A PRAGMATIC AND HUMAN-CENTERED APPROACH TO PROMOTING SOFTWARE ACCESSIBILITY: DESIGN, EDUCATION, GOVERNANCE

BY

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DISSERTATION

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Abstract

In this dissertation, I explore three approaches to software accessibility: design, education, and governance. I aim to facilitate a discussion toward a pragmatic and integrated approach to accessibility.

In the design chapter, I approached cancer survivors and spotlighted their lived experiences and challenges with software. A survey study, in-depth semi-structured interviews, and a diary study were conducted to capture the multi-faceted software experiences of cancer survivors. Cancer survivors may have multiple disabilities, including visual impairments, dexterity impairments/neuropathy, and chemo brain unique to this population. These impairments led to difficulty in using software, which is a fundamental way for cancer survivors to search for health-related information and socialize with others. Based on the results, I proposed simple yet practical accessibility guidelines to accommodate the software needs of cancer survivors. For example, bulleted content, highlighting key information, and simplified User Interface (UI) designs make navigation easier for people with chemo brain. Such guidelines can be easily incorporated into software design and development practices.

In the education chapter, I validated the possibility of teaching software accessibility before post-secondary education. Accessibility education was found to be limited in the high school curriculum, which is a missed opportunity to equip the next-generation software designers with the mindset of accessible design. I used a set of disability simulation games to successfully enhance the knowledge, awareness, and empathy of high school students regarding accessibility. Games and gamified approaches help engage students in learning advanced computing concepts.

In the governance chapter, I examined the status quo of governance approaches to improving software accessibility. I analyzed 39 software accessibility laws in 32 countries or regions to understand how they did well and where they fell short. One notable gap is that software accessibility laws have very few rules, degrading their enforceability. The laws are often written vaguely and are not friendly to law novices. Better laws stand out with concrete technical recommendations and fine-grained implementations, i.e., distinguishing between websites and mobile applications.

In synthesizing the commonalities and differences between the three approaches to software accessibility, I argued that each approach has advantages and limitations — they ultimately complement each other. The design approach may best exercise a direct impact on software practitioners' mindsets and practices if conveyed in an approachable manner. Yet designers may find limited incentives to follow guidelines outlined and promoted by accessibility researchers, which are not always in line with corporate priorities such as shipping

products fast. The education approach can best prepare next-generation software practitioners. However, the long-term and actual effects of educational interventions are unpredictable and need further interrogation. The governance approach, in theory, has the power to force companies to comply with accessibility requirements. Yet, it barely works out in reality because of the ambiguous wording in accessibility laws and a lack of enforceability arising from scarce rules.

I argue that an integrated approach combining design, education, and governance interventions should be used to address software accessibility issues and create a more inclusive software ecosystem.

To Olivia.

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1

Introduction

Disabilities such as visual impairments and hearing impairments have a staggering impact on software use and even result in foregoing the use of computing devices. A 2021 Pew Research study reported a large digital divide for the general population – the rate of U.S. adults who reported not owning a desktop or laptop computer was more than double for those with disabilities than for those without (38% vs. 19%) [1].

It does not have to be this way. Advances in assistive technology make it possible for people with disabilities to use software applications and the Internet [2]. Yet, these assistive technologies do not help when applications and websites are not designed to accommodate these technologies.

A 2024 study of the top million home pages found that only 4.1% were fully accessible, in conformance with the WCAG 2 guidelines [3]. According to the study, "across the one million home pages, 56,791,260 distinct accessibility errors were detected—an average of 56.8 errors per page." When software is not accessible, users with disabilities often experience frustration, annoyance, and difficulties in accomplishing desired tasks.

This lack of accommodation is prevalent despite being wrong from both ethical and legal standpoints; many big businesses, including Netflix and Target, have been sued over the last decade over websites that are inaccessible to visually- or auditorily-impaired users [4], [5].

Information and communications technologies (ICTs), particularly software, are often designed without explicitly considering accessibility, effectively creating barriers to use for people with disabilities [6]. Extensive literature has been devoted to the design, education, and governance of accessibility. However, real-world software is still largely inaccessible [7]. Huge research gaps exist in terms of designing more accessible software and websites, educating designers about accessibility, and enforcing accessibility through legislation and regulation. Best practices to promote software accessibility in the wild deserve further investigation.

This dissertation comprehensively and pragmatically promotes software accessibility through design guidelines, classroom teaching/education outreach, and governance recommendations under the broader framework of "engaged scholarship" [8], which involves active partnerships between scholars and communities, organizations, and policymakers.

In this dissertation, disabilities refer to impairments that may be physical, cognitive, intellectual, mental, sensory, or developmental, which can affect a person's ability to participate fully in daily activities [9]. Accessibility refers to the design of products, devices, services, or environments for people with disabilities [10].

Design-wise, I elicited accessibility design guidelines from a comprehensive formative study with cancer survivors with impairments, which designers and developers can easily implement in the design process. Education-wise, I used disability simulation games to teach high school students about software accessibility, demonstrating effectiveness. Governance-wise, I conducted a comprehensive institutional analysis to understand how accessibility laws fell short in the past and can be improved in the future.

1.1 Accessiblity and Design

Numerous studies have uncovered poor accessibility of software and websites, evidenced by incompliance with accessibility guidelines such as the Web Content Accessibility Guidelines (WCAG) [7], [11]–[13]. On the other hand, accessible software design efforts have emerged in the past few years, in terms of both understanding the suboptimal software experience of people with disabilities (e.g., [14]), and designing toward accessibility and inclusivity (e.g., [15]).

Cancer survivors[1] experience a wide range of impairments arising from cancer or its treatment, which degrade their quality of life (QoL) [16] and potentially make software use more challenging for them. However, there has been limited research on designing for cancer survivors' well-being and designing accessible software for cancer survivors. To bridge these research gaps, I conducted a formative study with cancer survivors to formulate accessible design guidelines and design features that benefit cancer survivors' well-being. The formulated accessible design guidelines and design features can be used to bootstrap software designers' accessible design efforts.

1.2 Accessibility and Education

Accessibility education is important to equip current and future software designers and developers with awareness and knowledge of accessibility and empathy for disabilities. One major cause of inaccessible software is that software developers are often not sufficiently prepared to meet accessibility goals in the industry. A workshop with 197 software developers found that there were large gaps in accessibility knowledge as well as areas where developers were unable to empathize with people with disabilities and understand the challenges that they face when using inaccessible software [17].

Accessibility education has been covered in both Computer Science (CS) curricula [18]–[21] and non-CS curricula [22] in college, and even high school [23]. Both traditional pedagogical methods, such as lectures, assignments, and activities, and interactive methods, such as games [24], [25] and gamification [26] are utilized to deliver accessibility education.

Leveraging and adapting simulation games developed in [25], [27], I delivered accessibility education in different educational settings, including an undergraduate-level Information Science (IS) course and high school CS/non-CS courses. My research addressed several research gaps regarding accessibility education. First, by creating mobile-friendly adaptations of the simulation games [25], [27], I enabled college students to experience software challenges that people with disabilities have to deal with when using mobile devices. Second, I am one of the first to use games, which were more engaging than traditional pedagogical methods, to teach accessibility to high school students. With these education efforts, I provided insights into teaching next-generation software designers about accessibility by leveraging empathy-driven simulation games. This dissertation reports the high school education outreach as a case study.

[1] I follow the convention of the American Cancer Society in using the term "cancer survivors" to "refer to anyone who has ever been diagnosed with cancer no matter where they are in the course of their disease." See https://www.cancer.org/treatment/survivorship-during-and-after-treatment.html.

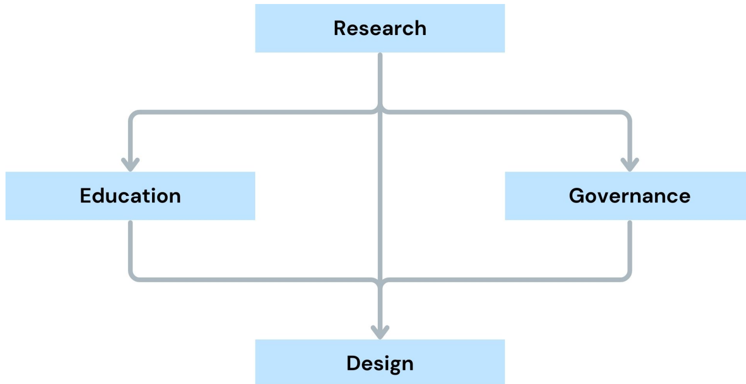


Figure 1.1: An integrated approach to accessibility.

1.3 Accessibility and Governance

Accessibility laws [28], accessibility guidelines [29]–[31], accessibility auditing following the guidelines [32], and automated auditing tools [33], [34] have been extensively studied. However, myriad accessibility pitfalls are still present in software in the wild [7], suggesting the limited efficacy of governance approaches to software accessibility. I suspected possible reasons for such failures: first, principles in accessibility laws may not have been converted into accessibility guidelines, and second, accessibility laws may not have regulated design recommendations in accessibility guidelines – we need better governance to meet accessibility needs and be effective. To understand where accessibility laws fall short, I conducted an exploratory yet comprehensive institutional analysis of 39 accessibility laws in 32 countries and regions. I then proposed recommendations to optimize governance approaches to accessibility.

1.4 A Pragmatic, Human-centered Approach to Promoting Accessibility

There has been a huge gap between rich accessibility research in academia and myriad accessibility issues in the real world. I showed the preliminary potential of translating research to impact real-world design accessibility through extracting design guidelines, conducting classroom teaching/education outreach, and suggesting policy recommendations under the broader framework of "engaged scholarship", which "describes intentional efforts to connect knowledge generated through faculty activity directly to the public in ways that collaboratively address social issues and community needs and concerns" [35].

Research is central in design, education, and governance approaches to promote accessibility. Research can impact design directly by formulating design guidelines for designers. Research can be translated into education to equip next-generation software designers and developers with knowledge and awareness of accessibility and empathy for disabilities. Research can also be translated into policy recommendations that policymakers and legislators can use to update or draft new legislation – submitting policy comments has been a provable way of impacting policymaking and legislation.[2] Up-to-date laws can then regulate (in)accessible designs in the industry.

Following a grounded theory approach, I further synthesized the differences and similarities between these approaches and lessons for maximizing their effect on accessible design. This comprehensive, pragmatic

[2] https://healthlaw.org/resource/do-my-comments-really-matter-demystifying-the-public-comment-process/

approach can potentially reduce the gap between numerous accessibility research studies and persisting accessibility issues in software in the wild.

1.5 Research Significance

This dissertation made four main contributions:

1. I characterized software challenges of cancer survivors with impairments (e.g., chemo brain) to formulate accessible design guidelines and design features to enhance cancer survivors' well-being.

2. I developed approaches to teaching high school students and other student populations about accessibility by leveraging empathy-driven simulation games.

3. I evaluated software accessibility laws to understand where they fell short and what should be done and proposed governance recommendations.

4. I synthesized a pragmatic, human-centered approach to promoting software accessibility by leveraging lessons learned from the empirical studies focusing on design-, education-, and governance-based accessibility solutions and building connections.

1.6 Summary of Empirical Chapters

In Chapter 3, I report an empirical design study on understanding cancer survivors' software challenges. Cancer survivors experience a wide range of impairments arising from cancer or its treatment, such as chemo brain, visual impairments, and physical impairments. These impairments degrade their quality of life and potentially make software use more challenging for them. However, there has been limited research on designing accessible software for cancer survivors. To bridge this research gap, I conducted a formative study including a survey (n=46), semi-structured interviews (n=20), and a diary study (n=10) with cancer survivors. The results revealed a wide range of impairments experienced by cancer survivors, including chemo brain, neuropathy, and visual impairments. Cancer survivors heavily relied on software for socialization, health purposes, and cancer advocacy, but their impairments made software use more challenging for them. Based on the results, I synthesized a set of accessibility guidelines that software designers can utilize when creating software for cancer survivors. Further, I suggested design features for inclusion, such as health resources, socialization tools, and games tailored to the needs of cancer survivors. This research aims to spotlight cancer survivors' software accessibility challenges and software needs and invite more research in this important yet under-investigated domain.

In Chapter 4, I report an empirical education study to teach high school students about software accessibility through disability simulation games. Before this study, software accessibility education had rarely been incorporated into the high school curricula. This is a missed opportunity to equip next-generation software designers and decision-makers with knowledge, awareness, and empathy regarding accessibility and disabilities. I taught software accessibility to students (N=93) in a midwestern high school through empathy-driven games and interviewed three Computer Science high school teachers and one librarian who taught programming. Accessibility education was found insufficient in high school education, facing challenges such as teachers' knowledge and conflicted curriculum goals. The students exhibited increased knowledge and awareness of accessibility and empathy for people with disabilities after playing the games. With this education outreach, I aim to provide insights into teaching next-generation software designers about accessibility by leveraging games.

In Chapter 5, I report an empirical governance study on evaluating software accessibility laws around the world. Industry compliance with disability, anti-discrimination, and software accessibility laws is socially significant and understudied from a sociotechnical perspective. Governance approaches to address accessibility have not proven as impactful in practice as many proponents and disability advocates hoped, with prevalent inaccessible software products. Through an institutional analysis of 39 software accessibility laws in 32 countries and regions, I identified where they fell short. The results found that accessibility laws contain more norms than rules or strategies, limiting the extent to which they are legally enforceable and illustrating that they are more aspirational than clear in approach. I further recommended enforceable, technically feasible, clearly operationalizable improvements to future legislation. This research has the potential to shed light on more enforceable accessibility regulations.

Chapter 6 synthesizes the advantages and limitations of three different approaches to software accessibility.

Finally, aggregate implications from the empirical work are presented in Chapter 7.

2

Background

In this chapter, I intend to lay the foundations for the empirical chapters of the dissertation. I start by discussing the past literature on technology and vulnerable populations, not limited to software and people with disabilities, and then discuss accessibility research through design, education, and governance approaches.

2.1 Technology and Vulnerable Populations

Before diving into software accessibility, there is a huge body of literature on technology and vulnerable populations, encompassing different technologies, such as social media and Artificial intelligence (AI), vulnerable populations, such as LGBTQ+ people and children, and ethical issues, such as privacy and inclusivity.

I will use the case of information technologies and healthcare to illustrate such disparities faced by vulnerable populations. Information technologies are an important means to access health care, yet are not widely accessible to low-income populations [36]. In fact, the adoption of digital health technologies may even further inequities in health care services [37] — the factors that influenced inequalities included age, race, region, economy, education level, health conditions, and eHealth literacy. Cheng et al. found that the role of eHealth literacy and user involvement was limited in developing eHealth interventions targeted at socially disadvantaged groups [38]. COVID-19 widened disparities and the digital divide regarding digital health [39] – factors that prevented access to digital health services included "lack of support and training, poor health, as well as the lack of strong e-identifcation or suitable devices."

Overall, there are significant gaps in research on understanding, designing, and governing ICT relative to vulnerable populations for several reasons.

First, there are no guidelines or best practices to understand vulnerable populations' ICT experiences contextually. Both vulnerable populations and technologies are heterogeneous. Vulnerable populations can include but are not limited to older adults who are perceived as passive technology adopters [40], women in conservative cultures who face more gender oppression [41], children and youth who are less prepared for ICT fraught with ethical concerns [42], people with disabilities [43], and people in authoritarian regimes who are more subject to surveillance [44]. ICTs are customized for people's healthcare [45], social [40], intimate relationship [46], and financial [47] needs, among many others, with unique challenges in each scenario. There has not been a guideline for researchers to navigate through this complexity.

A recent debate in the Human-Computer Interaction (HCI) field reflects this gap, concerning the tension between culture sensitivity and generalizability [48] – A group of researchers critiqued the critiques they received in peer review, saying that their research "is not generalizable to US and EU." Such misconception of generalizability fails to recognize the importance of cultural sensitivity in understanding social phenomena and human-computer interaction [49], and does not contribute to the decolonization thinking in HCI, Computer-supported cooperative work (CSCW), and beyond [50].

Existing frameworks such as contextual integrity (CI) [51] and participatory design (PD) [52] may shed some light on research in this complex field, as they provide a situated and contextual lens into design or privacy. A contextual way to inspect and design vulnerable populations' ICT experiences should be similarly adopted.

Second, the question of who should be responsible for understanding, designing, and governing ICT relative to vulnerable populations is not always clear.

ICT researchers and creators who do not affiliate with a vulnerable identity may struggle with their positionality in understanding vulnerable populations. Take gender studies as an example. Male researchers are expected to find it hard to interview female survivors of intimate partner violence (IPV), due to the participants' reluctance to share experiences with people of the gender that they mentally associate with suffering. Women were more comfortable talking about birth experiences and breastfeeding issues to other women [49]. Male researchers who do not affiliate with one of the vulnerable identities may also find it hard to gain genuine empathy, let alone the empathy gap between men and women, in general [53].

Though there is a large body of literature on uncovering and mitigating gender bias in AI, many of them fail to touch and reflect on algorithmic oppression against women but only focus on addressing discriminatory outcomes [54]. This can be possibly attributed to the lack of gender diversity in AI research teams [55].

Since researchers who do not affiliate with a vulnerable identity may have challenges working with vulnerable populations, epistemological and methodological suggestions are expected from senior researchers with a wealth of experience doing so. However, such research guidelines are currently lacking in the research community.

On the other hand, vulnerable populations oftentimes do not have a say in deciding the direction of technology development and evolvement. Male AI engineers have less awareness of gender disparity than their female counterparts yet comprise the majority of the IT workplace [56], [57]. Without considerate participation of vulnerable populations in the development and decision-making processes of ICT creation, the productions can barely be inclusive and serve their real needs. Ways to engage and empower vulnerable populations during the creation and use of ICT include promoting diversity in the IT workplace and ICT research and participatory research (PR) that includes the voice of the community and multiple stakeholders [58].

Third, research on serving the needs of vulnerable populations is not always translated into real-world practices, and there are no best practices for effectively engaging companies, governments, and other parties in the efforts.

Researchers have devoted extensive efforts to understanding, designing, and governing ICT experiences for vulnerable populations, both theoretically or methodologically [59]–[64], and empirically [43], [45], [47], [65]–[69]. However, industrial designs are often fraught with unethical features such as privacy leakage [70] and bias/discrimination [46], or completely neglect accessible, inclusive, and ethical considerations [71].

Empirical research validated this disconnection between academia and industry. Cao et al. found that though a non-negligible portion (20.1%) of papers published in top-tier HCI conferences were cited in US patents, the time lag between a patent and its paper citations was long (10.5 years) [72]. This partly explains why values (e.g., antidiscrimination, accessibility) and best practices (e.g., debiasing techniques, inclusive design) identified in the research on vulnerable populations are not translated into practice on many occasions.

ICT creators and companies do not have incentives to foster inclusive and ethical ICT for vulnerable populations if there are no financial or social benefits associated with making ICT more inclusive and ethical. A conflict between ethical considerations such as security and corporate priorities such as shipping products fast often exists [73]. Tech regulations and laws are generally non-binding [74] and far from timely [75], with some exceptions such as GDPR [76]. With such inaction from industrial players and governments, an integrated effort between academia, industry, and the government is not likely to occur.

Below, I will introduce research and practices in design, education, and governance, both broadly and particularly in terms of accessibility.

2.2 Accessibility and Design

In this section, I will introduce participatory research (PR) and participatory design (PD), two common approaches to designing with vulnerable populations. Then, I will discuss existing literature on revealing inaccessible designs and accessible design efforts. Last, I will identify gaps in accessibility and design research.

2.2.1 Participatory Design and Participatory Research

Participatory research (PR) and participatory design (PD) have significantly impacted my research on and with vulnerable populations, including this dissertation. They are two related yet different concepts in HCI – PD enables users to be active contributors during the design and development of ICT [77]; PR provides a way to gain a deeper and better understanding of vulnerable populations who are brought on board as research partners, or co-researchers [78].

Duarte et al. combined while intentionally differentiated between PD and PR, "PD emphasizes the creation of a tool, whereas PR focuses on the research process." PD, as a narrower term particular to design, is more commonly used in HCI [79]–[82]. HCI papers tended to overlook the difference between PD and PR and sometimes wrongly referred to PD as PR [83].

The success of PR draws on several considerations and principles [84]:

- *PR1: Democracy.* Allowing co-researchers to contribute to all stages of the research process as equal partners is particularly important for underprivileged and vulnerable communities.
- *PR2: Defining the "community" and its "empowerment".* This enables vulnerable populations to modify their practice or change their situation, which echoes with principles in [66].
- *PR3: Creating a "safe space."* This is important for vulnerable populations, e.g., IPV survivors [85], to express their opinions and values freely without fear of stigmatization or safety issues.
- *PR4: Different stages of participation.* PR strives to involve co-researchers during all stages of the research at a high yet flexible level of participation.
- *PR5: Dual objective.* There are several simultaneously important goals in PR, including gaining knowledge, deriving possible actions to improve a situation or routine, and creating opportunities for democratic participation and capacity-building.

Several considerations should be particularly adopted in PD [77], [86]–[88]:

- *PD1: Diverse participation and democratic decision-making.* The goal is to ensure target groups have more control over the design process.
- *PD2: Mutual learning, testing of premises, and generation of new concepts.* When several groups of experts are engaged in PD, each group has limited prior knowledge of the other (experience, behavior), thus mutual learning is essential.
- *PD3: Iterative actions in PD.* This is to ensure the final design of an artifact answers to the participants' requirements and ideas.

There are some other considerations in PR emerging from the HCI literature.

First, the demographic background of vulnerable populations can be extended by co-creating personas with co-researchers and co-designers [62]. Co-creating personas encouraged users with diverse needs to engage in co-designing.

Second, providing concrete benefits for vulnerable populations to engage in PR is essential. The Reddit community for d/Deaf people is annoyed by accessibility research, which does not aim to promote their well-being and address their real needs but only cares about publishing. Researchers should explicitly consider maximizing the benefits of their research for vulnerable communities. Anuyah et al. argued that researchers can empower and motivate vulnerable populations to participate in technology research and design by fulfilling their various technology needs, including basic needs (e.g., acquiring digital literacy skills, having experience with necessary technology), safety needs (e.g., awareness of safety risks and how these are mitigated, perception of being safe), relationship needs (e.g., perception of emotional support or sense of community), self-esteem needs (e.g., perception of competence), and self-actualization needs (e.g., contributing to impactful research, perception of autonomy and being valued, awareness of the outcome or impacts of their research contributions) [66]. Meeting such needs is not excessively challenging. For example, sharing research findings with the community in a way that is accessible and understandable to them can greatly fulfill their self-actualization needs.

Third, cultural sensitivity is vital for generating non-biased research results and avoiding disrespect for vulnerable populations [89]. Sensitivity to cultural norms, traditions, and beliefs is also essential for building trust and rapport.

One way to approach cultural sensitivity is to ensure diversity within the research team and involve members with experience or knowledge of the vulnerable population's needs and challenges [65]. This has been exercised in past research. Afnan et al. examined the privacy experiences and concerns of Muslim-American Women [65]. In this paper, there is a dedicated Researcher Positionality section: "Our research team consists of members with both insider and outsider perspectives, which contributed to our analysis approach and understanding of findings. Three authors identify as Muslim. Three authors identify as women, and two of them as Muslim women. The authors have diverse cultural backgrounds and religious attitudes, including Muslim women who wear the hijab and those who do not. The first author, who conducted all interviews, identifies as a cisgender Muslim-American woman."

Lastly, reflexivity is important in PR. Researchers should reflect on their own biases and assumptions and how they might affect the research process and outcome. Again, involving members with experience or knowledge of the vulnerable population's needs and challenges is helpful in this reflection process [65].

