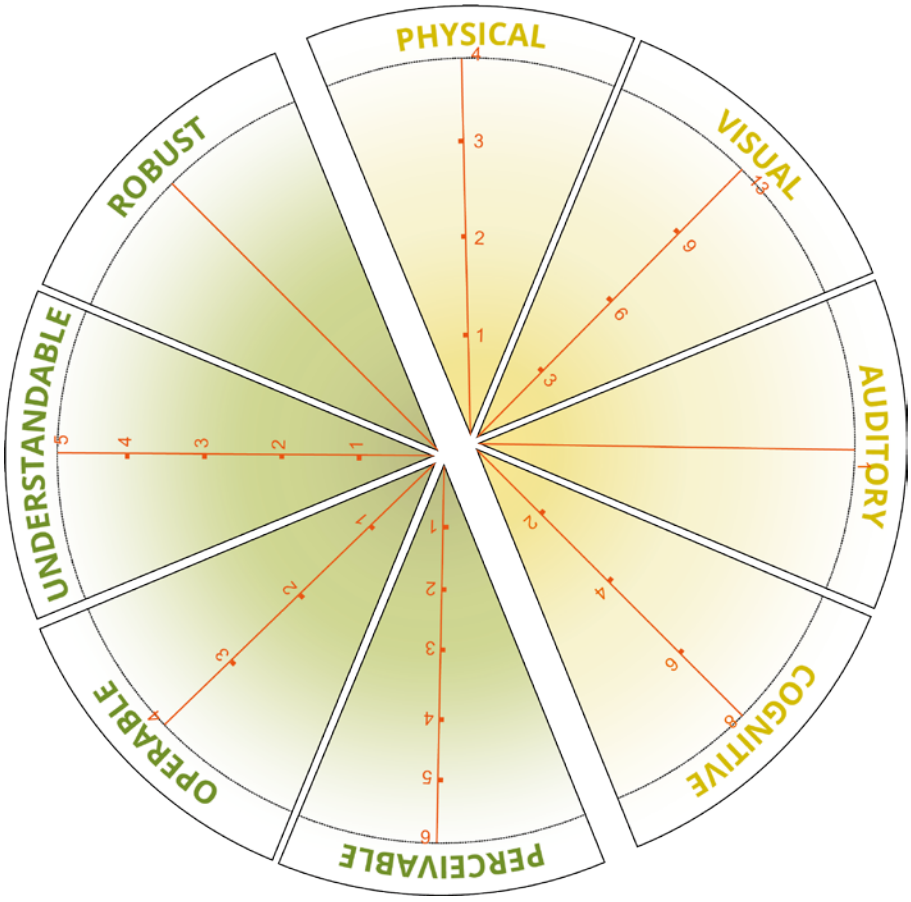

Figure 15: WCAG 2.0 Level AA A11yMon Mapping tool

The semi-circles representing the technical (POUR) criteria on the left side, and the functional (PVAC) criteria on the right side, reflect different views of the same set of WCAG Level AA success criteria. They are visually separated to indicate that the two are not independent of each other; rather, they represent different ways of grouping the success criteria.

I: WCAG 2.0 Level AAA Petals and Flower

Table 14: WCAG Success Criteria summary counts at Level AAA

WCAG Principle Technical	**Level AAA Success Criteria**
Perceivable	8
Operable	7
Understandable	7
Robust	0
Functional Requirements	**Level AAA Success Criteria**
Physical	5
Visual	13
Auditory	3
Cognitive	15