PR has several advantages. First, it ensures co-researchers can democratically engage with all stages of the research process, even with their vulnerable identities.

Second, vulnerable populations are empowered to change their situations, e.g., by contributing to decisions that directly affect them, or at least gain practical benefits, e.g., enjoying access to technology [66].

Third, researchers can obtain a holistic, nuanced, culture-situated understanding of vulnerable populations by letting them express their real needs and co-decide the direction of the research. This way, the research can meet these needs and provide relevant solutions. Building strong relationships with participants enhances trust, and thus makes it easier for researchers to collect data.

Fourth, PR often leads to community-based solutions, which can be more sustainable and effective than their individual-based counterparts [90].

The disadvantages of PR revolve around resources, ethics, generalizability, and research rigor.

First, PR is often resource/expertise-intensive and complex. In [90], several workshops were organized, each with a relatively large number of participants. PR also requires a longer timeframe for planning and execution. Björling and Rose spent three years on a project that aimed to co-design a social robot to improve the mental health of teens [91]. Managing the dynamics of PR can be challenging, especially with more than one party involved [90]. Balancing the needs and expectations of participants with researchers' own research goals can be complex. The resource-intensive nature of PR may discourage designers and researchers from co-designing with vulnerable populations but instead impose their own ideologies in design.

Second, ethical and safety concerns can arise, especially when vulnerable populations, such as IPV survivors, are involved. Survivor-centered, trauma-informed approaches are therefore encouraged [85], e.g., regularly checking in with participants about how they feel and if they need breaks or other support, and providing participants with a written agenda so that they feel a sense of control.

Third, findings from PR may not always be readily generalizable to other populations or contexts, as they are highly context-specific. Therefore, if researchers have not spotlighted a population, dedicated research needs to be done to understand their needs and accommodate their digital experiences.

Fourth, researchers have limited control over the research process – the research is guided by the input and needs of the participants. Often, researchers only serve as facilitators in co-design workshops [90]. The research process is often less structured than traditional research methods.

Lastly, researchers may unintentionally influence the research process, potentially leading to bias [92]. Maintaining research rigor is thus challenging and highly depends on the coordination between researchers and co-researchers, as well as both parties' expertise.

2.2.2 Inaccessible Designs

Software and websites in the real world are hardly accessible. Researchers have evaluated the accessibility of mobile apps and websites in different domains. An examination of 479 Android apps with IBM Mobile Accessibility Checker uncovered an astonishingly high rate of 94.8% in terms of accessibility violations [7] – most outstanding accessibility issues included "lack of element focus, missing element description, low text color contrast, lack of sufficient spacing between elements, and less than minimum sizes of text fonts and elements." Usability and accessibility pose significant challenges for using government systems [93].

Empirical research in certain regions revealed similar trends. Specific to certain regions and software realms, Su revealed accessibility issues of mobile apps in the higher education sector in Portugal, particularly challenges for people with visual impairments regarding text/image contrast, resize text, touch target, and accessibility label [11]. Using a WCAG checker, TAW, and a mobile readiness checker, MobileOK, Agrawal et al. found government service websites in India were of low usability, incompliant with WCAG 2.0, and not accessible on mobile devices [12]. E-government mobile apps in Brazil were similarly found saturated with accessibility problems [13].

Emerging technologies, such as Generative AI (GenAI) blockchain, are also inaccessible. There have not been design guidelines tailored for the inclusivity of GenAI tools [94]. Zhou et al. conducted user experiments with blind and low-vision users and uncovered inter-related accessibility, learnability, and security issues in MetaMask, a popular crypto wallet used by millions of people [71].

2.2.3 Accessible Design Efforts

Understanding and designing for the unique accessibility needs of people with disabilities is important to promote tech inclusivity. Understanding the ICT experience of people with disabilities can inform more accessible designs for them [14].

There has always been a digital divide in Internet use for people with disabilities [95], especially in less developed countries [96], whereas Internet access is important for their social well-being. ICTs provided inclusion to people with disabilities, e.g., students in special education settings [97] and people with intellectual disability in the blogging community [98]. However, frustration during ICT use may further exclude people with disabilities [14] and even lead to security and privacy risks. People with visual impairments may find difficulty navigating unfamiliar websites [99], receiving phishing email warnings [100], or identifying spoofing websites [101].

Inclusive design, also known as universal design, is an approach to creating products, services, and environments that are accessible and usable by people of diverse abilities and characteristics [102].

Numerous research studies have proposed designs to address the accessibility needs of people with disabilities. Progressive web apps (PWAs) were designed to develop cross-platform, cross-device apps and enhance the inclusivity and reachability of software – websites that adopted the PWA architecture exhibited more conformance to accessibility guidelines in practice [15]. Zhou et al. iteratively designed an accessible crypto wallet with features such as downloadable, pin-protected secret recovery phrases, and receiving address confirmation to make crypto wallet usage safer and more accessible [71]. Keyboard command-based access to website features was found helpful for people with visual impairments to navigate unfamiliar, cluttered, or infrequently visited websites [99]. Inclusive designs such as audio warnings and shortcut keys helped email users with visual impairments notice phishing email warnings [100]. Kaushik et al. developed a browser extension to help people with visual impairments determine if websites are legitimate or spoofs by extracting and listing privacy/security cues in one place [101].

Participatory design approaches are effective in the HCI and accessibility literature. Laitano argued for a participatory approach to accessible design instead of using standards to guide design [103]. In terms of assistive technology design for rehabilitation, "a participatory design can develop a holistic understanding of the participant's motivation and rehabilitation needs" [104].

2.2.4 Gaps in Accessibility and Design Research

There are several gaps in accessibility and design research. First, as argued before, although participatory design and participatory research have been effective in designing ethical and accessible ICT, they require dedicated efforts in different contexts. There is a wide range of disabilities, each presenting unique accessibility challenges and needs. It is barely possible for researchers and designers without sufficient resources to co-design with each population.

Second, how the research on accessibility and design impacts real-world software practices is unknown. HCI research is known to be cited in patents in a delayed manner [72]. How accessibility research impacts accessible design practices needs further interrogation.

Third, there is limited research on how software designers and developers navigate conflicting goals of accessibility and corporate goals, such as shipping products fast.

Fourth, past research in design and education toward software accessibility is siloed. Dedicated knowledge and skills are required to ensure software accessibility, yet few researchers have attempted to understand software designers' accessibility knowledge.

I aim to address some of the gaps in this dissertation, particularly relating to (1) finding alternatives to participatory design in low-resource contexts and (2) connecting design and education research regarding accessibility.

2.3 Accessibility and Education

In this section, I will first discuss the broader literature on computer ethics education. Then, I dive into computer accessibility education and identify gaps in accessibility and education research.

2.3.1 Teaching Computer Ethics

Ethics issues around computing, such as privacy, cybersecurity, fairness, and misinformation, have been widely taught as early as in K-12 education.

Take the State of Illinois as an example. According to the Illinois Computer Science Standards (January 2022) [105] by the Illinois State Board of Education, students in Grades K-2 are required to learn the "impacts of computing," in terms of Culture, Social Interactions, and Safety Law and Ethics,

- Culture: K-2.IC.16 Compare how people live and work before and after the implementation or adoption of new computing technology.
- Social Interactions K-2.IC.17 Work respectfully and responsibly with others online.
- Safety Law and Ethics: K-2.IC.18 Keep login information private and log off of devices appropriately.

At this stage, students learn the impact of computing technology on life, how to keep themselves safe online, and how to respect others.

As students progress in their K-12 education, they are taught more advanced knowledge in these ethical aspects. For students in Grades 3-5, they learn the following topics in the impacts of computing:

- Culture: 3-5.IC.18 Discuss computing technologies that have changed the world and express how those technologies influence, and are influenced by, cultural practices; 3-5.IC.19 Brainstorm ways to improve the accessibility and usability of technology products for the diverse needs and wants of users.
- Social Interactions: 3-5.IC.20 Seek diverse perspectives for the purpose of improving computational artifacts.
- Safety Law and Ethics: 3-5.IC.21 Use public domain or Creative Commons media and refrain from copying or using material created by others without permission.

At this stage, students learn about the interaction between computing technologies and culture, ways to improve the accessibility and usability of technologies, diverse perspectives on computing, and copyrights.

At the end of K-12 education, students in Grades 11-12 learn the following topics in the impacts of computing:

- Culture: 11-12.IC.29 Evaluate computational artifacts to maximize their beneficial effects and minimize harmful effects on society; 11-12.IC.30 Evaluate the impact of equity, access, and influence on the distribution of computing resources in a global society; 11-12.IC.31 Predict how computational innovations that have revolutionized aspects of our culture might evolve.

- Safety Law and Ethics: 11-12.IC.32 Debate laws and regulations that impact the development and use of software.

At this late stage of K-12 education, students are able to learn about more abstract concepts of ethics, such as equity, access, and law regulations.

In addition to mandated CS ethics education in schools, researchers have also contributed to the ad-hoc, voluntary teaching of computer ethics. In the domain of cybersecurity education alone, various systems and tools have been developed to help people learn about privacy, security, and other concepts. These include Capture-the-flag (CTF) systems, such as picoCTF developed by Carnegie Mellon University researchers [106], game-based learning platforms [107], and learning environments based on Virtual Reality/Augmented Reality [108].

Computer accessibility education is potentially more challenging than ethics education in general since students without disabilities may have difficulty understanding the challenges of people with disabilities in software experiences, technology adoption, and beyond.

Next, I discuss the status quo of computer accessibility education, which has been recognized as an important part of computer ethics education.

2.3.2 Computer Accessibility Education

Researchers and industrial practitioners such as Baker et al. advocated accessible computing education in colleges and universities, framing accessibility as a cultural competence in computing [109].

In 2016, Putnam et al. only found a few stand-alone courses about accessibility [110]. In recent years, however, researchers have devoted extensive efforts to understand objectives and principles of accessibility education in higher education, especially computing education [111], [112], develop new pedagogical methods such as simulation games [25], [27], and understand how students perceive accessibility education [113]. A systematic literature review found that awareness of accessibility (e.g., abilities, laws, ethics), technical knowledge (e.g., requirements, guidelines, WCAG, testing), empathy (e.g., understating disabilities, inclusive design), and potential endeavors (e.g., pursuing career in accessibility) were four common learning objectives; HCI and Web Design/ Programming courses were more likely to include accessibility education; and the most frequently used pedagogies were in-class activities, projects, and lectures [114].

Learning objectives and principles for teaching accessibility have been extensively studied. Conn saw knowledge of programming techniques, awareness of accessible technologies, and attitudes towards individuals with a disability as three key objectives in accessibility education [111]. By interviewing university professors in computing-related disciplines such as CS, IS, and HCI, Putnam et al. found that when teaching accessibility, professors tended to emphasize awareness and understanding of diverse software users through experiences such as involving users with disabilities, field trips, and simulating disabilities [110]. Kang et al. believed the following learning objectives were important for accessibility education [112]: (1) understanding fundamental principles of inclusive design, (2) interacting with diverse people, (3) showing increased empathy towards people with disabilities, (4) viewing accessibility from cultural, social, and legislative perspectives, and (5) showing motivation to continuously learning about accessibility. Gellenbeck argued that similar to ethics education, the integration of accessibility education into the CS curriculum should follow four recommendations: (1) early introduction; (2) continued discussion in most courses; (3) integration of topics within the courses; and (4) maximum coverage with minimum overlap [115].

Accessibility is taught in a wide range of scenarios in universities. A comprehensive survey (N=1,857) with computing and information science faculty found that 175 institutions in the US had at least one instructor teaching accessibility [116]. Focused courses such as Accessible Computing have been taught to both CS students [18], [19] and non-CS students [22]. Accessibility has also been widely integrated into courses such as HCI [20] and Web Design [21]. Siegfried and Leune reported a dedicated full-semester Accessibility Seminar [117]. Besides teaching universal design (UD) and accessibility in CS-related courses and programs, some CS departments also provide relevant project work, summer courses, and master thesis topics [118]. Notably, faculty who were female, had expertise in HCI and software engineering, or knew people with disabilities were more likely to teach accessibility in computing and information disciplines [116].

Empirical evidence showed the success of integrating accessibility education into high education computing curriculum – gains in awareness and knowledge regarding accessibility occurred when accessibility lectures were part of the course [119]. Chávez and Van Wart unpacked how students in a web development course perceived accessibility [113], asking students to respond to two open-ended questions embedded in a lab and homework: “Why, and to whom, is accessibility important?” “Do you think that designing for accessibility also improves the usability of the site for all users? Why or why not?” 62.5% of the students perceived accessibility as beneficial for all users of a website. However, a survey (N=114) with final-year computing undergraduates revealed that they did not personally view accessibility training as essential career preparation [120], inviting more research to study the long-term and objective effect of accessibility education.

Various teaching methods have been used to teach accessibility, with in-class activities, projects, and lectures being the most common [114]. For example, technical projects such as “implementing a Braille translator capable of converting English sentences into Grade 2 Braille representation using dictionaries” were integrated into core CS courses [121] – these assignments successfully increased students’ familiarity with accessibility concepts yet failed to cultivate a mindset of accessibility. In addition to traditional pedagogical methods, experiential labs and simulation games have been developed to build empathy in students and facilitate experiential learning regarding accessibility and disabilities. El-Glaly et al. developed a set of Accessibility Learning Labs using an experiential learning structure to simulate the experience of people with disabilities and teach students to repair accessibility issues using a simulated code editor [24]. These labs have been incorporated into computing-related courses [122].

Gamification was proposed as a potentially engaging way to teach accessibility [26]. Simulation games suitable for beginner CS students and non-majors without a coding component but with non-jargon accessible design guidelines have also been developed [25], [27]. After playing these simulation games, students showed increased empathy for disabilities and intention to design accessibly; they also had more accessibility ideas, such as including people with disabilities when testing design [123].

2.3.3 Gaps in Accessibility and Education Research

There are multiple gaps in accessibility and education research. First, the long-term effect of accessibility education is not well-investigated. Students are likely to gain awareness and knowledge in accessibility during the educational session or semester-long course, without retaining the knowledge after they enter the IT workforce. The best way to help students retain knowledge in accessibility requires further interrogation.

Second, compared to the ample literature on nifty tools for cybersecurity education, there are relatively few tools for accessibility education. This poses significant challenges to teachers in terms of demonstrating disabilities to students without disabilities, who may lack empathy for the software experiences of people with disabilities. Creating and testing tools is a necessary step to further accessibility education.

Third, the venues of accessibility education have been limited in existing literature. Past accessibility education mostly happens in CS courses. Non-CS courses and K-12 classrooms have not witnessed much accessibility education. This is a missed opportunity to equip a broader range of populations with awareness and knowledge of accessibility.

This dissertation aims to address several gaps, particularly regarding assessing games for accessibility education and expanding accessibility education to a broader audience.

2.4 Accessibility and Governance

The scope of governance goes beyond regulation. According to Sanfilippo and Liu, governance "is fundamentally an assemblage of institutions that are at once intentional and unintentional, formal and informal" [124]. From a social informatics perspective, design, management, infrastructure, use, practice, and regulation all intersect to impact people's experiences with technologies [124], [125]. Governance is thus key to understanding the accessibility of ICTs because of the rich interaction between design practices, regulation efforts, and beyond.

In this section, I first reflect on governance challenges around ICT and vulnerable populations in general and corresponding solutions. Then, I discuss governance approaches to software accessibility, including accessibility laws, accessibility guidelines, accessibility auditing, and automated tools.

2.4.1 Governance Challenges around ICT and Vulnerable Populations and Solutions

Three challenges hurdle the effective governance of ICTs that impact vulnerable populations. Fortunately, some frameworks, theories, and precedents can be used to address these challenges.

First, rights-based approaches to information ethics based on individual rights have largely failed in practice. It is unrealistic to anticipate individuals with vulnerable identities to exercise and enforce their rights (e.g., privacy rights) through costly court action, which involves complex information privacy decisions [126]. Viktor Mayer-Schönberger instead argued for a "systems" theory of information governance, i.e., resting on a system of information governance rather than just individual rights. The collective action engages such parties as audits by specialized agencies, direct regulatory enforcement such as information privacy laws, and information privacy professionals. Such a rich network of information governance intermediaries ensures information privacy in a larger societal context.

Second, legally binding and up-to-date regulations, especially those concerning vulnerable populations, are scarce. Unlike GDPR [76], recent advancements in AI regulation, e.g., The Blueprint for an AI Bill of Rights, are not legally binding [74]. Algorithmic Discrimination Protections is one of the five principles outlined in the guideline. Precautions to mitigate discrimination from AI systems in design and development processes are also suggested, such as using representative data and conducting equity assessments. However, failing to conform to such rules of thumb does not incur punishments for companies. Thus, AI developers are less likely to devote efforts to enhancing user experiences and solving ethical challenges for vulnerable populations.

Governments also often fail to follow up with extant research on governing ICT for vulnerable populations. Take the United States, which is one of the few countries in the world that does not guarantee paid maternity leave [127], as an example. On the tech side, "the US Congress has not passed a single piece of comprehensive regulation to protect internet consumers and to rein in the power of its technology giants" [75]. It is of timely interest to use laws to incentivize inclusive and ethical design efforts and simultaneously punish non-complying parties, as failing to make ICT inclusive can constitute bias or discrimination against vulnerable identities [46]. GDPR, as the strongest privacy law in the world, is a good example for future regulation and legislation efforts – privacy policies have been forced into satisfying GDPR requirements [128]. Existing laws, such as anti-discrimination laws, may also be directly applied or adapted to apply to various issues faced by vulnerable populations [129].

Third, the heterogeneity of ICT systems, vulnerable populations, and cultural contexts makes governance more challenging. He et al. unpacked senior street vendors' challenges in mobile money collection in China [130]. The senior street vendors had to use their family members' QR codes to collect money due to their relatively low digital literacy. The family-dependent vendors lost their money freedom when their income flew into their families' wallets. In this example, several factors collectively contribute to the unique financial risks – older adults are often found to lack adequate digital literacy [131], [132]; Chinese families are associated with a heightened level of financial dependence between family members [133]; mobile payment is increasingly popular in China and introduces new forms of exclusion [134], [135]. Governing mobile payment for older adults in China thus involves complex and contextual decisions.

The contextual lens has been better applied to the governance of privacy compared to other human concerns and values, such as fairness and safety. Contextual integrity ties adequate protection for privacy to norms of specific contexts [51]. Under this framework, privacy is provided by appropriate information flows, with data subject, sender of the data, recipient of the data, information type, and transmission principle as the five critical parameters. Using contextual integrity, Selbst reexamined the meaning of the Fourth Amendment's "reasonable expectation of privacy" and explained why some legal rulings, e.g., United States vs. Miller, were wrongly decided [136].

Despite the usefulness of the CI framework, it has primarily been applied to the governance of privacy-related risks. O'Neill develops a general, functional approach to evaluating technological change inspired by CI, which can aid the thinking about how technological changes affect human concerns and values beyond privacy [137]. Key steps in the procedure include identifying a technological change, comparing the new/changed situation with the old situation, examining how the ends of individuals are likely to be affected, examining how shared ends (both contextual and general) are likely to be affected, and identifying CI (broadly construed) reduction. Context sensitivity and adaptability are at the core of this procedure.

The Governing Knowledge Commons (GKC) framework provides a contextual lens by examining patterns of interactions around knowledge resources within particular settings [138]. GKC and CI frameworks have further been united in understanding privacy as both governing institutions and appropriate information flows [139].

From an empirical and pragmatic perspective, incident cataloging helps understand ICT risks in specific contexts and prevents repeated failures [140]. Meng and Zhou argued that taxonomies of AI risks built on such cataloging efforts had the potential to inform more contextual policies, e.g., how to regulate a certain AI risk (bias) in a certain application area (personalized recommendation) informed by real-world cases [141].

In this dissertation, I attempt to examine a specific type of governance for accessibility, namely, accessibility laws, and their relationships with WCAG, which is the most popular accessibility guideline. Below, I introduce existing research on accessibility laws, guidelines, and auditing based on the guidelines to contextualize the governance chapter.

2.4.2 Accessibility Laws

Accessibility laws have long existed but did not always achieve the goal of accessibility [142], [143]. The European Union (EU) has fostered web accessibility by implementing and updating policies and legal rules [28]. EU's Web and Mobile Accessibility Directive "establishes EU-wide rules for accessibility of public sector websites and mobile apps." However, even though accessibility is a priority in EU countries, government websites were still found largely inaccessible, since web accessibility "largely depends on website developers and designers" [144].

I speculate a few reasons for the worldwide failure to ensure software/website accessibility. First, accessibility laws only exist in a few countries (see Chapter 5), and in many other countries, there are only non-binding recommendations or opinions issued by governments.

Second, accessibility laws may not always update with emerging technologies and accessibility challenges, given the unprecedented pace of technological advancement.

Third, accessibility guidelines, which accessibility auditing often follows, may not implement all the important principles in accessibility laws.

These aspects have not been well studied in prior literature and need further interrogation.

2.4.3 Accessibility Guidelines, Auditing, and Automated Tools

Accessibility guidelines provide recommendations for making Web content and mobile applications more accessible. WCAG, one of the most known accessibility guidelines for web content, defines how to make Web content more Perceivable, Operable, Understandable, and Robust to people with disabilities [29], understand the broader umbrella of W3C[1] Accessibility Standards [30]. W3C has three additional accessibility guidelines for Web content: Authoring Tool Accessibility Guidelines (ATAG), User Agent Accessibility Guidelines (UAAG), and W3C Accessibility Guidelines (WCAG) 3 Working Draft. WCAG can also be applied to mobile contexts, according to W3C recommendations [31]. Other accessibility guidelines include BBC Standards and Guidelines for Mobile Accessibility and IBM Accessibility Checklist.

Accessibility auditing involves evaluating digital products, services, or environments to identify barriers that may prevent people with disabilities from using them effectively and provide recommendations to ensure they are accessible [32], following accessibility guidelines. Quantitative metrics such as Web Accessibility Barrier Score (WABScore) [145] have been proposed to quantify the level of conformance of software to certain accessibility guidelines.

Automated tools for auditing accessibility have been developed. For example, Tsampoulatidis et al. presented a tool to collect georeferenced accessibility data for streets and points of interest in urban areas [33]. In the software domain, accessibility analysis tools such as WCAG Accessibility Checker and Accessibility Inspector exist for iOS apps, and WCAG Accessibility Checker and Accessibility Testing for Android apps. W3C provides a list[2] of Web accessibility evaluation tools and the accessibility standards they follow.

[1]W3C, the World Wide Web Consortium, is the main international standards organization for the World Wide Web.
[2]https://www.w3.org/WAI/test-evaluate/tools/list/

These tools work effectively but are not perfect. A systematic literature review revealed that few automated tools were suitable for evaluating the accessibility of both web-based and mobile applications [34]. Further, some semantic design pitfalls may not be captured by checking the conformance to accessibility guidelines [146] – examples include (1) not hiding information properly for screen readers, (2) using complex interactions, (3) wide space between related information, and (4) not showing important information at the top.

2.4.4 Gaps in Accessibility and Governance Research

Again, multiple gaps in accessibility and governance research hurdle the effectiveness of governance approaches to accessibility.

First, governance research in accessibility tends to examine the outcomes of accessibility laws or policies. Limited research has been dedicated to assessing the laws themselves, looking into the enforceability and level of clarity of accessibility legislation.

Second, governance research in accessibility tends to overlook the compliance aspect of the governance approach. More research should take place to understand how companies and developers attempt to comply with accessibility requirements.

Third, limited research has been devoted to understanding the efficacy and consistency of accessibility laws, as well as challenges in implementation.

This dissertation aims to narrow the first and third research gaps and suggest ways to optimize future accessibility laws.

3

Design for Accessibility: Toward Designing Accessible and Meaningful Software for Cancer Survivors

Design approaches to accessibility have proven effective in accommodating the software needs of people with various disabilities [147]–[149]. In particular, co-design and participatory design are known as collaborative methods where stakeholders, including designers, researchers, and people with disabilities, work together to create solutions, either accessible software or assistive technologies that meet the needs of the users (e.g., [150]). However, there are two limitations of design approaches to accessibility.

First, given the wide range of disabilities and the emergence of new technologies, researchers and practitioners may find themselves unable to co-design with every population and on each technology. Past research has emphasized designing software for and with people with different disabilities, such as physical disabilities [151] and visual impairments [71]. Older adults have also received considerate attention in the accessibility literature (e.g., [152]), since they face age-related changes and impairments that can impact their ability to interact with digital technologies. The existing literature does not center on cancer survivors as a population that needs particular accommodations when using software. This is one of the main gaps I aim to bridge in this chapter.

Second, despite the ample literature on software accessibility, it is hard to translate accessible designs or assistive technologies developed in academia to industrial practices or products. More broadly, HCI research exercises its impact on industrial patents in a very delayed manner [72]. As a result, software products that people with disabilities interact with daily may not be accessible and may remain so for a long time. To ease the process of leveraging academic progress in software accessibility in design efforts for software designers and developers, I argue the importance of synthesizing actionable design principles and features that can be easily used by software practitioners.

3.1 Introduction

By January 2022, there were more than 18 million cancer survivors in the United States, representing approximately 5.4% of the population [153].

Cancer survivors may have impairments that impact their processing of information, including visual [154], hearing [154], physical/motor [155], and cognitive [156] impairments, as a result of cancer or its treatments. For example, "chemo brain" (a.k.a. chemo fog) is a common cognitive impairment faced by cancer survivors, accompanied by memory problems and a lack of mental sharpness [156]. According to the Institute of Medicine and National Research Council of the National Academies, around 40% of cancer survivors experience some form of impairment [16], which has a significant impact on their Quality of Life (QoL) and potentially makes software use challenging for this population.

While there is a focus on software accessibility in general and a specific focus on software accessibility for older adults [157]–[159], there is limited attention given specifically to cancer survivors with impairments. Recently, cancer survivors were included in participatory design sessions of mobile health (mHealth) applications, allowing small groups of cancer survivors to co-design accessible prototypes [160]. However, the effects of such a workshop are limited to the design of a specific app. To extend the results to impact all types of software, designers of every website and application would need to consult with cancer survivors, which is not feasible and does not scale well.

Therefore, I aimed to consider the best approaches in software design for cancer survivors with impairments by spotlighting cancer survivors and their accessibility needs. This will allow software designers to focus on this demographic of users even if they cannot recruit members of this demographic as part of the design process.

Through a formative study involving a survey, in-depth interviews, and a diary study, I derived a set of accessibility guidelines that software designers can adopt in their design. This allowed me to suggest optimal ways to design websites and applications that cancer survivors can easily use despite the impairments they face as a result of cancer or its treatment.

My probe of cancer survivors' accessibility challenges went beyond software barriers and concerned other aspects of life, such as health, socialization, and cancer rehabilitation – factors that can contribute to cancer survivors' QoL. The elicited design features can be implemented in future applications designed for this population.

Through the current study, I answered the following research questions (RQs):

- **RQ1:** What are the challenges and needs of cancer survivors with impairments when using software?
- **RQ2** What are cancer survivors' needs regarding health, socialization, and cancer rehabilitation?
- **RQ3:** What accessibility guidelines and design features should be formulated for software design for cancer survivors with impairments?

3.2 Related Work

Here, I discuss information technologies for cancer survivors, cancer-related impairments, including chemo brain, and their impacts on cancer survivors' QoL, and software accessibility for cancer survivors.

3.2.1 Information Technologies for Cancer Survivors

There is a growing body of literature on cancer survivors' technology use to support cancer management and treatment. mHealth websites and apps tailored for cancer survivors are a growing field (e.g. [161], [162]).

Accurate health information is essential for cancer treatment. Personalized, up-to-date, and trusted health information is vital for cancer patients to learn about and manage their condition [163]. Research suggests that technology may help patients share information with providers, despite their hesitation to share emotions such as loneliness [164].

Collaboration plays a huge role in managing and treating cancer [165]. Jacobs et al. illustrated collaboration and technology's roles in supporting navigation work by describing a rural cancer navigation organization that helped patients overcome emotional, financial, and logistical challenges [166]. CSCW technologies have been used to support family care coordination across cancer patients' illness journey, which helped reduce stress levels and improve connectedness [167]. Online peer support improves psychosocial well-being in terms of anxiety and stress [168]. Online spaces may be helpful for young adult cancer survivors to collaborate toward reducing isolation, coping with the fear of mortality, and managing their changing body image and identity [169]. At the same time, boundary management with caregivers is important for cancer survivors, especially when transitioning to adulthood as a cancer survivor [170].

One notable gap in the computing cancer survivorship literature is that too little is known about designing accessible software for cancer survivors despite the prevalence of impairments experienced by this population. In fact, one significant area where impairments manifest is technology and software use. Visual impairments can make it difficult to see images and read text; physical impairments can make it challenging to control mouse movement or to select items on an interface with precision; and cognitive impairments can make it difficult to comprehend densely written text or confusing instructions.

Researchers in accessibility have focused on older adults as a category of people with disabilities since they share many common impairments [157]–[159]. Cancer survivors with impairments similarly need accessible software design, which has not been studied in literature so far to the best of my knowledge. I argue that research should be conducted on cancer survivors to identify common accessibility needs and accommodations that this population requires so that the next-generation health-related or general-use software can be designed for ease of use by this population.

3.2.2 Cancer-related Impairments

Cancer survivors face impairments that can have a substantial effect on their QoL. These impairments are "physical and functional difficulties that do not always resolve with the conclusion of treatment or that become problematic in survivors earlier than expected with normal aging" [171]. Cancer survivors may experience impairments caused by the cancer itself or by the treatment, including chemotherapy, radiation, and surgery. For example, they may experience cognitive impairments, including chemo brain [172]; physical, muscular, or motor impairments, including chemotherapy-induced peripheral neuropathy [155]; visual impairments, sometimes as a result of tumors in the central nervous system or chemotherapy [154], [173], [174]; and auditory impairments, as a result of tumors or chemotherapy [154], [174].

Cancer-related impairments impact many people, for a long time, and to a great extent. The number of affected people is large – an estimated 40% of cancer survivors in the United States experience a form of impairment [171], [175]. The rate of impairments is frequently underreported: "Functional problems are prevalent among outpatients with cancer and are rarely documented by oncology clinicians" [176]. The effect is long-lasting – cancer-related impairments can arise at any point along the course of cancer diagnosis and treatment or in the years thereafter. Acute toxicities may arise during and immediately post-treatment, long-term effects can persist for years after cancer diagnosis and treatment, and late effects may arise long after the completion of treatment [177]. One study found that over 60% of breast cancer survivors continued to experience impairments six years after diagnosis [178]. Additionally, cancer-related impairments have a significant effect on survivors' QoL. One study found that the risk of psychological distress has more to do with the level of disability than cancer itself [179].

Although the bulk of cancer research concerns the medical needs of cancer survivors, research into aspects that affect their QoL is also vital. As Stein et al. wrote, "Initial efforts to address the needs of long-term cancer survivors focused on causes of late mortality and medical late effects, such as recurrences, second cancers, and cardiopulmonary risks." More recently, research has begun to document physical and functional difficulties due to the realization that "long-term and late effects of cancer can have a negative effect on cancer survivors' quality of life" [171]. There is a great need to formulate a set of accessibility guidelines and design features that help software designers create applications that can be easily used by cancer survivors and that are purposefully designed to meaningfully impact their lives, and thus improve their QoL.

3.2.3 Chemo Brain and Software Accessibility

Chemo brain is a form of cognitive impairment that often arises after chemotherapy treatment of cancer. Chemo brain can lead to weakened cognitive abilities, slower information processing, longer reaction time, and weakened organizational skills. Cognitively, chemo brain negatively affects language ability, memory, concentration, and attention [156]. Estimating the prevalence of chemo brain is difficult, but prior research reports a range from about 19% to 78% [180], and its effects can persist for many years post-treatment [181].

As cancer incidence increases, as well as survival rates for many cancers, the adverse cognitive effects of chemotherapy and the resultant impact on the QoL of cancer survivors are increasingly an area of concern [182]. Although chemo brain has received a fair deal of attention in the medical world, with the goals of diagnosis and possible prevention and treatment, it has received insufficient attention in other domains, where adaptations can be made to improve the functional skills of cancer survivors affected by chemo brain.

There is recent attention to the challenges that neurodivergent users may face when using inaccessible software – e.g., users with attention-deficit/hyperactivity disorder (ADHD) may be distracted by extraneous content; users with dyslexia may be challenged by textual content [183]; and users with autism spectrum disorder (ASD) may be overwhelmed by complex or time-limited tasks [184]. All of the above, along with other difficulties, may apply to cancer survivors with chemo brain. Therefore, a major goal of this chapter is to introduce to the computing community the effects of chemo brain on software use and to promote accessible software design for cancer survivors with chemo brain.

3.3 Methodology

This IRB-approved study included a survey, semi-structured interviews, and a diary study, lasting from November 2023 to July 2024. Survey respondents who provided detailed, insightful responses were invited to an interview; willing interviewees further submitted software diaries over the course of one week. Below, I elaborate on each component of this study, following an introduction of the research team.

3.3.1 Research Team

The research team was comprised of five researchers. I was the lead researcher for this study, responsible for study design, data collection (both qualitative and quantitative), data analysis, and the reporting of the research. The second author, then an undergraduate student, assisted in the data collection (mainly interviews) and analysis process. She served as the second coder in the qualitative analysis of the interview transcripts. The third, fourth, and fifth/last authors were senior researchers with considerable research experience in accessibility, both from technological and medical perspectives. I had multiple discussions with them regarding research design, analysis, and writing throughout the research process. The fourth and fifth authors validated my survey analysis and revised the manuscript.

3.3.2 Survey

The survey acted as both a means of data collection and a screening tool for follow-up interviews and the diary study.

Survey Design

Following a consent process, the survey started by asking for demographic information and information related to cancer and its treatments, e.g., the type and stage of cancer the respondent was diagnosed with, the current stage of cancer, and types of treatment.

Next, the survey asked if the respondents experienced any impairments before or after cancer diagnosis and treatment. These questions are used to contextualize the respondents' software experiences and challenges against their cancer and disability experiences.

Participants then answered nine 5-point Likert-scale questions about the frequency of software (e.g., websites, apps) challenges, including (1) reading text on websites/apps, (2) seeing images/icons on websites/apps, (3) hearing audio on websites/apps/videos/podcasts, (4) typing, (5) manipulating or selecting (e.g., scrolling, zooming, clicking on buttons) on websites/apps, (6) following the instructions on websites/apps, (7) navigating on websites/apps (e.g., finding the correct option or page), (8) focusing while using websites/apps, and (9) feeling frustrated or annoyed. These questions provided descriptive insights into how cancer survivors experienced software challenges in everyday scenarios.

The survey further asked open-ended questions such as descriptions of the difficulties faced while using websites or apps, features of website/app design that make the use easier or more challenging, and strategies/technologies/tools used to mitigate the effects of the impairments on software use. These questions provided in-depth insight into how cancer survivors navigated software challenges arising from cancer and its treatment as well as impairments.

Next, the respondents were asked whether they considered the impairments as a result of cancer or its treatment to be a "disability." The survey concluded by asking if the respondents wanted to participate in the follow-up interview.

The full survey is attached in Section A.1 in Appendix A, including the recruitment message used when distributing the survey. At the beginning of the survey, respondents were told that the survey would take approximately 20 minutes of their time.

Recruitement

The survey was distributed via various channels, such as one cancer research advocacy group, one cancer research center, closed Facebook groups of cancer survivors, Twitter, Mechanical Turk, and through distribution channels of healthcare professionals (e.g. flyers on hospital walls).

The survey link was included in a recruitment message posted on online platforms,

> "With [another researcher on the team], we're conducting a research study examining best practices for software design for cancer survivors. If you are a cancer survivor who has experienced challenges (such as chemo brain), please take this survey and you will be compensated with a $10 gift card: [survey link that is no longer active]."

A flyer containing the survey link was additionally put up in hospitals in New York and distributed in Facebook groups for cancer survivors to reach more respondents in a targeted way.

In the end, 1,076 responses were received. However, the majority of survey responses obtained through mass recruitment (Mechanical Turk, Twitter, and even the closed Facebook groups) were generated by bots, evidenced by (1) one person filling in multiple surveys, (2) response that indicated seeing the survey in a platform where it had not been distributed, and (3) ChatGPT-styled open-ended responses that were generalizable or situational rather than individualized.

Smaller scale recruitment (through cancer centers, advocacy groups, and hospitals) yielded far fewer responses, but responses that were legitimate. A total of 46 legit responses were used for analysis. The legit respondents were compensated with $10 for their time.

3.3.3 Interview

To better understand cancer survivors' accessibility challenges and life needs, a follow-up interview study was conducted with survey respondents who had impairments because of cancer that contributed to their software challenges and who provided insightful responses. The interview covered topics similar to those in the survey in a more in-depth fashion.

First, the participants were asked to introduce themselves, including their personal background and experiences with cancer treatment. This is for the researchers to build rapport with the participants and help them talk more about their experiences.

The participants were then asked about the impairment(s) they faced as a result of cancer and its treatment, types of software they used, challenges they faced while using the software as a result of the impairments, possible solutions to the challenges faced, assistive technologies used, and manual help leveraged. These questions were designed to help inform accessibility guidelines for cancer survivors with impairments.

Then, the participants were asked about the daily life aspects of cancer survivors, such as exercise and social life, and how these activities and interactions were affected after their cancer diagnosis. These questions were used to synthesize design features.

The interview protocol is attached in Section A.2 in Appendix A.

The interviews lasted about an hour over Zoom, and each interviewee received $25 as compensation. The interviews were recorded upon consent for transcription and analysis. The 20 interviewees' demographic information is summarized in Table 3.1.

ID	Gender	Age	Race	Highest level of education	Type(s) of cancer	Stage of cancer first diagnosed with	Current stage of cancer	Type(s) of treatment
P1	Male	85	White	Graduate degree	Colorectal	Stage 1	Unknown	Surgery, Radiation, Chemotherapy
P2	Female	69	White	4-year college degree	Ovarian	Stage 1	No evidence of disease	Surgery, Chemotherapy
P3	Female	63	White	4-year college degree	Myeloma	Stage 2	Complete remission	Chemotherapy, Immunotherapy
P4	Female	68	White	4-year college degree	Breast	Stage 2	No evidence of disease	Surgery, Radiation, Chemotherapy, Estrogen suppression therapy
P5	Female	42	White	Doctoral degree or equivalent	Leukemia	Not sure	Complete remission	Surgery, Radiation, Chemotherapy, Bone Marrow Transplant
P6	Female	40	White	Graduate degree	Breast	Stage 3	No evidence of disease	Surgery, Radiation, Chemotherapy, Hormonal treatment
P7	Female	60	White	Graduate degree	Breast, Colorectal	Stage 1	No evidence of disease	Surgery, Chemotherapy, Hormonal treatment
P8	Female	54	White	Graduate degree	Colorectal	Stage 3	Complete remission	Surgery, Radiation, Chemotherapy

Table 3.1 continued from previous page

ID	Gender	Age	Race	Highest level of education	Type(s) of cancer	Stage of cancer first diagnosed with	Current stage of cancer	Type(s) of treatment
P9	Male	23	White	4-year college degree	Brain, Thyroid	Stage 2	No evidence of disease	Surgery, Chemotherapy
P10	Female	35	White	4-year college degree	Breast	Stage 1	Complete remission	Surgery, Chemotherapy
P11	Male	24	Black	2-year college degree	Brain	Stage 1	No evidence of disease	Chemotherapy
P12	Female	24	Black	2-year college degree	Breast	Stage 2	Progressed to stage 3	Chemotherapy
P13	Female	25	Black	2-year college degree	Kidney	Stage 2	Progressed to stage 3	Surgery
P14	Male	34	Black	Graduate degree	Lung	Stage 2	No evidence of disease	Chemotherapy
P15	Female	27	Black	4-year college degree	Breast	Stage 2	Complete remission	Chemotherapy
P16	Male	26	Black	4-year college degree	Prostate	Stage 2	Stage 3	Surgery, Radiation, Chemotherapy
P17	Male	28	Black	Graduate degree	Eye, Pancreatic, Prostate	Stage 2	Stage 2	Chemotherapy, Hormonal treatment
P18	Female	28	Black	Graduate degree	Breast	Stage 2	Partial remission	Chemotherapy
P19	Female	48	Creóle	4-year college degree	Breast, Liver	Stage 4	Stage 4	Surgery, Radiation, Chemotherapy
P20	Male	28	Black	Doctoral degree	Eye, Ovarian, Prostate	Stage 2	Partial remission	Radiation, Hormonal treatment

Table 3.1: Demographic information of cancer survivor interviewees.

3.3.4 Diary

The interview participants who were interested in the diary study were asked to keep a diary of software (e.g. websites, apps, computer programs) used and any challenges and accessibility issues found while using software over the course of one week.

Participants who opted to keep a software diary were provided with the template table that had five columns: (1) Date and time, (2) Device used (e.g., desktop computer, laptop computer, mobile phone, ebook reader, etc.), (3) Name of software, app, or website (if website please also list the browser used – e.g., "Website: abc.com, Browser: Chrome"), (4) Accessibility issue noticed: What was challenging/difficult/impossible about the software interaction? If you have any ideas for solutions, please list them as well, and (5) Any information that would have been helpful but was not included. The diary template is provided in Section A.3 in Appendix A.

Two examples were provided at the top of the table to help the participants create their own entries. In the first example, a person used a desktop computer to navigate the website abc.com through a Chrome browser. They encountered small font, and raised the solution of larger font. They provided additional information that they use a magnifier on their computer to read small text.

The participants were asked to fill out the diary over the course of a week and to keep an eye out for accessibility issues/challenges that arose when they used digital devices and software/websites. The participants were compensated $10 for the diary study with one $5 bonus if the diary contained at least 7 events (quantity of entries) and another $5 bonus for the quality of entries. They were encouraged to make multiple entries during that week and provided with space for 20 entries.

In the end, ten interview participants opted for the diary study. Nine of them encountered software accessibility challenges from cancer-induced impairments during the diary period. The participant who did not encounter any software challenges wrote,

> "Thanks again for the invitation to participate in the logging portion of the project. I unfortunately did not experience any accessibility issues in the 7 day period. I did experience technical problems, but they were related to login restrictions and a lack of information rather than accessibility."

3.3.5 Analysis

Descriptive statistics were reported for survey responses, such as the number/percentage of respondents with each type of impairment and the number/percentage of respondents with each type of software challenge.

Similarly, I counted how many participants reported software challenges associated with each impairment in the diary study and used their notes taken as examples.

Rich qualitative data was collected for the analysis. The interview transcripts contained 16,025 words in total. For open-ended survey responses, interviews, and diary entries, a thematic analysis approach [185] was adopted to analyze the data. First, open coding of the data was conducted to have a general understanding. Then, in a more in-depth round of analysis, emerging themes and subthemes were extracted and organized into a hierarchical structure. Emerging themes included cancer-induced impairments, software challenges, and cancer survivors' life needs. Under cancer survivors' life needs, for example, subthemes included cancer advocacy, socialization, and health. A consensus was reached within the team regarding the themes and subthemes. This chapter will use anonymized quotes to report the qualitative results.

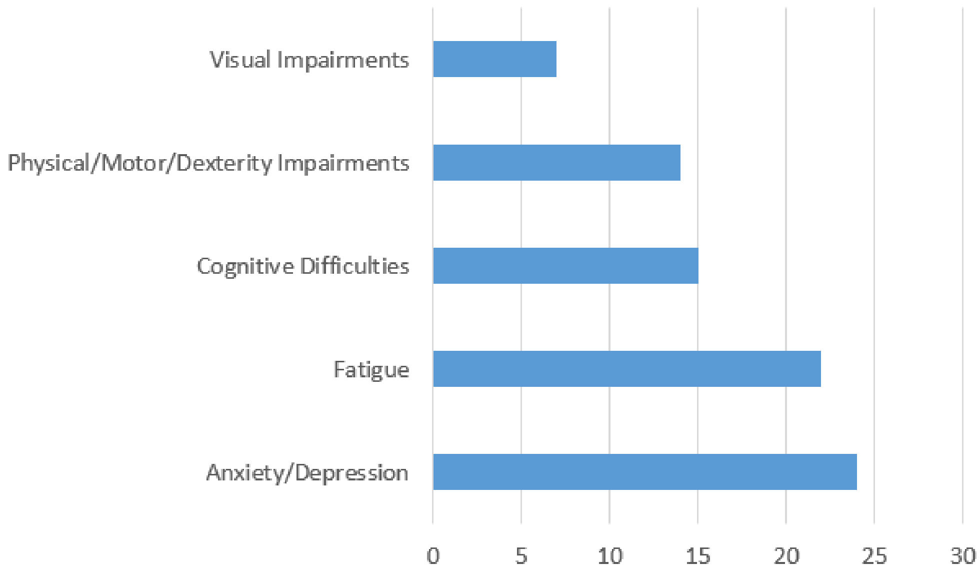


Figure 3.1: Cancer-induced impairments in survey respondents.

3.4 Results

3.4.1 Survey Results

Gender		Race		Age		Education	
Male	16	White	28	20-29	12	High School	4
Female	29	Black	15	30-39	13	2-year college degree	4
Prefer not to say	1	Asian	1	40-49	8	4-year college degree	18
		Creóle	1	50-59	5	Graduate degree	17
		Prefer not to say	1	60-69	6	Doctoral degree or equivalent	3
				70-79	2		

Table 3.2: Demographic information of survey respondents (N=46).

The demographic distribution of the survey respondents can be seen in Table 3.2. Of the 46 survey responses, 16 (34.8%) came from male cancer survivors, and 29 (63.0%) came from female cancer survivors. The respondents averaged 42 years old and were mostly White (N=28, 60.9%) and Black (N=15, 32.6%). They had a relatively high level of education, with 42 (91.3%) having a college degree or above.

Chemotherapy was the most common treatment (N=34, 73.9%), followed by surgery (N=25, 54.3%) and radiation (N=18, 39.1%). Eighteen (39.1%) of the survey respondents indicated "no evidence of disease" and 11 (23.9%) indicated "complete remission" at the time of the study.