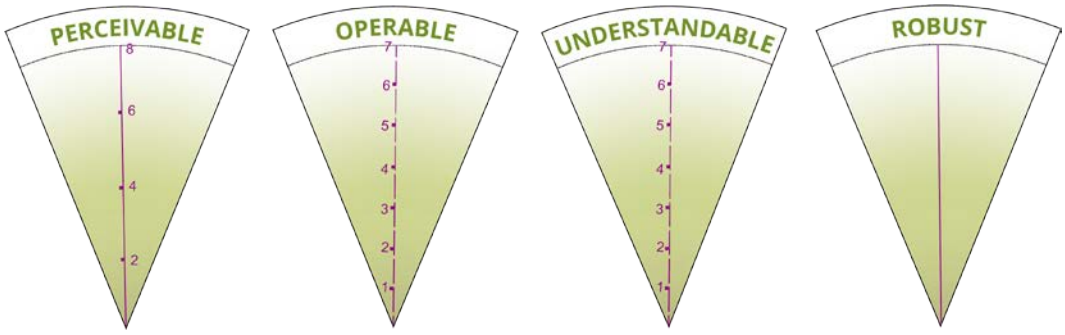

Figure 16: WCAG 2.0 Level AAA Technical Criteria Petals

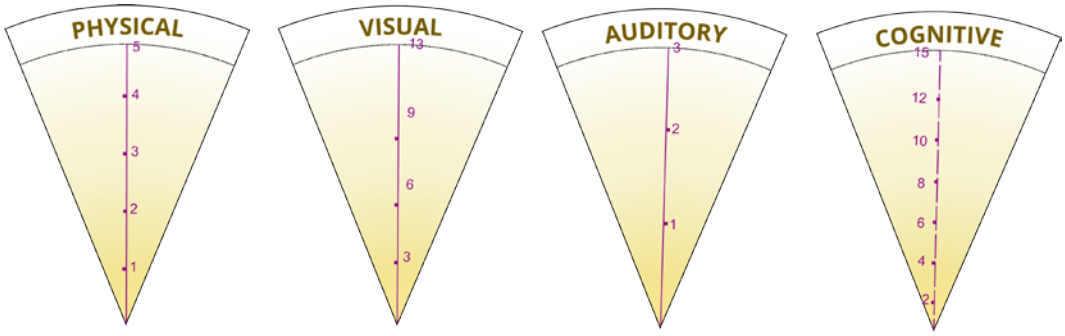

Figure 17: WCAG 2.0 Level AAA Functional Accessibility Criteria Petals

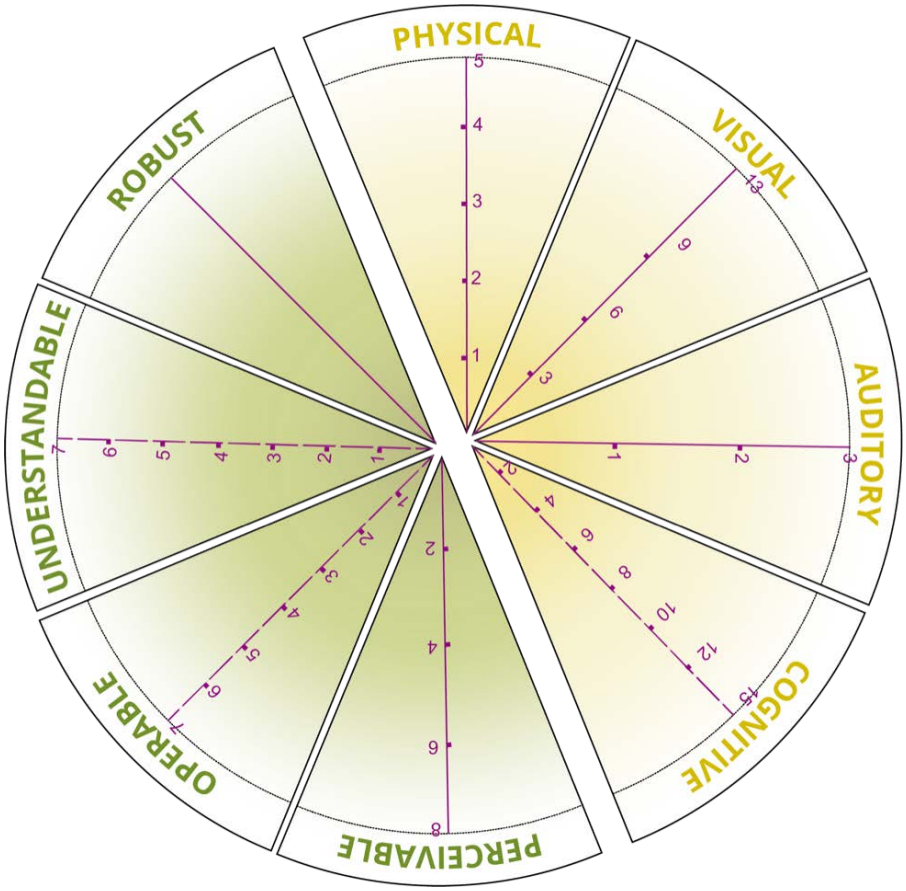

Figure 18: WCAG 2.0 Level AAA A11yMon Mapping tool

The semi-circles representing the technical (POUR) criteria on the left side, and the functional (PVAC) criteria on the right side, reflect different views of the same set of WCAG Level AAA success criteria. They are visually separated to indicate that the two are not independent of each other; rather, they represent different ways of grouping the success criteria.