Cancer-induced Impairments

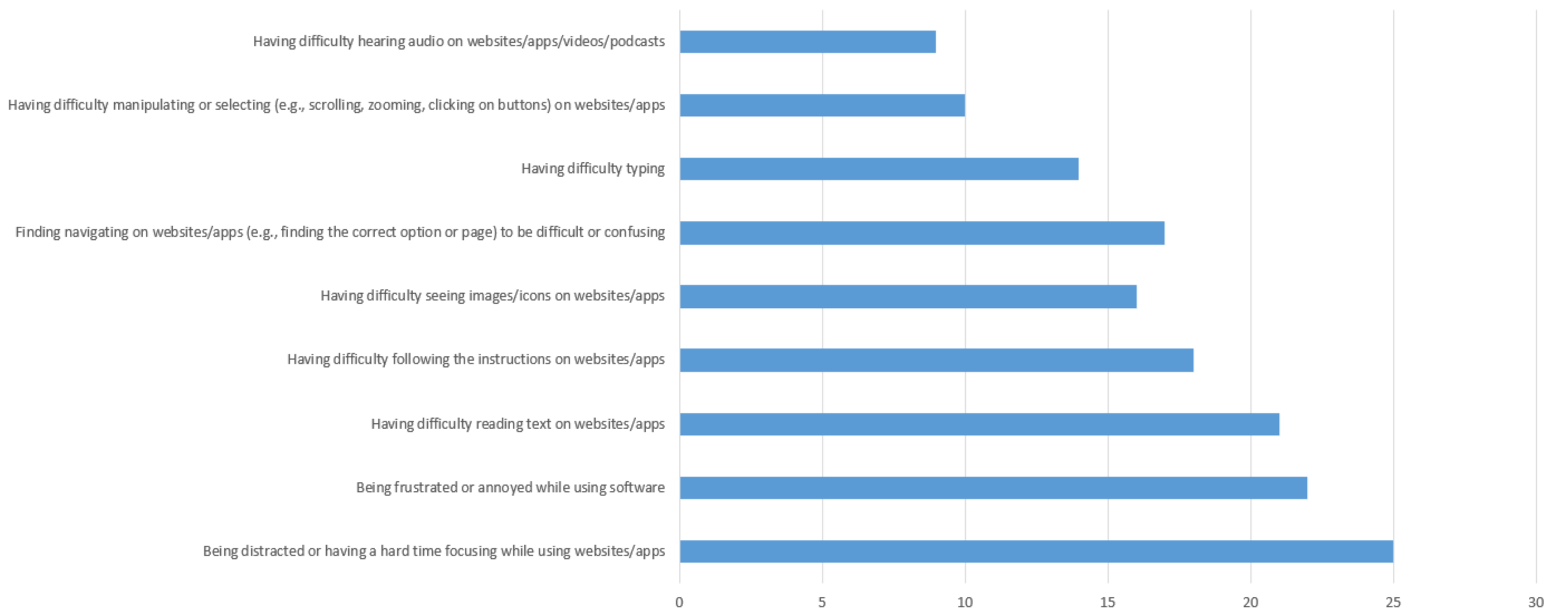


Figure 3.2: Software challenges faced by survey respondents.

After their cancer diagnosis and treatment, 24 respondents (52.2%) newly developed anxiety/depression, 22 (47.8%) developed fatigue, 15 (32.6%) developed cognitive difficulties, including chemo brain, 14 (30.4%) developed physical/motor/dexterity impairments, and 7 (15.2%) developed visual impairments (see Figure 3.1).

Fatigue (e.g., "I don't schedule things in the evening") and anxiety/depression (e.g., "I was depressed because of body changes and new look.") are common side effects of cancer or its treatment.

Chemo brain could lead to forgetfulness, e.g., "inability to remember where I put things (keys, purse, phone, etc.)"; trouble concentrating and shortened attention span, e.g., "lack of focus"; difficulty "finding the correct word to use"; difficulty learning, e.g., "hard to grasp concepts quickly"; or lack of brain sharpness in general, e.g., "slowing of thought process and inability to multitask and difficulty with memory and easily overwhelmed."

This respondent vividly pictured what a chemo brain was like,

> *"Cognitive fog is like having a big cloud in your mind that makes it difficult to think clearly."*

Forty-one (89.1%) respondents developed at least one new impairment after cancer, while nineteen (41.3%) respondents reported at least one ongoing impairment at the time of the study. These two respondents were examples whose cognitive impairments had lasted till the time of the study,

> *"I had the worst of the chemo brain (brain fog, inability to retrieve words, and lack of focus) for less than two years, however, I believe chemo or hormone treatments have left me with ongoing cognitive issues, particularly lack of focus."*

> *"Most effects lessened but I would say that my attention span is much less and my ability to focus and my memory has been permanently affected."*

The respondents expressed frustration about the impairments and their impacts on daily life. This quote illustrates how one cancer survivor experienced difficulty remembering people's names, which she used to be good at, due to chemo brain,

> *"I couldn't remember names when introduced to someone new. I had always prided myself on remembering someone's name when introduced and to not have that ability felt abnormal, as though I'd done something wrong and was somehow lesser. I tried multiple ways to help my memory (using their name when talking to them, writing it down, etc.) but nothing seemed to work. I now just tell them I can't remember their name and reintroduce myself. The lack of accurate recall lasts until this day."*

The respondents also mentioned their coping strategies with the impairments. For example, this respondent often found herself struggling to find the correct words when speaking or writing and would use a variety of strategies to mitigate this issue, such as Googling words or leaving a placeholder and revisiting the word choice later,

> *"When writing, I would often put a dash in the middle of my sentences, where I knew "what" I wanted to convey/say but I couldn't quite come up with the proper term. I would finish the thought as best I could with that gap, and return to fill it in later when the word/phrase finally came to me. Often I would have to Google other words to find the word I needed. While this happens less frequently now, there are still times I struggle with cognitive issues related to communication and focus."*

Software Challenges

Software challenges arose from the cancer-related impairments, i.e., being distracted or having a hard time focusing while using websites/apps (N=25, 54.3%), being frustrated or annoyed while using software (N=22, 51.2%), having difficulty reading text on websites/apps (N=21, 45.7%), having difficulty following the instructions on websites/apps (N=18, 39.1%), having difficulty seeing images/icons on websites/apps (N=16, 34.8%), finding navigating on websites/apps (e.g., finding the correct option or page) to be difficult or confusing (N=17, 37.0%), having difficulty typing (N=14, 30.4%), having difficulty manipulating or selecting (e.g., scrolling, zooming, clicking on buttons) on websites/apps (N=10, 21.7%), and having difficulty hearing audio on websites/apps/videos/podcasts (N=9, 19.6%) (see Figure 3.2).

Respondents expressed strategies to mitigate the software challenges and preferred design accommodations. Cancer survivors with visual impairments favored high contrast, big font, and zooming functionality. Participants with a chemo brain had difficulty focusing on content and had to read instructions multiple times to comprehend them. Remembering multiple instructions simultaneously was particularly difficult for some. Besides using tools like Pomodoro apps or ad blockers to help them focus, "bulleted instructions, pictures/icons, more visuals, clear and simple instructions, shortlisted options, and simplified design" helped their comprehension of instructions and websites. Easy downloads and account openings were favored by those with chemo brain who were "sick of dealing with apps." "Autofill is priceless" for those with chemo brain who had difficulty coming up with words. Overall, participants condemned websites and apps for their bad designs, including lengthy instructions, too much information, password management, complex interfaces, and too many options. In a contrasting sentiment, simplicity, autofill, voice input, bulleted instructions, pictures/icons, and calendars/alerts were helpful software features for cancer survivors with chemo brain.

People diverged in their opinions of whether the impairments count as disabilities. Of the forty-one respondents who developed at least one new impairment after cancer, seventeen (41.5%) of them viewed impairments as disabilities given the inconvenience they brought,

> *"YES, particularly cognitive impairments make it impossible for me to return to normal activities."*

> *"I didn't at the time, probably as a defense mechanism. But looking back on it, it was absolutely a disability, a pretty serious impairment that impacted my work and life."*

Others did not see impairments as disabilities since they could overcome the challenges with efforts and strategies,

> *"No, because I was able to compensate for the deficits."*

> *"No, I look at it as a challenge to overcome or adapt to."*

Some of them thought impairments were not as severe or enduring as disabilities,

> *"No, I don't view my cognitive issues or ongoing side effects as a disability. I personally consider my experiences as an impairment or limitations; they are effects that I live with and can work around. Personally, I believe a disability is much more severe and prevents a desired outcome."*

> *"It's not a disability since the impairments only lasted for some time."*

3.4.2 Interview Results

"Cancer doctors make no promises about post-cancer effects (P7)", and people only realize the impairments after experiencing them. Due to these impairments, fatigue, or depression, cancer survivors' QoL is significantly affected.

P1 described how he sat and stared at the wall for hours or slept all day. Everything he was accustomed to doing, including exercise (hiking and swimming), was now possible. He said that he just had no energy and no motivation. His phone use offered a way to break the monotony because it provided a relatively low-effort way to connect to the outside world. For example, it was easier for him to read brief news clips on his phone than an article in a newspaper. However, since his energy and motivation were so low, the software needed to be both motivating and easy to use, or he would give up.

Overall, software offers to be a lifeline for cancer survivors, but it has to be carefully designed to achieve that aim. Other interviewees similarly reported various life challenges and software challenges arising from cancer-induced impairments, especially chemo brain. They also expressed life needs in the process of recovery and rehabilitation, including socialization, health, and cancer advocacy. These are valuable insights for software designers to design products accommodating cancer survivors' accessibility needs and life needs.

Chemo Brain

Chemo brain was a frequently mentioned impairment by the interview participants. Out of eighteen cancer survivors who used chemotherapy as a means of treatment, thirteen of them had or were experiencing chemo brain at the time of the study.

Cognitive challenges that arose from chemo brain were commonly expressed. P1 could not concentrate and had poor memory. P3 also indicated short-term memory issues – when she shifted between multiple tabs in the browser, she sometimes forgot what she wanted to look at. P11's memory issue led him to forget passwords, and he often had to register for new accounts. He found computers particularly challenging since he tended to forget key locations on the keyboard. P2 similarly experienced bad memory and a lack of focus (during the interview, she said: "something just popped up in my head"). She typed slowly on her computer and smartphone and occasionally experienced "episode incidents" when she could not understand words. She disliked this new normal when using digital devices and in daily life. P8 experienced a shorter attention span due to chemo brain. She also found it harder to retain knowledge and had to re-read things all the time. Chemo brain did not affect her work as she was able to "adapt and find ways around." For example, she would set alarms to remember things when she was in a supervisor role. P6 acknowledged cancer-led cognitive impairments, including chemo brain, were the scariest part of her cancer journey. At some point, she was concerned that she may not be able to teach as she could not process things quickly and put things together. Despite improvement, her brain was still slow in processing things, including websites. P5 did not have chemo brain at the time of the interview but worried about developing it in the future.

Software is often designed without considering accessibility, making its use more challenging for cancer survivors with chemo brain. P5 pointed out some medical apps were not designed in an accessible and user-friendly way and may impact cancer survivors with chemo brain:

> *"The navigation process in the hospital app is not consistent. Sometimes, I cannot find an affiliated hospital. Sometimes, I cannot find a digital letter after being alerted by text. They are put in weird places."*

Suboptimal information organization and navigation structures posed significant challenges to people with chemo brain.

Participants suggested approaches to make software more accessible and usable for people with chemo brain. To help mitigate the effects of chemo brain, P9 thought fonts on websites and apps should be well-seen, big, and bold; Siri or screen readers helped in understanding the text. According to P11, voice typing helped with chemo brain, especially when he could not spell a word out. Google Password Manager helped him autofill passwords that he could not remember. P6 suggested websites be made in a simple way and provide information in pieces to ease understanding,

> *"Websites should help consume as much info as possible. Sometimes, I have to read things multiple times before understanding them. Simplifying things is important to me, like breaking things up into small pieces."*

At the end of the interview, she again emphasized websites should deliver quality, helpful information in smaller pieces leveraging bullet points, infographics, and chunks. P14 preferred watching videos at a slower speed to capture information at an easier pace and also used subtitles as a secondary way to focus. P10 suggested bold text, more images to help people concentrate, colors other than black and white, and highlighting topics using bullet point summary. P11 suggested bold and black text for concentration, using lines instead of italicized text to highlight important content, using bold colors such as red instead of light colors such as light green, and using images to accompany the text. Due to difficulty typing, he liked video games where he did not need to type and could use a microphone to communicate with teammates. P1 repeatedly suggested making websites simple (e.g., using short snippets) to reduce cognitive loads, redesigning software, like games, to motivate people to use them instead of sleeping all day, and using a positive tone to accommodate cancer survivors' mental status.

All participants with chemo brain indicated playing games to improve their cognition. P2 played Candy Crush, mindfulness games, and word games like Wordscapes and Word Connect to help her "concentrate and sharpen focus." P3 played another word game, Wordle, and other cognitive games such as puzzles to "put her brain somewhere else [besides her cancer]." Similarly, P10 found herself playing more games after cancer to keep herself busy. P8 thought games, such as role-playing games and shooting games, were helpful to her cognitive ability by stimulating her brain. P11 picked up word games as suggested by the doctor to recover from chemo brain. He played shooting and sports games less during chemo brain since they were "too complex." P5 did not experience chemo brain, but to prevent it, she played three to four games (e.g., crossword, word search puzzles, strategy games) after waking up to exercise her brain. P7 observed that many people picked up games during chemotherapy. P14 expressed frustration with attention span and difficulty while playing games. When overcoming a level in a game was difficult, he got bored and frustrated and even stopped playing. For a person who struggles to muster energy and focus on a task, having this process interrupted by overly complicated design and a lack of adjustability regarding gameplay difficulty takes away from the already small pool of activities available to maintain their mental health and livelihood.

Visual Impairments

Some cancer survivors experienced visual impairments. P3 needed glasses more often than she used to. Small fonts on websites were a struggle for her, so she used a computer more than a smartphone for a larger screen. P8 experienced worse vision after chemotherapy and had difficulty reading text. She had to make text bigger on her computer but generally found computers easier to use than phones because they allow for a larger font. P5 had low vision even before cancer but was diagnosed with a cataract after cancer treatment. She experienced challenges in reading text and icons and had to zoom in on screens constantly. When she used smartphones, she either used her fingers to zoom in or took screenshots and zoomed in the pictures. She complained about the tiny text in images on social media platforms like Facebook and other websites. She often asked colleagues to make content larger in screen sharing during meetings. After developing poorer eyesight because of cancer, P17 stopped playing video games, which used to be an essential means of entertainment. P19 became more photo-sensitive after cancer and had to close her eyes when scrolling on digital devices to avoid getting light-headed.

Dexterity Impairments

Some cancer survivors have peripheral neuropathy, which is a unique condition in the accessibility community. P4's friend had "fat fingers" when typing, unsure whether keyboard pressure was sufficient, and ended up with typos. P5 similarly found typing hard and missed letters. She instead used voice-to-text tools such as Siri when using smartphones and corrected grammar if necessary; when using computers, she could not find similar accommodations and could only type slowly and steadily. After cancer, P8 was more sensitive to coldness and found her "metal laptop is too cold to touch." She would use finger gloves for this reason. As a result, she could not use the trackpad seamlessly and always attached a mouse to her computer.

Multiple Sources of Software Challenges

Software challenges can be attributed to both cancer- and cancer treatment-induced impairments and other non-cancer factors, according to the participants. Aging is a commonly cited cause of challenges in software use. For example, P2 said,

> *"I'm older. If I don't need it, I don't do it. I don't have the capacity to do things I used to do. It's not [a problem with] the software."*

P1 similarly expressed that older people were not as familiar with computers in general.

Tech literacy is another important factor. Not all cancer survivors are tech-savvy users. P2 acknowledged herself as a mediocre tech user and said her software usage was "as bad as before" after being diagnosed with cancer. She deemed a library workshop for smartphone use helpful. P7 spent a long time figuring out the consent form and setting up Zoom before the interview. She would ask her daughter for help when encountering technical difficulties. She paid for extra customer service for her Dell laptop.

Users found some devices are more accessible than others. For example, P3 preferred computers over smartphones for bigger text. Similarly, P7 did not like phones since "words are too small for an old person," and she wanted a bigger screen.

Cancer Survivors' Life Needs: Cancer Advocacy

Cancer advocacy requires legislation and social, financial, and informational support for cancer survivors. P1 was engaged in cancer advocacy and founded a nonprofit organization dedicated to educating about the early detection of cancer. P2 actively worked with the American Cancer Society to advocate legislation and raise funding for cancer research. She expressed the urgent need for cancer advocacy,

> *"Currently, there is no diversity in trials, and people in rural areas and underrepresented groups are not included."*

P2 also worked with cancer advocacy groups to organize seminars for cancer survivors and invite speakers. P4 participated in advocacy groups so that she did not "remain within her own silent brain." P5 explained why she wanted to advocate for cancer survivors given her dual roles as a cancer survivor and a public health scientist,

> *"I'm a different cancer survivor. I'm a public health scientist and a survivor at the same time. So, I really want to put my thoughts out there as an advocate. I share a lot with people going through treatment. I also join the fundraising walks."*

Cancer Survivors' Life Needs: Socialization

Socialization plays an integral role in enhancing cancer survivors' social well-being. Social media and gatherings of cancer survivors are two primary means for them to share information and support. P2 noted survivors wanted to share information and were happy at conferences organized for them. P8 participated in online support groups where people experienced similar challenges, such as chemo brain. By attending a local support group, she could get help and provide help at the same time. P3 was active on Facebook during cancer treatment and recently started using Twitter to follow cancer doctors. She thought social media helped her social life and enabled her to help others, which helped her mental status ("I'm a helper"). P6 acknowledged using social media a lot during treatment, which helped her meet people with similar experiences and share struggles – she got friendship and support in this process. P2 expressed that social media was essential for her to keep in touch with family and other cancer survivors. She did not post but felt less isolated by connecting with people with direct messages, even by just reading people's messages in her inbox.

Some participants avoided socialization or connecting with new friends for physical constraints or to avoid the social stigma attached to the socially-ascribed identity of cancer survivors. P7 was such an example, who did not want to be reminded of her identity as a cancer patient,

> *"I didn't like [being a cancer patient] to be a part of my identity there [on social media]. I only stuck with people I've known for years."*

P9 was depressed during cancer treatment and was not in the mood to hang out with others, even though he knew this isolating behavior was not beneficial. P12 practiced meditation to stimulate focus, which was also a more solitary activity. P8 experienced severe fatigue and often found herself too tired to socialize,

> *"Fatigue cut that out. I had no energy left after work but picked it [socialization] up again when energy recovered."*

P11 socialized less because he often found himself "blank out of words to say" due to chemo brain, which he thought was embarrassing. He only talked to family members and friends who understood his situation. P14 expressed frustration when he asked friends and family for help and was told the tasks were "easy." He was often told, "It's not rocket science," which discouraged him from asking for more assistance and generally increased his tension.

People found their social habits and preferences were evolving. After cancer treatment, P6 has tried to "cut away from social media to stay connected to the family" and preferred cancer-specific social networks, which were more private. According to her, such social networks should contain like-minded people gathered by a shared interest in scientific information and grouped by subject matter (e.g., cancer vs other topics) and provide quality information, e.g., videos for exercising or recovering. P13 similarly took a break from social media to spend more time with family.

Cancer Survivors' Life Needs: Health

Living a healthy lifestyle is of vital importance to cancer survivors. All the participants emphasized the importance of exercise for health, yet some felt it was difficult to exercise due to cancer-induced fatigue or immune deficiency.

More emphasis on health (exercise, nutrition, sleep) is common in the participants after cancer diagnosis and treatment. P5 acknowledged more regularly exercising after her cancer diagnosis as she got to know how important it was for health. She used a Fitbit to track her step goals and sleep patterns, which were intertwined matters for her,

> *"I sleep better after exercise and my fatigue issue is improved. Using it [Fitbit] encourages me to exercise."*

P3 similarly expressed the positive relationship between exercise and energy. P6 thought she was healthier than before by exercising a lot after her cancer diagnosis, as health has become her priority. She had an exercise mentor to keep her on track. The mentor prepared courses, videos, and handouts for their mentees. P7 tried chair exercises to relieve her sciatica, which "kicked in after cancer treatment."

Some participants experienced more difficulty exercising. P10 exercised less because of physical pain after cancer. P8 had intense chemo reactions, and it took her a couple of years before regaining energy. P11 stopped intensive sports such as football after cancer but generally exercised more to keep in shape. P1, who was interviewed shortly after a complete course of radiation, reported that he had no energy for the exercise (such as swimming and hiking) that he used to engage in.

The participants used technology and strategies to facilitate exercise, such as apps for step-counting and calorie-counting. P6 liked checklists for the dopamine-driven effect, which motivated her to make progress on small goals. P8 used a water intake app, a sleep tracking app, and a medication app. However, when it came to her severe anxiety regarding cancer, she did not think a medication app was helpful; she would use self-soothing or talk to her oncologist to relieve anxiety.

Cancer survivors have a powerful need to seek health-related information. To some, learning about cancer/medicine research empowered them. P7 thought positive information, such as advancements in cancer research, made cancer patients hopeful. She did not want negative information from online sources and event speakers; "just let people look at cool or positive stuff." P17 actively sought health information and doctors/clinic recommendations from social media, Mayo Clinic, Google, Bloomberg, and other sources. Exercise tips are needed by those with immune deficiency or bone issues. P3 has not gone to gyms since being diagnosed with myeloma, as she had a suppressed immune system and bone issues. She thought safe exercise tips were helpful to protect her spine during exercise. P6 expressed concerns with the quality of information online. She thought social features such as message boards were helpful for people to share general information and experiences. Yet, when it came to cancer-related questions, dedicated boards should be used where questions were only answered by medical professionals.

3.4.3 Diary Results

The participants filled out the diary template in a detailed manner. An example of the filled diary template can be seen in Section A.4 in Appendix A.

In the diary period, the participants experienced software accessibility challenges due to hearing, physical, and visual impairments, chemo brain, and cancer treatment.

One participant reported experiencing limited access to software due to cancer treatment. P3 noted, *"I recently had surgery, so access to my main computer was/is limited."*

She, therefore, suggested an app that could "easily link all devices."

One participant experienced software challenges due to hearing impairments. When P15 used YouTube on her mobile phone, she had difficulty hearing audio. She suggested potential solutions such as adding subtitles,

"I'd love to get assistive listening devices because I think this would help. Also, there should be more options for volume enhancement."

Two participants experienced software challenges due to physical impairments. P13 had difficulty adjusting brightness due to physical dexterity issues when using the Kindle app on the laptop. She suggested voice-activated controls for adjusting brightness and instructions on using voice commands to adjust settings. P15 had difficulty typing and using a mouse when Googling on the laptop. She suggested using a pen to control the cursor and making sound recorders available to transform audio into text. She also had difficulty controlling in-game actions on the laptop and would like programs allowing voice commands to control gameplay. She stressed the importance of accessibility thinking for app developers, which is vital to cancer survivors,

"I would suggest that software and app developers should have cervical cancer survivors and other cancer survivors in mind while developing apps. They should make it easy for us to have access to the features we need and make available text expanders, screen readers or mouse alternatives. When we experience difficulties which weren't there prior to our cancer journey, it makes us become sad, depressed and avoid technology."

Eight participants had difficulty with software because of visual impairments. The small font size was a pain for P3, P8, P11, P12, P13, P14, P15, and P16. For example, P3 said,

"Very blurry, I always need my glasses and if they are not in reach, I cannot read. A larger font would be helpful."

In addition to larger fonts, P11 suggested the "incorporation of zooming gestures such as using two fingers to zoom in and out of the screen." P13 similarly suggested a "quick-access button for text size adjustments." P15 additionally suggested text-to-speech to compensate for small fonts. Small fonts may further lead to financial risks. P16 documented how he lost money when interacting with the blockchain,

"I recently had my wallet drained perhaps I clicked on a wrong thing due to the font size."

Color and color contrast between text and background caused struggles for P8, P11, P15, and P16. For instance, when P11 read novels on his mobile phone, he struggled with light yellow writing and had to put his phone on dark screen mode to make brightly colored texts more outstanding from the background. When using Instagram on a mobile phone, P13 found distinguishing between similar icons challenging due to visual impairment from cancer treatment. She suggested more distinctive icon designs and text labels for icons, as well as a high contrast mode to make icons more distinguishable. When P16 used Netflix on his mobile phone, he experienced visual disturbance,

"There are too many bright colors when trying to navigate through the app."

Five participants encountered challenges due to chemo brain. Memory issues made software use more challenging for P3, P8, and P13. P3 suggested reminder apps to help people with brain fog,

> *"I just looked at a saved document on my desktop and realized I totally forgot about this journal... SO some kind of app to remind people of things or to help with brain fog!?"*

P8 had poor short-term memory, which made it difficult for her to go through multiple steps in apps. When using Microsoft Word on the laptop, P13 experienced difficulty remembering where tools are located due to chemo brain and suggested a simplified toolbar layout and customizable shortcuts for frequently used tools. She also had difficulty remembering how to navigate to privacy settings in the Facebook app on her mobile phone. She suggested a more intuitive, step-by-step guide for finding settings or a help feature with voice commands to guide navigation. She found difficulty finding and using the mute button during Zoom calls due to cognitive delays, and she suggested a larger, more prominent mute button and a voice command option to mute/unmute or an audio reminder about mute status when joining a call. She struggled with complex formulas when using Excel due to cognitive fog, and would like simplified formula wizards and video tutorials. P8, P11, and P16 experienced a lack of focus when interacting with apps. P11 experienced a lack of focus and a "cloudy mind" when playing video games, especially driving simulation games. P8 lacked focus when selecting from multiple options,

> *"Poor focus makes this irritating; I either ignore or slowly focus on each option."*

She had learned to compensate by calming herself down and re-focusing. P16 found it more difficult to focus when "there's too much going on in the app at once."

3.5 Discussion

Cancer survivors often find themselves living with impairments as side effects of cancer or its treatment, including chemo brain, visual impairments, and neuropathy/dexterity impairments. These impairments significantly impact their QoL and software experiences. In this work, I begin a conversation around the software accessibility needs of this population, extending the prior CSCW literature on using technology to facilitate collaboration [165] and health information seeking [163] for cancer survivors. Through a formative study with interviews, a survey, and a diary study, I spotlight this population's impairments and software challenges, which have rarely been discussed in the CSCW and computer accessibility literature.

3.5.1 Summary of Results

Cancer and its treatment led to a wide range of impairments, including anxiety/depression, fatigue, cognitive difficulties, physical/motor/dexterity impairments, and visual impairments, among others. Chemo brain was a particular impairment experienced by cancer survivors, leading to cognitive issues such as memory problems, trouble concentrating, slower processing speed, word-finding difficulties, reduced problem-solving ability, and emotional/psychological effects such as frustration, stress, anxiety, and depression.

These impairments led to significant challenges for cancer survivors to interact with software. More than half of the survey respondents reported being distracted or having difficulty focusing while using websites/apps (54.3%) and being frustrated or annoyed while using software (N=22, 51.2%).

The suboptimal experiences with software affected cancer survivors to a great extent since they tended to rely on software for multiple essential life activities, including cancer advocacy and community promotion, information seeking regarding health, and socializing with like-minded people.

Cancer survivors suggested potential improvements in software to help them adapt to newly developed impairments and have a better software experience. I synthesize these suggestions into accessibility guidelines and design features in Section 3.5.3.

3.5.2 Cancer Survivors' Software Accessibility Challenges and Needs

Cancer-induced impairments such as chemo brain [172] and visual impairments [173] have been reported in the literature. The findings echoed the long-lasting nature of these impairments [177]. Impairments lead to more psychological distress than cancer itself [179] and significantly impact cancer survivors' QoL. I spotlighted the software accessibility challenges and needs of cancer survivors with impairments, which is an under-investigated aspect of cancer survivors' QoL.

While software challenges posed by visual and physical impairments have been well-documented, peripheral neuropathy, as well as "chemo brain" – a condition specific to cancer survivors – presents unique difficulties. The participants reported issues like shortened attention spans, diminished focus, and trouble with word retrieval, which complicates their use of software. For example, they found large chunks of text on websites overwhelming, whereas bullet points and images eased their reading. Cancer survivors' perceptions of the newly developed impairments and how such perceptions impact behavior are under-investigated. Individuals with chemo brain may not have expected or accepted this side effect of treatment. They may feel less in control of their situation as this is not normal age-related progression. Practically, chemo brain impacts word search and affective states, and ultimately influences the nature of human-computer interactions and how much time cancer survivors want to spend on digital devices, which are often important for their well-being.

The accessibility needs of older adults have been extensively studied in the accessibility literature due to common impairments shared by this population [157]–[159]. I advocate for a similar depth of research into software accessibility for cancer survivors to ensure that accommodations meet their specific needs, for several reasons. First, cancer survivors need software for a wide range of purposes, such as mental well-being and socialization, but their multiple cancer-induced impairments necessitate accessible software. Second, cancer survivors are a unique set of individuals who are facing as of recent many disabilities they have not had before, and this combination of disabilities is unique. Around 40% of the survey respondents who newly developed impairments after cancer saw cancer-induced impairments as disabilities, given the inconvenience they brought. While others may have experienced lingering effects of cancer and its treatment, as discussed in prior research, some cancer survivors may not self-identify as having a disability [162]. Therefore, software designers should understand that cancer survivors experience these diverse impairments. Third, chemo brain is an impairment unique to cancer survivors, necessitating dedicated research in the computing and accessibility literature.

While this research provides a set of guidelines for software designers, it is essential to note that the results also showed that, when possible, co-design and user-centered design should be emphasized. Otherwise, the software would frustrate cancer survivors with impairments, according to some participants. Designers of software for cancer survivors should, therefore: (1) co-design with cancer survivors by including them in the desing process, if resources and time permit; (2) make software accessibility a priority; and (3) think about strategies cancer survivors may like, such as gamification. I will elaborate more concrete strategies in the following subsection.

3.5.3 Design Recommendations: Accessibility Guidelines and Design Features

Based on the findings, I elicited accessibility guidelines and design features for cancer survivors with impairments.

According to the findings, software designs should accommodate various impairments related to cancer or its treatment, including chemo brain, visual impairments, and neuropathy/dexterity impairments. Table 3.3 lists accessibility guidelines and the impairments they accommodate. The accessibility guidelines accommodate shortened attention span, memory issues, and lack of focus, among other challenges, for cancer survivors with chemo brain; difficulty seeing content for cancer survivors with visual impairments; and difficulty typing for cancer survivors with physical impairments.

Some accessibility guidelines accommodate more than one impairment. For example, voice input is important for cancer survivors with either chemo brain or dexterity impairments – the former makes typing harder cognitively, while the latter makes typing harder physically.

Some accessibility guidelines expressed by the participants, such as high contrast between text and background and zooming function, have been outlined in WCAG 2.2 checklist[1] (Contrast and Resize Text, respectively).

The accessibility guidelines to accommodate chemo brain are spelled out in WCAG to a lesser extent, though many align with accessibility guidelines for neurodiverse users proposed by Kletenik et al., e.g., allowing users to customize font size and shape, contrast, and spacing; and clearly explaining instructions and consistent navigation [183].

In addition, I found several design features that are valuable for cancer survivors' well-being.

1. *Games or gamification* are favored by cancer survivors to sharpen minds and relieve fatigue.
2. Features and offline/online communities should be created to support *cancer advocacy,* an integral mission for many cancer survivors.
3. *Socialization* is important for cancer survivors to share information and exchange support.
4. Cancer survivors need features such as goal-setting, tracking, reminders, and to-do lists to support *healthy lifestyles* regarding exercise, sleep, and nutrition.
5. Cancer survivors have *information needs* regarding health, whereas medical professionals should address cancer-related questions.

Software designers can directly use these accessibility guidelines and design features as the first step toward accessible and beneficial design for cancer survivors. Conducting co-design workshops with cancer survivors with various impairments is the ideal way to design accessible and beneficial apps for this population [160]. Due to time, resource, and expertise constraints, software designers may consider the accessibility guidelines and design features as well as general accessibility guidelines such as WCAG to meet basic accessibility requirements.

3.5.4 Implications for Design Research

Several implications for design research toward more accessible software emerge from this empirical study. First, researchers should spotlight the lived experiences of people with a unique disability (such as chemo

[1] https://www.w3.org/WAI/WCAG22/quickref/

Table 3.3: Accessibility guidelines for cancer survivors.

Accessibility guidelines	**Impairment accommodated**
Bulleted content	Chemo brain
Highlight key information	Chemo brain
More visuals (pictures/icons), less text	Chemo brain
Simplified UI design	Chemo brain
Clear and simple instructions	Chemo brain
Avoid too many options	Chemo brain
Easy download and account opening	Chemo brain
Voice output	Chemo brain
Voice input	Chemo brain, Dexterity impairments/Neuropathy
Large font	Chemo brain, Visual impairments
Compatible with computers for larger screens	Visual impairments
High contrast between text and background	Visual impairments
Zooming function	Visual impairments
Gesture input	Dexterity impairments/Neuropathy

brain) or a unique combination of disabilities. They tend to have software experiences and challenges that are specific to them, which is worth dedicated interrogation. It is not a good practice to "group" them with other populations when studying their software or technology practices. In this chapter, cancer survivors were found to have unique impairments and software experiences, which have not been well-studied by HCI, CSCW, and computer accessibility researchers.

Second, extracting actionable and concrete accessibility guidelines and design features was viable by digging into the lived software experiences of people with disabilities. This goal was achieved with a comprehensive formative study combining a survey study, in-depth semi-structured interviews, and a diary study.

Third, although I uncovered software challenges faced by cancer survivors with impairments through in-depth, open-ended questions and data triangulation, it should be acknowledged that the sample size is relatively small (n=46 for the survey study, n=20 for the interview study, and n=10 for the diary study). Future research may consider larger-scale surveys to confirm the generalizability of the results.

Fourth, there is currently very limited research in understanding cancer survivors' software experiences. I targeted cancer survivors with impairments in the recruitment. Future research should understand the software experience of cancer survivors in general.

Finally, few researchers have tried to understand the impact of design research in HCI/CSCW. The best way to convey accessible design principles, or more broadly, ethical design principles, to software practitioners is unknown. In particular, The effectiveness and usability of the synthesized accessibility guidelines and design features in this chapter need further interrogation. Later, I will seek feedback from cancer app designers, survivors, oncologists, and researchers to validate the practicality of the guidelines and features, which is outside the scope of the current study.

3.6 Conclusion

Through a survey, semi-structured interview, and a diary study, I uncovered various software challenges faced by cancer survivors with impairments. I further synthesized accessibility guidelines and design features for software designers to make products more accessible and beneficial for this population, which was overlooked in the existing computer accessibility and CSCW literature. With this research, I encourage more researchers and practitioners to consider the accessibility needs of cancer survivors with impairments when designing software.

One notable limitation of the design approach to software accessibility is its voluntary nature. If software practitioners fail to receive the messages or principles from academics, or if they are not equipped with the knowledge, awareness, and skills to solve accessibility issues, the software will remain inaccessible. Therefore, it is important to educate software practitioners and next-generation software practitioners who are college students and K-12 students, in software accessibility. Educating high school students on software accessibility will be the main scope of the next chapter.

4

Education for Accessibility: Teaching Accessibility to High School Students Through Games

Accessibility tends to be treated as an afterthought in software design practices. A part of the reason is that software accessibility has not been mandated or commonly adopted as a topic in the computing curriculum.

Through my efforts in expanding accessibility education in a wide range of educational contexts, including K-12 classrooms and undergraduate-level courses, I have argued the importance of educational approaches to software accessibility in the Information Sciences and Computer Accessibility research communities.

Educational approaches to software accessibility have several advantages over design interventions. First, many students, either high schoolers or undergraduate students, will enter the IT workforce in the future, given the booming of IT, particularly AI and Generative AI, in recent years. Equipping them with knowledge, awareness, and concrete skills regarding software accessibility will help with their professional practices as software engineers, product managers, UX/UI designers, or administrative roles. This can potentially bridge the gap where software practitioners have difficulty leveraging advancements in academia, as future practitioners are now directly educated on the topic of accessibility and are now interacting with researchers in education outreaches.

Second, students who do not intend to enter the IT workforce can still benefit from software accessibility education. They are better poised to help family members, friends, and strangers with disabilities use software. The accessibility design principles they learned will benefit themselves and the people around them in life and workplaces — as inclusive design researchers argued, accessible designs will eventually benefit everyone [186].

In this chapter, I will introduce the exploration of game-based software accessibility education for high schoolers.

4.1 Introduction

Information and communications technologies (ICTs) are often designed without explicitly considering accessibility, effectively creating barriers to use for people with disabilities. Accessibility education is important to equip future software designers and developers with awareness and knowledge of accessibility and empathy for disabilities. It has been widely covered in both Computer Science (CS) curricula [18], [19] and non-CS curricula [22] in college.

In particular, game-based approaches have been effective in teaching accessibility. Kletenik and Adler developed games to simulate different types of disabilities, the empathy-inducing and educational effects of which were demonstrated through testing with undergraduate CS majors and non-CS majors [25], [123], [187].

Compared to the rich literature on accessibility education in college, only a handful of literature discusses accessibility education for K-12 students. Kelly and El-Glaly taught high schoolers about a web content accessibility guideline, Reflow, through a hands-on online module [23]. Adler and Kletenik introduced accessibility games in a university-level web development course taken by K-12 teachers who taught or planned to teach CS courses [188]. The teachers thought the games would benefit elementary, middle, and high school students.

In contrast to accessibility education, the literature on AI ethics and cybersecurity education for this younger audience is rich, emphasizing topics taught [189], methods used [190], and tools and games developed [106]. I argue that it is similarly important to introduce the topic of accessibility to pre-college students, given the prevalence of software in the modern world.

There are two reasons why incorporating accessibility into K-12 education is important. Firstly, students tend to consider accessibility as an afterthought instead of tightly integrating it within the design and development cycle [120], [191], [192]. This is compounded by the fact that students' first exposure to accessibility usually comes many years after they have learned to program and after they have become accustomed to inaccessible technology design. Accessibility education in higher education thus requires undoing already-established bad software development habits.

Secondly, research suggests that no single intervention results in long-lasting changes in student attitudes towards accessibility [120], [193]. Rather, accessibility needs to be included throughout the educational trajectory, as early and as frequently as possible so that it is viewed not as a special topic but as a natural part of software development.

For both reasons, I see the inclusion of accessibility in K-12 CS education as the necessary next step in training software designers and developers in accessible design.

To equip high school students with knowledge, awareness, and empathy about software accessibility, I used games in the accessibility education literature [25], [27], [123] to teach accessibility in CS and non-CS classes in a midwestern public high school. By delivering game-based, empathy-driven accessibility education to high school students, and interviewing CS teachers, I aspired to bridge the research gap in educating pre-college students about accessibility in an engaging way and probe the possibility of incorporating accessibility education into the high school curriculum.

Specifically, I answered the following two research questions (RQs):

- How do students' empathy, knowledge, and awareness regarding accessibility change after playing the games?
- How is and how should software accessibility be taught in high school?

The contributions of this empirical study are two-fold. First, I expanded engaged scholarship in accessible computing to high school education and innovatively used games to teach accessibility to high school students. I show the preliminary potential of equipping next-generation software designers and developers with knowledge, awareness, and empathy regarding accessibility as early as high school. Second, I discussed with teachers how to best integrate computer accessibility into the current high school curriculum. Therefore, this study informs future teaching practices around computer accessibility.

4.2 Related Work

In Section 2.3.2, I have reflected on a large body of literature on accessibility education in universities. Below, I will discuss accessibility education outside of universities, which is more relevant to this chapter, and the simulation games I leveraged for the teaching.

4.2.1 Accessibility Education outside Universities

Literature has been abundant on accessibility education in higher education, discussing learning objectives [111], short-term [119] and long-term [120] outcomes, traditional teaching methods [114], and game-based teaching [25], [123], [187]. However, since accessibility education has long been confined to universities, the technology sector's accessibility skills gap is persisting, highlighting "the need for academia and the workplace to learn from each other and adapt together to generate pedagogies that will better prepare learners for accessibility practice" [194].

One approach to enhancing practitioners' inclusive thinking and accessibility knowledge is to cultivate these values early. Kletenik and Adler argued that "accessibility should be taught as early as possible to CS-majors and non-majors" to enable them "to build awareness of the need to design accessibly and to increase empathy for people with disabilities" [25]. K-12 teachers were receptive to including accessibility topics in their classrooms [188].

So far, few studies have focused on teaching accessibility in high school education or earlier. Kelly & El-Glaly designed an online module combining an interactive lecture and quizzes to demonstrate Reflow, one of the web content accessibility guidelines, to high school students, successfully increasing students' awareness of disabilities and knowledge of accessibility [23]. Accessibility education through games [27] or gamification [26] is naturally more approachable and engaging to K-12 students, which has not been investigated to the best of my knowledge.

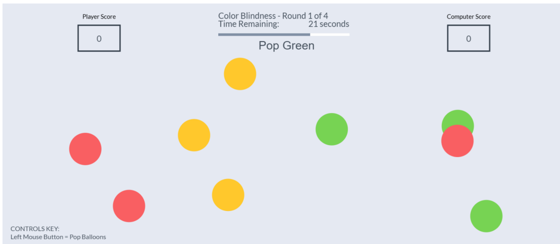
I bridge the research gap through the current study, teaching high school students about accessibility through simulation games.

4.2.2 Disability Simulation Games

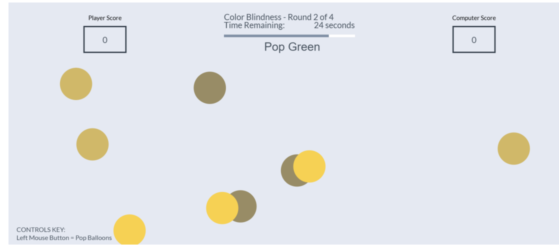
Kletenik & Adler developed a set of disability simulation games to teach computer accessibility in an engaging manner [25], [123], [187]. These simulation games cover a wide range of disabilities, including Color Blindness, Auditory Impairment, Physical Impairment, Blindness, Low Vision, and Dyslexia.

Each game has four rounds. In the first round, users are instructed to select and pop balls of specific colors (or words in the Dyslexia Game) without a disability condition.

In the second round, users play the game with conditions that simulate the software challenges faced by people with disabilities (i.e., inability to tell colors in the Color Blindness Game, unable to hear colors to pop in the Auditory Impairment Game, having a shaky mouse in the Physical Impairment Game, unable to see balls in the Blindness Game, playing with blurry vision in the Low Vision Game, and seeing words with the phonemes remapped on the balls in the Dyslexia Game).

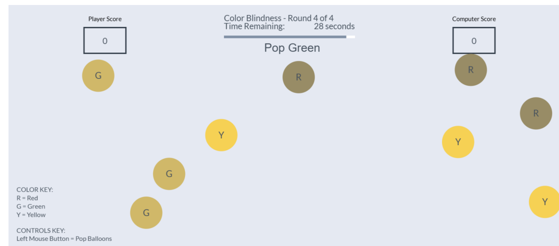


(a) Round 1 of the Dyslexia Game.



(b) Round 2 of the Dyslexia Game.

(c) Round 3 of the Dyslexia Game.



(d) Round 4 of the Dyslexia Game.

Figure 4.1: Four rounds of the Color Blindness Game [25].

In the third round, users play the game without a disability but with enhanced accessibility features (i.e., labeling balls with letters representing respective colors in the Color Blindness Game, additional text instructions in the Auditory Impairment Game, an additional keyboard input method in the Physical Impairment Game, additional audio instructions in the Blindness Game, a zooming bar in the Low Vision Game, and accompanying a word with a corresponding picture in the Dyslexia Game).

In the fourth round, users play the game with conditions faced by people with disability and with enhanced accessibility features.

The four rounds of the Color Blindness Game are demonstrated in Figure 4.1 as an example.

Guidelines to make software more accessible are summarized at the end of each game. In the context of color blindness, for example, guidelines include: Don't use color alone for identification; Use sufficient contrast to make the text stand out from the background; Underline links and don't rely only on the color to indicate a link; Use descriptive text or alternate text to indicate color if it is important (for example, in color choices for clothing).

4.3 Methodology

In this education outreach, I taught a group of high school students about software accessibility through games, and interviewed Computer Science teachers about their experience and perception of teaching accessibility to students. This way, I was able to gauge perceptions from two key stakeholders in high school education regarding game-based teaching of accessibility. Below, I introduce the teaching activities, teacher interviews, the research team, and the data analysis process.

4.3.1 Teaching Activities

I taught students about accessibility in a selective enrollment midwestern public high school, including students from 8th graders (pre-freshmen) to 12th graders. Gamified approaches were found helpful in engaging Computer Science students in learning activities [195]. Game-based learning has been leveraged to meet the developmental and academic needs of students from middle school through higher education [196]. Therefore, I deemed game-based learning a more effective way to teach high school students about software accessibility than traditional pedagogies such as lectures and discussions.

Three CS courses I used to teach accessibility included Computer Literacy 1, Computer Literacy 2, and Digital Media Productions. Computer Literacy 1 is a mandatory introduction course for 8th graders to learn concepts such as computer use, media literacy, AI, library service, HTML/CSS, and Python. Computer Literacy 2 is a mandatory course for freshmen to implement projects such as games and drones in teams. Digital Media Production is an elective course. I also utilized Coding Club (a lunchtime student activity), a Study Hall session, and two non-CS courses, i.e., Theater Class and Stage Craft.

The teacher informed students and their parents about this IRB-approved teaching activity. The parents were told that the activity would help enhance their children's knowledge and awareness of accessibility. They were also told that the activity was completely voluntary and not a part of the regular curriculum. Therefore, the parents were allowed to opt their children out of the activity. In the end, a total of 93 students participated in the teaching activities and completed the study. Demographic information of the participating students is shown in Table 4.1.

Grade		**Gender**		**Race**		**Class**	
8th Grade	35	Female	39	American Indian or Alaska Native	4	Coding Club	3
9th Grade	25	Male	48	Asian	25	Computer Literacy 1	35
10th Grade	14	Other	4	Black or African American	5	Computer Literacy 2	26
11th Grade	9	Prefer not to say	2	Hispanic or Latino	7	Digital Media Productions	7
12th Grade	10			Prefer not to say	1	Stage Craft	6
				Two or more races	16	Study Hall	8
				White	35	Theatre Class	8

Table 4.1: Demographic information of participating high school students (N=93).

Student Game Playing and Classroom Discussion

In each class, the research team first introduced themselves and the intention to understand how students learn about digital accessibility. The students were told about the voluntary nature of this activity and that the research team would not share anything that they wrote or said with their teachers, principals, or the school. The students were then introduced to the six simulation games developed by Kletenik & Adler [25], [123], [187]. Students were prompted to play three of the six games.

Upon consent, students filled in a survey modified from Kletenik & Adler [25] The survey started by asking students' demographic information, including grades in school, gender, and race, and which class they were in during the study session.

Then, the survey asked about the students' CS/programming knowledge and experience, including whether they have created coding projects, how the projects looked like, what programming languages they used to create the projects, and the intended audience of the projects.

Students' accessibility considerations when developing software were gauged through two scenario questions, imagining they were either coding a game for people to play or creating a voting booth for people to use in an election. The students were asked what sorts of people they should ask to try the products out if they wanted to make sure everyone could use the products.

Then, several 5-point Likert-style questions were asked to understand students' awareness and empathy

1. Please rate your level of agreement with the following statements: (5-point Likert scale – Strongly Disagree to Strongly Agree)
    a. Many current software applications are difficult for people with disabilities to use.
    b. People with disabilities are interested in new technology.
    c. A person with disabilities should not have to rely on someone around who can help.
    d. Software developers should provide technology suitable for use by people with disabilities.
    e. People with disabilities are likely to face challenges when interacting with many applications.
    f. If I design applications, I will try to keep in mind people with disabilities.
2. For example: If I design applications, I will try ...
3. Suppose you were coding a game and wanted to make sure that everyone could play it. Which sorts of people should you ask to try it out?
4. Suppose you were creating a voting booth for people to use in an election, and wanted to be sure that everyone could use it. Which sorts of people should you ask to try it out?

Figure 4.2: Survey given before and after the games.

regarding software accessibility. The Likert-scale questions included four attitude questions (a-d), asking about students' understanding of the difficulty people with disabilities face when using software and technology, and two challenge questions (e-f), asking about the challenges people with disabilities may face when using applications [25]. See the full list of Likert-scale questions in Figure 4.2.

Following the Likert-scale questions, an open-ended question was asked about design features to include when designing apps for people with disabilities (Question 2 in Figure 4.2). The question was used to interpret students' knowledge of software accessibility.

After finishing the three games they chose, students were directed to the exit survey, which asked the same set of questions as in the pre-study survey, with extra open-ended questions eliciting feedback and suggestions to improve the games. The whole survey is attached in Section B.1.

The game-playing process took roughly 25 minutes in each class, and almost all students could finish three games and two surveys within this timeframe.

In the last ten minutes of each class, except for Coding Club and Theater Class, which had shorter time due to an event conflict, a classroom discussion was facilitated with several question prompts.

First, students were asked whether they had previously learned or thought about accessibility issues in computer software. This question was designed to understand students' prior teaching/learning of accessibility. The responses were intended to be compared with teachers' descriptions of software accessibility education to reach a holistic view.

Then, students were asked about their current thoughts on accessibility challenges in software. They were expected to talk about their awareness of accessibility issues in software, their understanding of software accessibility challenges faced by people with disabilities, and so on. This question was to understand students' change in terms of awareness and empathy regarding accessibility after playing the games.

Next, students were asked about the strategies they had learned to improve digital accessibility. In particular, they were asked how software designers and developers could make applications so people with disabilities can use them. This question was designed to interpret students' knowledge gain regarding concrete design strategies after playing the games.

Lastly, the students were asked about their perceptions of the teaching activity and the simulation games in terms of clarity of instructions, any confusion, and areas for improvement. They were further asked how they would design the games and to provide additional comments.

The study session conducted with freshmen in Computer Literacy 2 had the most heated discussion and the richest student reactions while they played the games. The Computer Literacy 1 class with 8th graders was the quietest during game playing, possibly because the students were the youngest.

Two researchers, including myself, took notes of student reactions and discussions during game playing and students' responses to the discussion questions at the end. Noted were compared after each session to ensure accuracy. Another researcher was designated to lead the discussions. No recordings were obtained to protect student privacy.

4.3.2 Teacher Interviews

To understand teachers' perspectives on accessibility education and obtain a more holistic understanding, I interviewed CS-related faculty in the high school.

The recruitment process was relatively smooth since the high school teachers were enthusiastic about talking about CS pedagogy and emerging topics in CS education. There were two full-time CS teachers in the high school. One of them was the research team's point of contact, who introduced us to other faculty members. There was one part-time CS teacher who was simultaneously a PhD student focusing on engineering pedagogy at a local university. Further, there was a librarian who taught programming in this high school. She attended all the teaching activity sessions in CS courses through the teaching activities, Three of the interviewed faculty members were male, and one was female.

The 45-minute interviews aimed to understand the teachers' perspectives on accessibility education, as well as CS education in general, in order to contextualize accessibility education in a realistic CS curriculum.

I started by asking about the courses and grades the CS teachers taught. This was to have a basic understanding of the status of CS education in this high school, which turned out to be a selective-admission high school with advanced CS courses, and to build rapport with teachers. They all willingly shared their experiences in teaching CS courses.

Instead of diving into accessibility education immediately, I asked if and how the CS teachers covered computing and social/ethical concepts in their classes. Accessibility is a part of the ethical discussion and has several commonalities with other ethical topics, such as cybersecurity and AI bias. First, these ethical topics tend to be treated as afterthoughts by software practitioners without dedicated objectives from the corporations. Second, technological ethics have been incorporated into the CS or engineering curriculum, but not for a very long time, and are not mandated by universities or education bureaus. Third, ethical issues in technology similarly have a significant impact on vulnerable populations and require empathy from the general public to fully understand their lived experiences. The utmost motivation for asking this question, however, was to see whether the high school CS teachers left out accessibility in the ethics discussion.

Next, I asked if and how accessibility education was integrated into the CS curriculum. I specifically probed aspects such as learning objectives, barriers to teaching accessibility, and teachers' own knowledge level in accessibility. Teachers' knowledge level in accessibility is, in theory, a part of the barriers to teaching accessibility. The question was singled out because teachers may not acknowledge their lack of knowledge on a particular CS topic as a barrier.

To let the teachers share in-depth insights and concrete examples, throughout the interviews, I used multiple prompts to nudge them to talk more. For example, I would ask, "Do you teach any computing concepts in your course(s)? In what way? Could you give me an example?" All the teachers turned out to be relatively talkative and interested in expanding their curriculum with emerging topics such as accessibility.

The full interview script is attached in Section B.3 in Appendix B.

The interviews were recorded upon the consent of the teachers. The recorded videos were later transcribed using Otter.ai, an automated AI-based transcription tool. I manually corrected errors in the transcripts.

4.3.3 Data Analysis

Triangulation is a methodological approach to enhance validity, credibility, and reliability by integrating multiple perspectives, data sources, or methods [197]. It allows researchers to cross-check findings and reduce biases.

Through data triangulation, i.e., using different sources of data; method triangulation, i.e., using different methods of data collection or analysis; and investigator triangulation, i.e., using different researchers, I managed to corroborate findings and compensate for weaknesses in the data, thus increasing the validity and reliability of the results.

Below, I introduce quantitative and qualitative analysis methods, following the introduction of the research team as a context.

Research Team

The research team was comprised of five researchers. I was the lead researcher for this study, responsible for study design, data collection (both qualitative and quantitative), data analysis, and the reporting of the research. This was one of my first experiences studying the topic of software accessibility education. The second author, then a master's student, assisted in the data collection and analysis process. She served as the second coder in the qualitative analysis and validated my survey analysis. The third author, then a junior PhD student, assisted in the data collection and analysis process. She served as the second coder for annotating students' knowledge in the game, voting booth, and design considertation questions. The fourth and fifth/last authors were senior researchers with considerable research experience in accessibility education. I had multiple discussions with them regarding research design, analysis, and writing throughout the research process. The fifth/last author validated my survey analysis and revised the manuscript submitted and accepted to ASIS&T.

Quantitative Analysis

I employed statistical methods to understand how the disability modes affected students' performance and emotions and how the games improved student empathy and awareness regarding accessibility. I also compared the results to those in Kletenik & Adler [25] to see if there were differences in educational effects between high school students and college students.

I analyzed students' emotions and performance in different rounds of the games. For each game round, the percentage of winning players and those who selected positive emotions ("relaxing," "fun," "enjoyable," "educational" as opposed to "boring," "frustrating," "difficult," and "confusing") in the question after playing each round within the game were calculated. For each accessibility game, a Cochran's Q test was conducted to see if statistical significance existed among rounds regarding winning and positive emotion percentages. For the statistically significant tests, post-hoc pairwise McNemar tests were conducted to identify significant round comparisons, employing the Bonferroni p-adjustment. Whether Round 2 (disability mode) led to degraded performance and negative emotions and whether Round 4 (accessibility accommodations) improved performance and emotions were specifically examined.

To assess student empathy and intention to design accessibly, a two-tailed Wilcoxon signed-rank test with continuity correction was used to compare Likert-scale question responses in pre- and post-surveys.

For open-ended responses to the questions regarding population considerations for game design, population considerations for voting booth design, and feature considerations for app design, a qualitative content analysis approach [198] was first followed to make them suitable for quantitative analysis. Two researchers coded the responses into either 0 or 1, where 0 indicated no awareness of accessibility, and 1 indicated some awareness of accessibility. For the game and voting booth questions, if students mentioned specific or general disabilities or impairments, the responses were rated as 1; for the app design question, if students mentioned specific design features such as larger font, the responses were rated as 1. I calculated Krippendorff's Alpha to assess inter-coder reliability between two independent coders and reached Krippendorff's Alpha of 0.792, 1.000, 0.922, 1.000, 0.925, and 0.978 for the pre-game, pre-booth, pre-design, post-game, post-booth, and post-design questions, respectively, averaging 0.936. This indicates a high degree of agreement between the two coders [198]. McNemar analysis was then employed to compare the pre- and post-survey responses with continuity correction.

To see if there were differences in students' accessibility perceptions between recreational (game) and duty-bound (voting booth) design, I used McNemar tests to compare responses to the game and voting booth questions. The analysis was carried out for both the pre-game survey and the post-game survey.

Qualitative Analysis

A collaborative thematic analysis [185] was adopted for the qualitative analysis of the data. Two researchers, including myself, independently conducted open coding of the open-ended survey responses, in-game comments about emotions, observation notes taken during the classes, and teacher interview transcripts. The research team regularly discussed to reach a consensus on emerging themes.

Codes and different levels of themes emerged as the analysis proceeded. For example, in analyzing teacher interviews, emerging themes included (1) social/ethical topics covered in CS classes, including cybersecurity, AI's social impact, and information literacy; and (2) accessibility education in high school, including learning goals, challenges encountered, and teachers' knowledge of accessibility.

XMind, a mind-mapping tool, was used to organize different levels of themes and quotes into a hierarchical structure. A subset of the mindmap on accessibility education for teacher interviews is illustrated in Figure 4.3.

Anonymized quotes will be used to illustrate the findings in this chapter.

Inter-coder reliability was not calculated following best practices. Because of the study's exploratory nature and the grounded coding process, which aimed to use coding as a process rather than as a product, I was interested in models and association, not quantification [199].

4.4 Findings

According to the open-ended response in the pre-survey which asked if students had created coding projects and what they looked like, 58 out of 93 students who participated in the study had learned programming language(s) or created apps/websites. This confirmed the importance and relevance of teaching software accessibility to high school students.

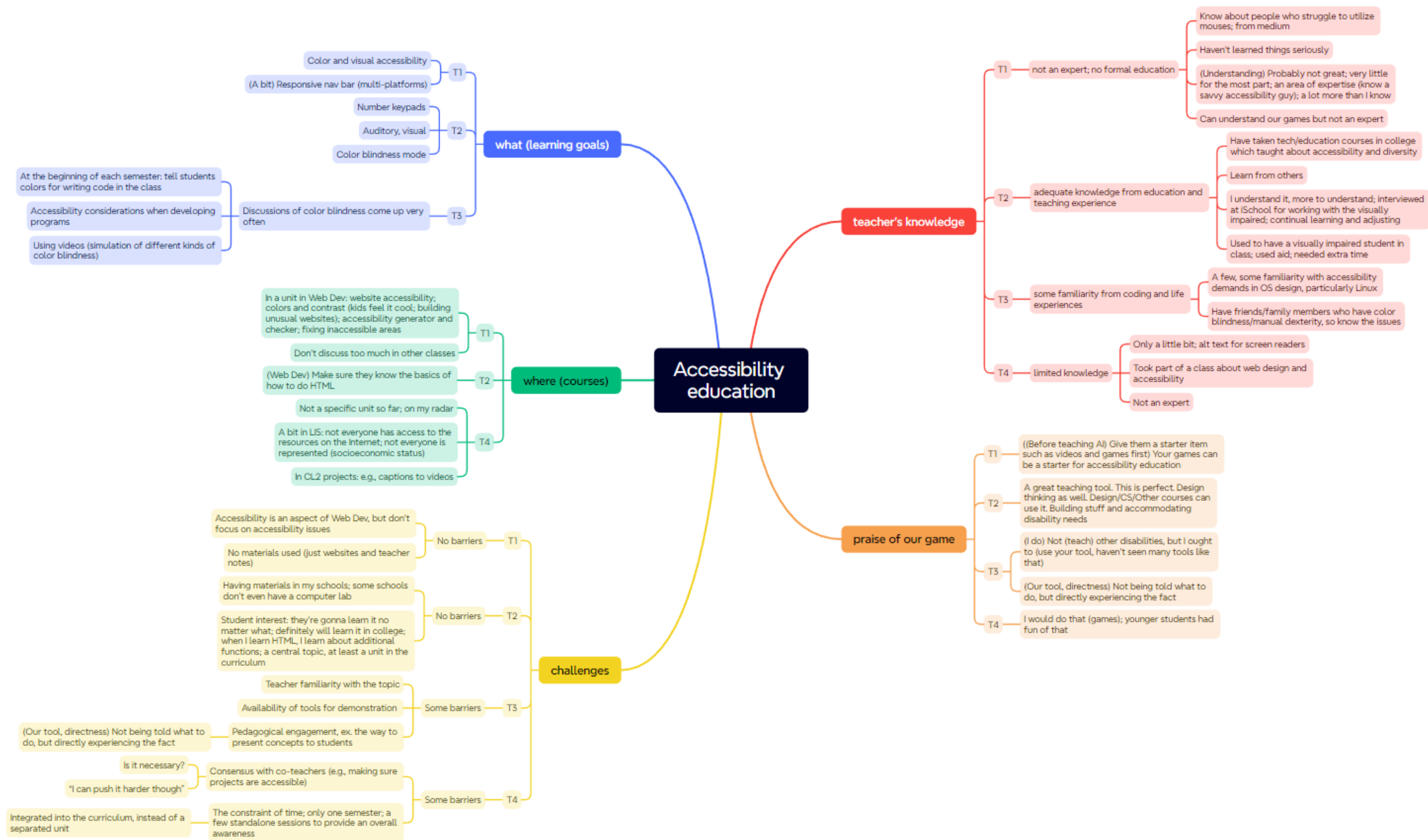


Figure 4.3: Mind map on accessibility education for teacher interviews.

4.4.1 Students' Perspectives

Game Performance and Emotions

Cochran's Q test revealed a significant difference in the proportions of winning players across four rounds in the Auditory (Q(3) = 57.7, $p < .0001$), Color blindness (Q(3) = 37.6, $p < .0001$), Visual (Q(3) = 88.8, $p < .0001$), Low vision (Q(3) = 76.6, $p < .0001$), and Dyslexia (Q(3) = 96.1, $p < .0001$) games. Further, Pairwise McNemar tests showed that players faced significantly more difficulty playing Round 2 of these games, with lower proportions of winning players in this round than all other rounds ($p < .05$). No significant difference is revealed in different rounds of the physical game (Q(3) = 4, p = 0.261), echoing results in Kletenik & Adler [25], since the disability mode with a mouse is harder, and more frustrating, but not impossible.

Accessibility features, if implemented appropriately, helped students perform better in disability modes. Notably, students' performance in Round 4 was comparable to Round 1 in the Auditory, Color Blindness, Physical, and Dyslexia games. During game-playing, some students expressed that they did not like Round 4 of the Blindness game, which was still challenging for them without being able to see anything. In the classroom discussion, one student commented, "Still impossible even in Round 4 of the blindness game."

The rounds simulating disability made students anxious and frustrated. During game playing, the students were frustrated by the challenges faced by people with disabilities. When playing Round 1 (normal mode) of the games, they verbally commented, "Easy game." "See, five [points]." When playing Round 2 (disability mode) of the games, they were surprised by the level of difficulty people with disabilities had to face when using software, "It's so hard. What is that?" "Why is it like that?" "Oh dear, that's..." "It's frustrating!" They also reacted to different disability modes, e.g., "(Low vision) I'm tired." "(Physical) Shaky mouse? What? I'm so shaking." "(Blindness) I can't see anything [sigh]." "(Color blindness) I got negative scores! Click yellow? It's a bit challenging."

Survey analysis revealed significant differences among rounds in terms of emotions for all six games (Q(3) = 36.0, $p < .0001$ for Auditory, Q(3) = 60.0, $p < .0001$ for Color Blindness, Q(3) = 25.6, $p < .0001$ for Physical, Q(3) = 57.8, $p < .0001$ for Visual, Q(3) = 59.3, $p < .0001$ for Low Vision, and Q(3) = 107. 0, $p < .0001$ for Dyslexia). For all six games, the percentage of positive emotions in Round 2 is significantly lower than in other rounds, as indicated by Pairwise McNemar tests ($p < .05$). Students' open-ended comments during game-playing explained these negative emotions: "(Low Vision) It was impossible to see what color I was supposed to click." "(Auditory) was literally impossible." "(Color Blindness) I felt my anxiety rise." "(Dyslexia) It was very stressful and confusing. It gave me a headache." "(Visual) I was just clicking randomly. It felt like I had no control over anything." "(Physical) I did not realize how hard it would be to play with this disability!" Except for the Blindness game, where Round 4 showed significantly fewer positive emotions than Round 1 ($p < .01$), and the Auditory game, where Round 4 showed significantly more positive emotions than Round 1 ($p < .05$), emotions in Round 4 of all other games were comparable to Round 1, without significant difference.

Student Empathy and Awareness of Design Accessibility

The potential of disability simulation games to cultivate high school students' empathy for disabilities and their awareness and knowledge of accessibility was explored. Overall, after playing games, the students showed increased knowledge, awareness, and empathy for disability and accessible design.

Statistically significant differences between the pre-game and post-game Likert-scale question responses were observed: pre-mean and median of the attitude question responses were 3.91 and 3.75, respectively;

post-mean and median increased to 4.20 and 4.25, respectively ($p < .0001$, effect size = .65). Similarly, pre-mean and median of the challenge question responses were 4.07 and 4.00, respectively; post-mean and median increased to 4.41 and 4.50, respectively ($p < .0001$, effect size = .59). Based on Cohen's classification of effect size, where 0.1 to 0.3 represents a small effect, 0.3 to 0.5 indicates a medium effect, and more than 0.5 suggests a large effect [200], statistically significant changes coupled with a large effect size regarding attitude questions and challenge questions according to Cohen's d were observed. These findings suggest a substantive improvement in high school students' empathy for disabilities and their increased intention to design with a focus on accommodating the needs of people with disabilities, echoing Kletenik & Adler [25].

After coding the game, voting booth, and app design responses into 0 or 1, indicating whether students explicitly considered people with disabilities or expressed concrete accessibility features, I compared pre- and post-responses utilizing McNemar analysis. In the game question, responses mentioning people with disabilities increased from 35 (37.6%) in the pre-survey to 83 (89.2%) in the post-survey (χ^2 (1, N = 93) = 41.49, $p < .0001$, effect size = .46). Similarly, in the voting booth question, responses including people with disabilities rose from 48 (51.6%) to 77 (82.8%) (χ^2 (1, N = 93) = 23.76, $p < .0001$, effect size = .44). In the app design question, there was an increase from 25 (26.9%) to 39 (41.9%) (χ^2 (1, N = 93) = 5.63, $p < .05$, effect size = .23) in responses mentioning people with disabilities. According to Cohen's g, a large effect size was observed in the game question and the voting booth question, whereas a medium effect size was observed in the app design question. Before playing the games, many students would only ask their family, friends, or classmates to try out designs they created. After game-playing, they were more inclined to include people with various disabilities, such as blindness and dyslexia, to test the designs. A few more students could indicate specific design features to accommodate accessibility challenges, which were taught in the games used, e.g., "Make sure to put the name of the colors over them so people with colorblindness can see them."

During the classroom discussion, several students expressed their awareness regarding accessible design after playing the games, e.g.,

> *"I never thought about it [accessibility]. I often just overlook it. Now I think it's necessary to take it into account. It's not only for people with disabilities. It benefits everyone."*

> *"Previously I didn't understand what the captions were for on the websites. I thought it was not necessary. After playing the games, I find it important to make them more accessible for people with disabilities."*

They also learned practical strategies to make software more accessible. Some of them shared their learned strategies to make software more accessible. For instance, they understood developers should ask people with disabilities for feedback/testing, "They [Developers] can consult people who have those disabilities"; and should play the simulation games to understand accessibility challenges, "The developers should play these games so they know the challenges". They also learned design features that could enhance accessibility, including different options for input/output, "Nice to have other options in addition to mice"; visual assistance for dyslexia, "Shouldn't only rely on words for dyslexia"; zooming affordances, "Zooming can be implemented easily but helps"; and personalized interface, "Personalization is really important. Dark mode is one. Mode to disable animations. Turn on the audio. A lot of games have a color-blind mode."

When asked how they would have designed the simulation games, the students emphasized the simulation of disability experience, e.g., "Present difficulty brought by different games and different disabilities"; connection to daily software use to inspire empathy, "Connecting it with common things is interesting, like navigating a website. People don't realize how difficult it is to process information. Helpful for empathy"; and integrating perspectives from people with disabilities, "Include personal angles from people with disabilities." Several students indicated they would take a similar empathy-driven approach to ours,

> *"Understand who you're trying to educate. Go about similar ways you guys are demonstrating the difficulty faced by people with disabilities."*

Accessibility Perception in Different Design Scenarios

Kletenik & Adler [25] found that students were more inclined to consider users with disabilities during the design of voting booths than games since they may subconsciously perceive individuals with disabilities as more actively engaged in voting activities than game participation. Similarly, it was found that 51.6% of participants included people with disabilities in the voting booth question in the pre-survey, compared to 37.6% in the game design question – the difference is significant (χ^2 (1, N = 93) = 7.58, $p < .01$, effect size = .34) with a large effect size based on Cohen's g. After engaging with the accessibility games, this distinction vanished: 82.8% of the students indicated accessibility considerations in the voting question, and 89.2% in the game question (p = 0.332).

Feedback and Suggestions on Games

Open-ended responses at the end of the post-game survey were analyzed to gauge the students' feedback and suggestions regarding the education activities. Most students gave positive feedback about the games, describing them as thought-provoking, fun, educational, informational, and easy to digest. One particular advantage of the games was that they could simulate software challenges for people with disabilities and let students see what software use is like for people with disabilities. This way, students were able to learn about disability challenges when software is inaccessible through the games, "It was an educational experience to help me see how hard it is for people with disabilities to use websites"; and learn how to make technologies more accessible, "I enjoyed learning how accommodating to people with disabilities makes technology more accessible and enjoyable." In terms of suggestions, some students wished the games were made more entertaining and complex, e.g., having a variety of games instead of being limited to the ball-popping game. The robot voice was annoying to some.

During the classroom discussion, the students similarly had an overall good experience with the games. They agreed that the instructions were understandable, nothing was confusing, and thought the games would "work well in K-12 contexts." They "liked the way it shows different types of disabilities." Some students expressed interest in playing the remaining three games other than the three they had played.

They also provided suggestions for improving the games. For example, several students mentioned a bug in Round 4 of the Blindness game and other games that used audio features, where two colors are announced simultaneously in audio. According to other students, having audio for instructions, having more visuals such as pictures for the arrow keys, demonstrating how to play the game in the first round, and having games in other languages could make the games more understandable and accessible for younger kids in different countries.

A Lack of Accessibility Education in High School

According to most of the students in the classroom discussion, accessibility education was not included in the current CS curriculum in high school. They shook their heads when asked if they had previously learned or thought about accessibility issues in computer software. Only one student mentioned that a brief discussion about accessibility occurred in a tech class in her middle school, and another student mentioned the teaching of accessibility principles in a university-level Psychology class. As a result, a lack of awareness of accessible designs was commonly expressed,

> *"I tended to underestimate how difficult it would be."*

> *"I never thought about putting text in the color-blindness game."*

One student nevertheless implemented accessibility features in practice when she posted on social media,

> *"I write a lot for the school's social media account. Different levels of visual impairments make social media difficult to use in different ways. I'd always add captions to images."*

4.4.2 Teachers' Perspectives

Social and Ethical Topics Covered

CS courses covered several social and ethical topics, such as cybersecurity, AI's social impact, copyright, and information literacy. All four teachers covered cybersecurity in their classes. For example, T3 taught about responsible computing in daily use, given the prevalence of data breaches. T4 taught about malware and phishing broadly, not limited to financial risks, but also about safety and sexual risks. She tended to teach these concepts in a sociotechnical manner, often without coding.

Two teachers taught about copyright. For instance, T3 covered a wider range of topics regarding copyright, including responsible use of content, fair use, licenses for code, and authorship, which, in his eyes, are "a part of the CS culture."

Information literacy was a large part of T4's classes. In Computer Literacy 1, she taught about library and information, navigation, and information credibility assessment.

AI's impact on society was taught by T1. He used videos from the Internet to teach different versions of AI, its history, its impact on life, and more recent advancements like ChatGPT.

All teachers thought social and ethical issues were important topics to cover in CS classes as a part of "socially appropriate training" (T1). T4 was the co-teacher of CL1 and CL2 along with T1 and T3 and estimated a ratio of 60% vs. 40% regarding the time devoted to technical vs. social aspects in these two compulsory courses.

Notably, the teachers did not mention accessibility when inquired about ethical and social topics covered.

Accessibility Education

According to the teachers, accessibility education was mostly covered in Web Dev courses and briefly mentioned across other CS courses, and topics included visual accessibility (T1, T2), auditory accessibility (T2), color blindness (T1, T2, T3), and multi-platform accessibility (T1). T2 tried to ensure students knew the basics of how to do HTML properly including making websites accessible in the Web Dev course. Similarly, T1 included a unit about website accessibility in his Web Dev course, teaching about colors and contrast, and accessibility generator and checker. He implemented hands-on practices for students to fix inaccessible areas on websites. According to him, students enjoyed building accessible websites,

> *"Kids feel it cool that they are building unusual websites with different colors, not black and white."*

However, he acknowledged not discussing much about accessibility in other courses. Not including accessibility into compulsory courses such as CL1 and CL2, which emphasized other ethical and social topics, is a missed opportunity.

Teachers were divided regarding perceived barriers to teaching accessibility in CS courses. T1 thought there were not any barriers since no fancy materials in addition to websites and teacher notes were needed. T2 also did not think access to teaching materials was a barrier in his school but pointed out that some schools did not even have a computer lab.

Different from these two optimistic teachers, T4 noted that each course usually lasts for one semester, and there is limited time to cover every possible topic in CS. She would choose to use a few standalone sessions instead of a separate unit to provide students with an overall awareness of accessibility. Alternatively, she might consider integrating accessibility throughout the curriculum rather than teaching it separately.

Barriers expressed by T3 included the availability of tools for demonstration, teacher familiarity with the topic, and pedagogical engagement, i.e., how to present concepts to students in an engaging manner. He thought the games used and the teaching activities could well address these barriers, particularly for their directness,

> *"Students are not being told what to do, but directly experiencing the fact."*

Among the four teachers, only T2 perceived himself as having adequate knowledge about accessibility due to his education and teaching experience. He had taken tech or education courses in college, which explicitly taught about accessibility and diversity. He also had a mindset of keeping learning about accessibility,

> *"I understand it, but there's always more to understand. Continual learning and adjusting is important."*

Other teachers had not received formal education about accessibility and were less confident about their knowledge level in this regard. T3 learned accessibility from coding and life experiences. For example, he had friends and family members who had color blindness or dexterity impairment, so he knew the issues. Likewise, T1 knew about people who struggled to utilize mice in life or from media but had not received formal accessibility education or "learned things seriously." He noted,

> *"My understanding of accessibility is probably not great. I know very little for the most part. It's an area of expertise. I know a very savvy accessibility guy. There's a lot more than I know. I can understand the games, but I'm not an expert."*

The teachers all expressed praise for the accessibility education delivered in the research. In addition to the directness expressed by T3, he further commented on how the simulation games added to the limited set of tools for teaching accessibility,

> *"I don't teach other disabilities than color blindness, but I ought to, potentially using your tools. I haven't seen many tools like that."*

T4 found younger students had fun with the games during the teaching activities.

T1 tended to "give students a starter item such as videos and games" before teaching AI. He thought the games used could be a starter for accessibility education.

T2 commented,

> "It's a great teaching tool. This is perfect. It teaches design thinking as well. Design, CS, and other courses can use it, like building stuff and accommodating disability needs."

4.5 Discussion

4.5.1 Summary of Results

The disability modes and accessibility accommodations effectively affected students' game performance and in-game emotions. Students' performance was poorer in Round 2 of the games, and they exhibited fewer positive emotions. Their performance in Round 4 was comparable to Round 1, and their emotions were as positive as in Round 1.

Game playing led to the students' increased knowledge, awareness, and empathy regarding accessibility, based on evidence from the Likert-scale awareness questions, open-ended questions on accessibility considerations, and classroom discussions. The students were more willing to design accessibly and learned practical strategies to do so.

The students praised the game-based learning as thought-provoking, fun, educational, and informational. However, they acknowledged that such accessibility education was scarce in school education.

On the other hand, the teachers interviewed reported teaching a wide range of social and ethical topics, such as cybersecurity, information literacy, and accessibility, in CS courses. Accessibility education, in particular, mostly occurred in Web Dev courses. Expressed barriers to teaching accessibility included already-packed curricula, a lack of tools for demonstrating disabilities, and teachers' own knowledge of accessibility. They all thought the games used had the potential to engage students and were willing to use them in their future teaching practices.

4.5.2 Deliver Accessibility Education Early

Educating next-generation software designers/developers about accessibility is a viable and profound way to instill computational thinking, design thinking, and responsible design/development principles [24]. This way, more accessible technologies will be designed when accessibility-literate designers enter the IT workforce. Accessibility education has been extensively studied in recent years but mostly emphasized university education. It was shown to be effective, at least in terms of short-term learning effect [119].

Limited prior literature has addressed accessibility education in high school. To the best of my knowledge, there was only one online module (lecture and quizzes) created by academics for teaching high school students about accessibility [23]. Through a landscape survey of PreK-12 CS Teachers, Blaser et al. found that 20% of K-12 teachers reported teaching accessibility, yet "accessibility was the least taught computing concept" [201].

Toward narrowing this research gap, I integrated research advancement, i.e., simulation games [25], [123], [187] into teaching materials and taught accessibility to high school students, in the hope that they are equipped with knowledge and awareness of accessibility and empathy for disabilities and that they can use the knowledge learned for accessible design practices one day.

Students' game-playing data and survey responses revealed similar learning effects compared to CS and non-CS undergraduate students [25]. First, simulating disabilities has the potential to help high school students understand the challenges faced by people with disabilities, as evidenced by their negative emotions and lower winning percentages in Round 2 of the games. With accessibility features, they could perform better in disability modes, which may motivate them to explicitly consider accessibility in future design practices.

Second, the analysis indicated students' improved empathy for people with disabilities and increased intention to design for them, as indicated by Likert-scale question and open-ended question responses.

Third, like college students, high school students felt it was more important to include people with disabilities to vote than game playing.

I, therefore, argue that barriers to the use of technology for people with disabilities are an equity issue and can be framed as such even without detailed technical examples such as WCAG guidelines or technical assignments [121]. The similar learning effects suggest the possibility of utilizing games, as well as other pedagogical methods such as experiential learning [24] in accessibility education in high school.

Prior research found K-12 CS teachers were willing to teach accessibility [188]. Through classroom discussions and teacher interviews, it was found that accessibility is not a core part of high school CS curricula. It was taught in elective Web Dev courses but appeared less often in mandatory courses such as Computer Literacy 1 & 2.

Accessibility is a social/ethical topic but is not typically seen that way by K-12 teachers. Challenges such as teachers' knowledge of accessibility, conflicted learning goals, and a lack of educational materials exist. Game-based teaching has the potential to narrow this pedagogical gap. Both students and teachers in the study were receptive to the games as educational materials and liked the way of learning accessibility through simulation. The findings also highlight the need to strengthen high school CS teachers' knowledge of accessibility.

4.5.3 Education Recommendations

I have multiple education recommendations to better integrate software accessibility into the high school curricula, both in CS and non-CS subjects.

First, teacher training should be in place to equip teachers with awareness and knowledge of accessibility. Teachers like T3 and T1 have not received formal education on the topic of software accessibility and are, therefore, less confident in teaching this topic to students. Though I do not have empirical evidence, it is natural to suspect that non-CS K-12 teachers have an even lower level of knowledge in software accessibility. To make software accessibility education occur organically in a wide range of CS and non-CS courses, just like what happened with ethics education [42], education bureaus should hold dedicated teacher training to build confidence in K-12 teachers.

Second, researchers and relevant non-profits should build nifty tools to help teachers demonstrate disabilities and accessible design. Our participants commonly expressed a lack of useful tools to teach the topic of software accessibility in an engaging manner. Experiential learning labs [24] and simulation games [25] have been developed in academia. However, the tools may not work for universal populations. For example, the experiential learning labs [24] developed by El-Glaly et al. are not suitable for K-12 students with limited or no coding experience. More tools should be developed to cater to the needs of different learners.

Third, limited education outreach efforts have been seen in teaching K-12 students about software accessibility. More researchers should go into local high schools to deliver such education and equip next-generation software designers with awareness and knowledge regarding accessibility. This will help cultivate a culture of accessible and ethical computing in schools and society.

4.5.4 Implications for Education Research

Education approaches to software accessibility are important but often challenging. For one who wants to teach software accessibility in general CS courses such as algorithms and databases, there are not many readily available materials or tools that integrate accessible design into these subject matters. For researchers who want to teach software accessibility in K-12 courses, they need to find a contact in the local school who is willing to spare one or more classes for them to teach a seemingly irrelevant topic — software accessibility.

Like any other study, this study has limitations and leaves much room for future education research in software accessibility.

First, the education outreach was only conducted in a selective admission midwestern public high school, where students were exposed to a wide range of computing concepts. As some teachers suggested, more barriers to teaching accessibility may exist in low-resourced schools. Future research can validate the findings in other types of high schools, such as less competitive public schools, private schools, or schools in rural areas.

Second, future research might want to understand how students' demographic variables (e.g., gender, race), cultural backgrounds, and prior computer literacy impact the learning effect, which is left out of the scope of the current study.

Third, researchers have shown that educational interventions often failed to incur long-term changes in student attitudes towards accessibility [193]. A longitudinal study is helpful to examine the long-term effect of games in accessibility education.

Finally, the researchers' presence during the activities might have primed students to give answers that suggested they cared about accessibility. Future research can ask teachers to facilitate the activities without the researchers' presence for a comparison.

4.6 Conclusion

Through teaching high school students about accessibility through education games, I showed similar learning effects compared to undergraduate CS/non-CS students. The high school students had more empathy for people with disabilities and more intention to design accessibly after playing the games. Interviews with CS teachers in this high school revealed insufficient accessibility education in mandatory CS courses, which is a missed opportunity to equip next-generation software designers/decision-makers with awareness, knowledge, and empathy regarding accessibility. I encourage more research to expand accessibility education in high schools by translating accessibility research into educational materials and conducting education outreach activities.

Education approaches to software accessibility have several limitations, including the unpredictability of their long-term effects and the voluntary nature of the education. Same for design approaches to software accessibility: software practitioners are not compelled to practice accessible design and software companies are not compelled to deliver accessible products. A natural complement is governance approaches to software accessibility, which provides more enforceability and will be elaborated on in the next chapter.

5

Governance and Accessibility: A Comprehensive Institutional Analysis of Software Accessibility Laws

Educational approaches to address software accessibility have several limitations. First, state boards or departments of education hardly mandate the teaching of accessibility in the computing curriculum. Second, although students showed a short-term gain in knowledge and awareness of accessibility (e.g., in [25]), the long-term learning effect of accessibility education and objective assessment of students' willingness to design accessibly need to be interrogated further [120].

Design approaches to address software accessibility also have several limitations. First, academic research in design is not translated into industrial practices or patents in a timely manner [72]. Second, companies are not necessarily equipped with sufficient staff who have the skills and knowledge to ensure software accessibility and may not devote enough consideration and resources to software accessibility — compliance with ethical goals such as security often misaligns with corporate goals of shipping products fast or revenues [73].

Governance approaches to address software accessibility can be more effective in forcing companies to comply with accessibility requirements through monetary or reputational consequences. They can be more enforceable and "visible" than education and design approaches to accessibility, which tend to exercise their effect in the long run.

In this chapter, I evaluated governance approaches to software accessibility by looking at a wide range of laws worldwide.

5.1 Introduction

Governance approaches to accessibility include but are limited to the following: (1) Accessibility laws [28] are legally binding documents that define what should be achieved and how creators of non-compliant software should be punished; (2) Accessibility guidelines [29]–[31] are accessibility standards and best practices made by standardization bodies and companies; (3) Accessibility auditing [32], manual or automated [33], [34], is often based on principles in accessibility guidelines. The desired impact has not been achieved through these governance approaches — myriad accessibility pitfalls are still present in software in the wild [7].

To understand where governance approaches to accessibility fall short, I conducted an institutional analysis of 39 accessibility laws in 32 countries and regions collected by W3C.[1] The analysis aimed to identify where current governance approaches fell short and what might be improved.

I aimed to answer the following research questions in this study:

- **RQ1:** How are strategies, norms, and rules used in accessibility laws?
- **RQ2:** How enforceable are the accessibility laws?
- **RQ3:** What aspects are missing in current legislation regarding software accessibility and can be implemented in the future?

In the analysis, norms (N=1,393) were highly prevalent: X must/should/can do Y. Rules (N=21) added an enforcement mechanism, but they were relatively rare in regulations. Strategies (N=143) were present in defining the scope of the laws and clarifying other aspects of accessibility regulation.

Characteristics of effective accessibility laws were identified, such as engaging with principles in co-design, i.e., including people with disabilities in the design and monitoring loop, providing concrete technical recommendations, providing procedural details, and avoiding over-generalizability, e.g., mixing mobile applications and websites when it comes to accessibility regulation.

On the other hand, less effective laws left more questions than clarity for the audience. Such laws often lack effective enforcement mechanisms, miss key details, or are too optimistic in estimating the audience's knowledge of the legal system.

Based on the results, governance recommendations to optimize governance approaches to accessibility were proposed.

5.2 Related Work

In this section, I introduce two different methods under the broader umbrella of governance approaches to software accessibility, namely, accessibility laws and accessibility guidelines.

5.2.1 Accessibility Laws

Legislation, standardization, and technological solutions for enhancing e-accessibility have been studied in domains such as e-health [202]. Legislation helps make companies adhere to accessibility standards. A survey of managers from different industries and countries revealed that "having a company required by law to adhere to website accessibility standards makes it more likely that the website will be accessible" [203]. On the other hand, some researchers, such as Brown et al., reflected on the dilemma between accessibility and technical/legal burden on software developers, particularly for open-source software that is not making revenue [204].

Research has been conducted on software accessibility legislation and enforcement in multiple countries and regions. Kešelj et al. identified positive changes in web accessibility associated with relevant legislation in Croatia [205]. They raised the urgent need for raising awareness about digital accessibility. This suggests

[1] https://www.w3.org/WAI/policies/

a comprehensive approach to accessibility combining governance and education. In the UK, efforts have been made to improve staff awareness of accessibility legislation in educational contexts [206]. Andersland conducted a case study in Norway through interviews, a literature survey, and a website assessment [207]. The results revealed that the supervisory authority had enforcement capabilities but lacked a specific plan to supervise the legislation. As a result, the interviewed respondents from both public institutions and private businesses had not heard about the legislation from the government but from other channels. This similar suggests the importance of integrating education and governance.

In addition to siloed legislation efforts in web accessibility, the European Union has fostered web accessibility by implementing and updating policies and legal rules [28]. EU's Web and Mobile Accessibility Directive "establishes EU-wide rules for accessibility of public sector websites and mobile apps." Overall, accessibility laws have long existed in many countries but did not always achieve the goal of accessibility [142], [143].

There are a few possible reasons for the worldwide failure to ensure software accessibility. First, given the unprecedented pace of technological advancement, accessibility laws may not always be updated to accommodate emerging technologies and challenges. Second, accessibility guidelines, which accessibility auditing often follows, may not implement all the important principles in accessibility laws. These aspects have not been studied in prior literature and need further investigation.

Another component of the governance approach to software accessibility is accessibility guidelines that provide recommendations for software developers and designers to make accessible designs. Next, I will introduce accessibility guidelines, particularly WCAG, which is a basis for the EU Directive and the implementations in the EU countries.

5.2.2 Accessibility Guidelines

Software accessibility guidelines provide recommendations for making Web content and mobile applications more accessible. Both standardization bodies and industrial companies have released software accessibility guidelines.

W3C, the World Wide Web Consortium, is the main international standards organization for the World Wide Web [30]. It creates the Web Content Accessibility Guidelines (WCAG), one of the most known accessibility guidelines for web content. The guidelines "address web content accessibility on any kind of device (including desktops, laptops, kiosks, and mobile devices)."

WCAG defines how to make web content more Perceivable, Operable, Understandable, and Robust to people with disabilities [29]. These are the four principles that "provide the foundation for web accessibility." According to WCAG, the Perceivable principle indicates that "information and user interface components must be presentable to users in ways they can perceive." Specific guidelines under Perceivable include:

- Text Alternatives: Provide text alternatives for any non-text content so that it can be changed into other forms people need, such as large print, braille, speech, symbols or simpler language.
- Time-based Media: Provide alternatives for time-based media.
- Adaptable: Create content that can be presented in different ways (for example simpler layout) without losing information or structure.
- Distinguishable: Make it easier for users to see and hear content including separating foreground from background.

The Operable principle indicates that "user interface components and navigation must be operable." Specific guidelines under Operable include:

- Keyboard Accessible: Make all functionality available from a keyboard.
- Enough Time: Provide users enough time to read and use content.
- Seizures and Physical Reactions: Do not design content in a way that is known to cause seizures or physical reactions.
- Navigable: Provide ways to help users navigate, find content, and determine where they are.
- Input Modalities: Make it easier for users to operate functionality through various inputs beyond keyboard.

The Understandable principle indicates that "Information and the operation of the user interface must be understandable." Specific guidelines under Operable include:

- Readable: Make text content readable and understandable.
- Predictable: Make web pages appear and operate in predictable ways.
- Input Assistance: Help users avoid and correct mistakes.

The Robust principle indicates that "content must be robust enough that it can be interpreted by a wide variety of user agents, including assistive technologies." There is only one specific guideline under Operable:

- Compatible: Maximize compatibility with current and future user agents, including assistive technologies.

The 13 guidelines above "provide the basic goals that authors should work toward in order to make content more accessible to users with different disabilities."

For each guideline, WCAG provides testable success criteria for requirements and conformance testing. Three levels of conformance, A (lowest), AA, and AAA (highest), are defined to "meet the needs of different groups and different situations." In particular, Level A (Minimum Accessibility) includes the most basic web accessibility requirements. Level AA (Strong Accessibility) addresses major accessibility barriers and ensures a wider range of users can access content. Level AAA (Highest Accessibility) is the strictest level of accessibility, ensuring the best experience for people with disabilities.

Take the guideline on Time-based Media as an example. The success criterion, Captions (Prerecorded), is categorized as Level A:

> "Captions are provided for all prerecorded audio content in synchronized media, except when the media is a media alternative for text and is clearly labeled as such."

This is a basic web accessibility requirement that web content authors and software developers must fulfill to accommodate the needs of people with disabilities.

The success criterion, Captions (Live), on the other hand, is categorized as Level AA:

> "Captions are provided for all live audio content in synchronized media."

Providing captions for live audio content ensures the wider accessibility of web content.

The success criterion, Sign Language (Prerecorded), is categorized as Level AAA:

"Sign language interpretation is provided for all prerecorded audio content in synchronized media."

This level of accessibility ensures an optimal experience for people with disabilities.

In reality, many organizations may aim for Level AA compliance, as it balances accessibility and practicality without imposing too much burden on developers and content creators.

In addition to WCAG, W3C also has other accessibility guidelines for web accessibility. Authoring Tool Accessibility Guidelines (ATAG) help make authoring tools, such as HTML editors, more accessible so that authors, e.g., web developers, designers, and writers, can create more accessible web content, and people with disabilities can create web content. User Agent Accessibility Guidelines (UAAG) provide guidelines for making user agents, i.e., "browsers, browser extensions, media players, readers, and other applications that render web content," more accessible.

Commonly used accessibility guidelines created by industrial entities include BBC Standards and Guidelines for Mobile Accessibility and IBM Accessibility Checklist. In this chapter, only WCAG will be reviewed along with the accessibility laws.

5.2.3 Research Gap

Governance approaches to software accessibility require empirical evidence to inform policy choices and standardization aims and conventions. The current literature is too sparse and fragmented to inform good decision-making and, much less, help people implement. There needs to be comparative work and more critical work to understand where the governance approach itself falls short and may be improved.

5.3 Methods

To understand the status quo of legislation and governance related to software accessibility, 39 accessibility laws in 32 countries and regions were collected, and an institutional analysis of these documents was conducted. Below, I will introduce data collection and the coding process for the institutional analysis, including coder positionality.

5.3.1 Data Collection

As of March 3rd, 2025, W3C collected 80 web accessibility laws & policies in 45 countries and regions. As acknowledged by W3C, "it is not a comprehensive or definitive listing." Nevertheless, the list provided us with ample data to draw insights into software accessibility. Figure 5.1 is a visualization of the countries with accessibility laws and policies based on W3C data.

There are different types of government-issued documents: some are binding, and others are not. Take the EU as an example: A "regulation" is a binding legislative act; A "directive" is a legislative act that sets out a goal that EU countries must achieve; A "decision" is binding on those to whom it is addressed and is directly applicable; and A "recommendation" and an "opinion" are not binding. According to the definitions provided by W3C, a law "has completed the legislation process, and is put into effect as the law of the land," while a policy "outlines the goals of a government ministry or agency as well as the methods and principles to achieve those goals."

In the data collection, I only focused on laws collected by W3C with a few exceptions For example, in China, technical requirements are not a law, yet have been used to punish non-compliant parties. In the

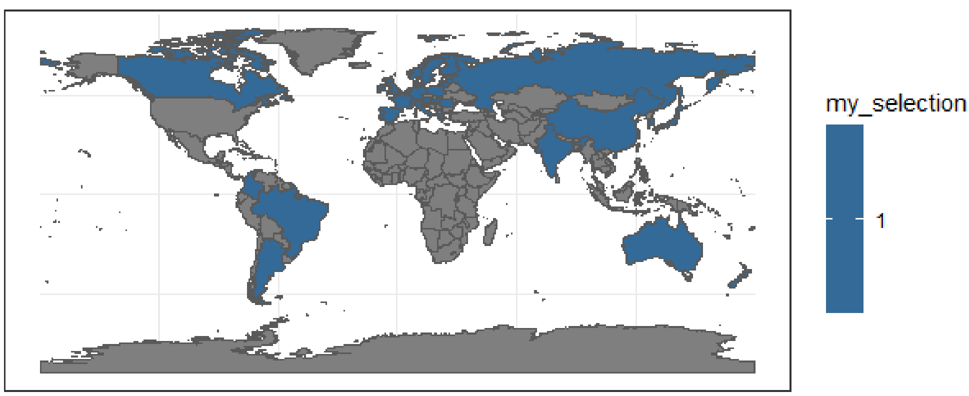


Figure 5.1: Visualization of countries with accessibility laws and policies based on W3C data.

end, I collected a subset of the W3C, i.e., 39 laws in 32 countries, for the institutional analysis. Non-binding policies are left out of the scope of the current study.

The metadata for the laws are listed in Table 5.1. The titles of the laws are provided in both English and the original language. Law type, year enacted, scope, and WCAG version used are directly provided by W3C, with several corrections made by the coders. In the paper, I will use abbreviations, such as Findland:1, to refer to the laws.

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbreviation
Åland	Landskapslag (2019:7) om tillgängliga digitala tjänster (2023/61)	Landscape Act (2019:7) on accessible digital services (2023/61)	Accessibility law	2019	-	None	Yes	Åland:1
Argentina	ACCESO A LA INFORMACION PUBLICA Ley 26.653	ACCESS TO PUBLIC INFORMATION Law 26,653	Non-discrimination law	2010	-	WCAG 2.0	No	Argentina:1
Austria	Bundesgesetz über den barrierefreien Zugang zu Websites und mobilen Anwendungen des Bundes	Federal law on barrier-free access to federal websites and mobile applications	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Austria:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Belgium	19 JULI 2018. - Wet inzake toegankelijkheid van de websites en mobiele applicaties van overheidsinstanties	JULY 19, 2018. - Law on accessibility of websites and mobile applications of public authorities	Accessibility law	2018	Public sector	WCAG 2.1	Yes	Belgium:1
China	网络设计无障碍技术要求	Technical requirements for web accessibility	*Recommendation*	2008	Government	WCAG 2.0 derivative	No	China:1
Croatia	Zakon o pristupačnosti mrežnih stranica i programskih rješenja za pokretne uređaje tijela javnog sektora	Law on accessibility of websites and software solutions for mobile devices of public sector bodies	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Croatia:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Cyprus	Ο περί Προσβασιμότητας των Ιστότοπων και των Εφαρμογών για Φορητές Συσκευές των Οργανισμών του Δημόσιου Τομέα Νόμος του 2019	The Accessibility of Public Sector Organizations Websites and Mobile Applications Act 2019	Accessibility law	2019	Government, Public sector	WCAG 2.0	Yes	Cyprus:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Czech Republic	ZÁKON o přístupnosti internetových stránek a mobilních aplikací a o změně zákona č. 365/2000 Sb., o informačních systémech veřejné správy a o změně některých dalších zákonů, ve znění pozdějších předpisů	LAW on the accessibility of websites and mobile applications and on the amendment of Act no. 365/2000 Coll., on information systems of public administration and on the amendment of some other laws, as amended	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Czech:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Denmark	Lov om tilgængelighed af offentlige organers websteder og mobilapplikationer	Act on accessibility of public bodies' websites and mobile applications	Accessibility law	2018	Government, Public sector	Other	Yes	Denmark:1
Denmark	Bekendtgørelse om afgivelse af tilgængelighedserklæring for offentlige organers websteder og mobilapplikationer, samt monitorering og indrapportering	Order on the submission of an accessibility statement for public bodies' websites and mobile applications, as well as monitoring and reporting	*Mandatory policy*	2018	Government, Public sector	WCAG 2.1	Yes	Denmark:2

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Estonia	Veebilehe ja mobiilirakenduse ligipääsetavuse nõuded ning ligipääsetavust kirjeldava teabe avaldamise kord	Requirements for the accessibility of websites and mobile applications, and the rules for publishing information describing accessibility	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Estonia:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
European Union	-	Directive (EU) 2016/2102 of the European Parliament and of the Council of 26 October 2016 on the accessibility of the websites and mobile applications of public sector bodies	Accessibility law	2016	Public sector	WCAG 2.0	No	EU:1
Finland	Laki sähköisestä asioinnista viranomaistoiminnassa	Act on Electronic Services and Communication in the Public Sector	Accessibility law	2003	Government	None	No	Finland:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Finland	Laki digitaalisten palvelujen tarjoamisesta	Act on the provision of digital services	Accessibility law	2019	-	WCAG 2.1	Yes	Finland:2
France	LOI n° 2016-1321 du 7 octobre 2016 pour une République numérique (Article 106)	LAW no. 2016-1321 of October 7, 2016 for a digital Republic (Article 106)	Digital Governance law	2016	Public sector, Private sector	None	No	France:1
France	Décret n° 2019-768 du 24 juillet 2019 relatif à l'accessibilité aux personnes handicapées des services de communication au public en ligne	Decree No. 2019-768 of July 24, 2019 relating to the accessibility of online public communication services to people with disabilities	Accessibility law	2019	Public sector, Government	WCAG 2 derivative	Yes	France:2

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Germany	Verordnung zur Schaffung barrierefreier Informationstechnik nach dem Behindertengleichstellungsgesetz (Barrierefreie-Informationstechnik-Verordnung - BITV 2.0)	Ordinance on the creation of barrier-free information technology in accordance with the Disability Equality Act (Barrier-Free Information Technology Ordinance - BITV 2.0)	*Accessibility policy*	2011	Government	WCAG 2.0 derivative	Yes	Germany:1
Greece	Ψηφιακή Διακυβέρνηση (Ενσωμάτωση στην Ελληνική Νομοθεσία της Οδηγίας (ΕΕ) 2016/2102	Digital Governance (Incorporation into Greek Legislation of Directive (EU) 2016/2102)	Accessibility law	2020	Government, Public sector	WCAG 2.0 derivate	Yes	Greece:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Hungary	Törvény a közszférabeli szervezetek honlapjainak és mobilalkalmazásainak akadálymentesítéséről	Act on the accessibility of websites and mobile applications of public sector organizations	Accessibility law	2018	Public sector	None	Yes	Hungary:1
Ireland	-	S.I. No. 358/2020 - European Union (Accessibility of Websites and Mobile Applications of Public Sector Bodies) Regulations 2020	Accessibility law	2020	Public sector	WCAG 2.1	Yes	Ireland:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Italy	LEGGE 9 gennaio 2004, n. 4 Disposizioni per favorire l'accesso dei soggetti disabili agli strumenti informatici	LAW 9 January 2004, n. 4 Provisions to encourage disabled people's access to IT tools	Accessibility law	2004	Public sector, Government	WCAG 2.0	No	Italy:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Italy	DECRETO LEGISLATIVO 10 agosto 2018, n. 106 ((Attuazione della direttiva (UE) 2016/2102 relativa all'accessibilità dei siti web e delle applicazioni mobili degli enti pubblici))	LEGISLATIVE DECREE 10 August 2018, n. 106 "Implementation of Directive (EU) 2016/2102 on the accessibility of websites and mobile applications of public bodies"	Accessibility law	2018	Public sector, Government	WCAG 2 derivative	Yes	Italy:2
Latvia	Kārtība, kādā iestādes ievieto informāciju internetā	The order in which institutions post information on the Internet	Accessibility law	2020	Government, Public sector	WCAG 2.0 derivate	Yes	Latvia:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Lithuania	nutarimas DĖL lietuvos respublikos vyriausybės 2003 m. balandžio 18 d. nutarimo nr. 480 „dėl bendrųjų reikalavimų valstybės ir savivaldybių institucijų ir įstaigų interneto svetainėms aprašo patvirtinimo“ pakeitimo	resolution ON the amendment of Resolution No. 480 of the Republic of Lithuania "on the approval of the general requirements for websites of state and municipal institutions"	Accessibility law	2018	Government, Public sector	WCAG 2.0 derivate	Yes	Lithuania:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Luxembourg	Loi du 28 mai 2019 relative à l'accessibilité des sites internet et des applications mobiles des organismes du secteur public	Law of May 28, 2019 relating to the accessibility of websites and mobile applications of public sector organizations	Accessibility law	2019	Public sector	WCAG 2.0 derivate	Yes	Luxembourg:1
Malta	REGOLAMENTI DWAR L-AĊĊESSIBBILTÀ TAS-SITI ELETTRONIĊI U TAL-APPLIKAZZJONIJIET MOBBLI TAL-KORPI TAS-SETTUR PUBBLIKU	ACCESSIBILITY OF THE WEBSITES AND MOBILE APPLICATIONS OF PUBLIC SECTOR BODIES REGULATIONS	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Malta:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Netherlands	Tijdelijk besluit digitale toegankelijkheid overheid	Temporary government digital accessibility decision	Accessibility law	2018	Government, Public sector	WCAG 2.1	Yes	Netherlands:1
Norway	Forskrift om universell utforming av informasjons- og kommunikasjonsteknologiske (IKT)-løsninger	Regulation on universal design of information and communication technology (ICT) solutions	Non-discrimination law	2013	**Public sector, Private sector**	WCAG 2.0 derivative	No	Norway:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Norway	Forskrift om endring i forskrift om universell utforming av informasjons- og kommunikasjonsteknologiske (IKT)-løsninger	Regulations on changes to regulations on universal design of information and communication technology (ICT) solutions	Non-discrimination law	2022	**Government, Public sector, Private sector**	WCAG 2 derivative	Yes	Norway:2
Poland	Ustawa z dnia 4 kwietnia 2019 r. o dostępności cyfrowej stron internetowych i aplikacji mobilnych podmiotów publicznych	Act of April 4, 2019 on the digital accessibility of websites and mobile applications of public entities	Accessibility law	2019	Government, Public sector	WCAG 2.0 derivate	Yes	Poland:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Portugal	Decreto-Lei n.º 83/2018 de 19 de outubro - Define os requisitos de acessibilidade dos sítios web e das aplicações móveis de organismos públicos, transpondo a Diretiva (UE) 2016/2102	Decree Law No. 83/2018 of October 19 - Defines the accessibility requirements for websites and mobile applications of public bodies, transposing Directive (EU) 2016/2102	Accessibility law	2018	-	None	Yes	Portugal:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Romania	ORDONANȚĂ DE URGENȚĂ nr. 112 din 21 decembrie 2018 privind accesibilitatea site-urilor web și a aplicațiilor mobile ale organismelor din sectorul public	EMERGENCY ORDINANCE no. 112 of December 21, 2018 on the accessibility of websites and mobile applications of public sector bodies	Accessibility law	2018	Government, Public sector	WCAG 2.0 derivate	Yes	Romania:1
Slovenia	Zakon o dostopnosti spletišč in mobilnih aplikacij (ZDSMA)	Website and Mobile Application Accessibility Act (ZDSMA)	Accessibility law	2018	Public sector	WCAG 2.1	Yes	Slovenia:1

Table 5.1 continued from previous page

Country	Law Title (Original Language)	Law Title (English)	Law Type	Year	Scope	WCAG Version	If EU Directive Implementation	Abbr.
Spain	Real Decreto 1112/2018, de 7 de septiembre, sobre accesibilidad de los sitios web y aplicaciones para dispositivos móviles del sector público	Royal Decree 1112/2018, of September 7, on accessibility of websites and applications for mobile devices in the public sector	Accessibility policy law, Non-discrimination law, Accessibility law, Accessibility policy	2018	Public sector	None	Yes	Spain:1
Sweden	Förordning (2018:1938) om tillgänglighet till digital offentlig service	Ordinance (2018:1938) on accessibility to digital public services	Accessibility law	2018	Government, Public sector	None	Yes	Sweden:1
Taiwan	網站無障礙規範(110.07)	Web Accessibility Guidelines (110.07)	*Mandatory policy*	2021	Public sector	WCAG 2.1 derivative	No	Taiwan:1

Table 5.1 continued from previous page

Country	**Law Title (Original Language)**	**Law Title (English)**	**Law Type**	**Year**	**Scope**	**WCAG Version**	**If EU Directive Implementation**	**Abbr.**
United States	-	Nondiscrimination on the Basis of Disability; Accessibility of Web Information and Services of State and Local Government Entities	Accessibility law	2024	Public sector	WCAG 2.1	No	US:1
United States	-	Telecommunications Act of 1996 (Section 255)	Accessibility law	1996	**Public sector, Private sector**	None	No	US:2
United States	-	21st Century Communications and Video Accessibility Act (CVAA)	Accessibility law	2010	**Private sector**	None	No	US:3

Table 5.1: Information for 39 accessibility laws around the world.

5.3.2 Institutional Analysis

In this study, I sought to identify and understand the institutions used to guide accessibility designs and implementations of software and websites in accessibility laws. According to the Institutional Grammar Research Initiative (IGRI), "institutions are the rules (e.g., laws), norms (e.g., social norms), and strategies (e.g., behavioral conventions)" that govern behavior in social systems.[2] I adopted the Institutional Grammar developed by Crawford and Ostrom [208], which provides a language to identify institutions in complex governance systems and has been applied in numerous research [209]–[212], for the institutional analysis of accessibility laws.

In institutional analysis, key components of regulative statements that are used to regulate or guide behavior include:

- **Attribute**, the actor(s) whose behavior is regulated as part of the institutional statement;
- **Modal logic**, including both deontics and hedging [138], which describe whether statement action is compelled, restrained, or discretionary;
- **Aim**, the activity, goal, or outcome regulated in the statement;
- **Context**, the statement clause capturing conditions that instantiate statement or qualify action; and
- **Or else**, the consequence of violating the statement.

Below is a more concrete example illustrating these five components:

> [Federal agencies](attribute) [must](deontic) [make their electronic and information technology (EIT) accessible to people with disabilities](aim) [when developing, procuring, maintaining, or using EIT](context), [or they will be fined $55,000 fine for the first violation, with fines increasing for subsequent offenses](or else).

Constitutive statements, on the other hand, are statements that establish or define something.

Institutional parameters combine to form strategies, norms, and rules: a strategy consists of an attribute, an aim, and a condition; a norm consists of an attribute, an aim, a condition, and a modal logic; and a rule consists of all institution components.

By definition, a rule is more enforceable than a strategy or a norm, as it defines the consequence of not being compliant with the aim. Norms and strategies are still important in the sense that they define the best practices and what should ideally be achieved — norms reflect social consensus, while strategies define ways to achieve things.

Coding Process

Two coders followed a four-eyes principle to analyze the collected laws. In an analysis following the four-eyes principle, two people will review the same data together, always reaching a consensus. This approach has been adopted in academic research [213] and security auditing efforts in the industry.

The coding process involved both the identification of strategies, norms, and rules and evaluatively commenting on the content of the laws. When a good or bad example of strategy/norm/rule occurred, the coders would briefly discuss and write down notes.

[2] https://institutionalgrammar.org/about/igri-mission/

Several guidelines were followed when conducting coding during the institutional analysis. First, institutional statements were not confined to a single sentence. Sometimes, multiple sentences constitute an institutional statement, e.g.,

> *"Everyone has the right to electronically submit notifications to the relevant authority that the website or mobile application is not considered to be compliant with the accessibility requirements of this Act."*
>
> *"The authority shall respond to such notification without delay."*

In this example, the first sentence serves as the context for the second sentence.

Second, in addition to coding the collected laws, directly quoted law content in these laws was also coded. For example, some Italian laws quote content from other laws or amend existing laws. In such cases, the whole law document was coded except for auxiliary components such as footnotes.

Third, some laws, such as Greece:1 and Latvia:1, concern the general governance of software systems, not particularly concerning software accessibility. In such cases, only the chapters regarding software accessibility are coded to keep the analysis coherent and concise.

Positionality of Researchers

The two coders have complementary research expertise and levels of language/research proficiency, making the analysis more robust and generalizable.

I am a PhD candidate at an R1 institution and will join another R1 institution as an assistant professor. My research interests are in human-computer interaction, computer accessibility, AI ethics, and computing education. Growing up in China, I witnessed how people with disabilities become invisible in society without sufficient accommodations, physically and digitally. I am not a native English speaker, but is proficient in speaking and academic writing, with 7 years of research experience.

The second coder [C2] is currently a staff and will soon become a PhD student at an R1 institution. He graduated with a master's degree, also from this institution. His research interests are in Human-Computer Interaction, digital health, social media, ethics, and AI-driven socio-digital interaction. Growing up in the US and Taiwan, he has become interested in how people from different cultures interact with technology and the inequalities that arise from it. He is a native English speaker and has 3 years of research experience.

Several facets of the researchers' positionality made the analysis more robust. In particular, accessibility laws should accommodate the reading skills of software developers, designers, and administrative staff with different levels of technical and language proficiency and different cultural backgrounds. The discussion between the coders was able to assess the usability of the accessibility laws comprehensively.

5.4 Results

In this section, I start by reporting descriptive statistics in the analysis, including the number of strategies, norms, and norms, interaction with WCAG, and so on. Then I go in-depth, illustrating what good and bad strategies/norms/rules are like with concrete examples extracted from the laws.

5.4.1 Descriptive Statistics

Of the 39 legal documents in 32 countries or regions, 31 were categorized by W3C as accessibility laws; 4 were non-discrimination laws; and 1 was digital governance law. China's "Technical requirements for web accessibility" was categorized as a recommendation, and Taiwan's "Web Accessibility Guidelines (110.07)" was categorized as a mandatory policy. However, in these two regions, recommendation or mandatory policy exercises legal power, i.e., entities that violate the regulations are subject to punishment. Similarly, Denmark's "Order on the submission of an accessibility statement for public bodies' websites and mobile applications, as well as monitoring and reporting" was categorized as a mandatory policy, with some legal power. Therefore, these documents were included in the analysis even though they are not laws.

Notably, only 6 laws apply to private sector entities, i.e., France:1, Italy:1, Norway:1, Norway:2, US:2, and US:3. Most laws have an exclusive emphasis on public sector entities and governments. This trend was partly due to the fact that EU Directive 2016/2102 mostly regulated public sector websites and mobile applications, not their private sector counterparts, and many EU countries followed suit.

According to W3C, 29 out of 39 laws used some version of WCAG as a reference. The analysis confirmed that software accessibility laws tend to emphasize the four key principles in WCAG, i.e., making software and web content perceivable, operable, understandable, and robust.

27 out of the 39 laws analyzed are implementations of EU Directive 2016/2102. Among these implementations, 12 were enacted in 2018, 11 were enacted in 2019, 3 were enacted in 2020, and 1 was enacted in 2022. Romania enacted its accessibility law (Romania:1) relatively early in 2018 following EU Directive 2016/2102 and called the law an "emergency ordinance," suggesting that Romania prioritized implementing the EU directive.

Of all the coded content, there were 1,393 norms, 143 strategies, and 21 rules. Below, I will report the main findings on the strategies, norms, and rules.

5.4.2 Strategies (N=143)

The 143 strategies in the laws are used to define the aim, scope, and other aspects, as well as suggest best practices in ensuring accessibility, sometimes leveraging researchers' and practitioners' insights.

First, strategies can be used to define the scope of the laws, i.e., when the laws apply and do not apply. For example, in Åland:1, three strategies together define the entities that are subject to the regulation of this law and those that are not:

> *"The Act applies only to public law bodies that provide services that are essential to the public or services that specifically meet the needs of or are intended for people with disabilities."*
>
> *"This Act does not apply to digital services provided by broadcasting and television broadcasting companies with a public service mission insofar as they are services other than services providing access to audiovisual media services. (2023/61)"*
>
> *"This law does not apply to the following content on websites and mobile applications:*
> *1) live broadcasts of time-dependent media,*
> *2) maps that are not intended for navigation; maps intended for navigation are also exempt if essential information about them is provided in an accessible digital form,*
> *3) third-party content that has neither been financed nor produced by the relevant authority nor is under its control;*

4) reproductions of objects from cultural heritage collections that cannot be made fully accessible without significant obstacles, and
5) websites and mobile applications of schools and daycare centers, with the exception of content relating to essential administrative functions of the website or mobile application."

Since many laws enacted by EU countries were implementations of the EU Directive 2016/2102 in the analysis, they exclusively apply to public bodies' websites and mobile applications, consistent with the Directive.

Portugal:1 establishes what public bodies include,

"This decree-law applies to the following entities:
a) State;
b) Autonomous Regions;
c) Local authorities;
d) Public institutes;
e) Independent administrative entities;
f) Public foundations;
g) Public associations;
h) Entities in the public business sector;
i) Non-Governmental Organizations that provide essential services to the public or that provide services that specifically aim to respond to people's needs with disabilities or which are directly addressed to them;
j) Higher education institutions, educational establishments pre-school education and school education, public and private with public funding, with regard to content relating to essential administrative functions by electronically;
k) Public law bodies, as defined in paragraphs a) and b) of § 2 of article 2 of the Code of Public Contracts;
l) Associations of which one or more entities referred to in the previous paragraphs are members, if these associations are created for the specific purpose of meeting needs of general interest, without an industrial or commercial character."

Denmark:1 further clarifies that schools and educational institutions are not categorized as "public bodies",

"Subsection 1 does not apply to schools and educational institutions within the territory of the Ministry of Education that are not classified as public administration, cf. Section 1, subsections 1 and 2 of the Public Administration Act. Schools and educational institutions that are not classified as public administration must, however, make content associated with essential administrative online functions available on websites and in mobile applications."

Some laws enacted before the EU Directive, such as Italy:1, had a broader scope, regulating both public and private entities,

"This law applies to the public administrations of referred to in paragraph 2 of article 1 of the legislative decree of 30 March 2001, n. 165, and subsequent amendments, to public economic bodies, to private companies concessionaires of public services, to companies regional municipal authorities, assistance bodies and public rehabilitation, transport companies and telecommunications with predominantly public capital participation e to IT service contracting companies."

Similarly, Norway:1, enacted in 2013, regulates both public and private entities,

> *"The regulations apply to all areas of society, with the exception of family life and other matters of a personal nature."*

The coders deemed it necessary for the EU to have a new directive regulating private entities to ensure software accessibility more effectively and broadly.

A few strategies concerning the scope of law confused the coders, e.g., the following one from Norway:1:

> *"The requirements in Section 4d do not apply to Norwegian ships and aircraft regardless of where they are located."*

The coders were confused about the sudden mention of ships and aircraft, *"[C2] It's a weird one. Why does it suddenly talk about ships and aircraft?"*

Second, strategies are used to clarify other key aspects of accessibility regulation, including disproportionate burden, time constraints, goals, and so on.

Åland:1 defines the disproportionate burden as follows:

> *"The assessment of whether compliance with accessibility requirements causes a disproportionate burden on the service provider is made according to the ratio between the net costs of compliance with accessibility requirements and operating and capital expenditures and according to the ratio between the net costs of compliance with accessibility requirements and net turnover, as well as according to the estimated costs and benefits, taking particular account of the needs of persons with disabilities to use the service."*

It defines the time after which the law is enforceable as follows:

> *"The provisions of this Act apply from 23 September 2019 to websites published after the Act enters into force."*

The EU Directive uses a strategy to define the overarching goal ("aim") of the Directive,

> *"In order to improve the functioning of the internal market, this Directive aims to approximate the laws, regulations and administrative provisions of the Member States relating to the accessibility requirements of the websites and mobile applications of public sector bodies, thereby enabling those websites and mobile applications to be more accessible to users, in particular to persons with disabilities."*

Overall, strategies are effective in terms of providing clarifications, especially when implementing EU Directive 2016/2102. When coding Austria:1, one of the coders commented, *"[C2] A little bit more strategy than the previous one [Argentina:1]. Like an add-on or clarification to the existing EU laws. They also refer back to the laws."*

Third, strategies are used to recommend good practices to ensure accessibility. For example, in EU:1, consulting with relevant stakeholders, which is a rule of thumb in co-design research, is seen as a good practice to conform to accessibility requirements:

> *"In order to ensure the proper implementation of this Directive, and in particular the implementation of the rules on conformity with accessibility requirements, it is of the utmost importance for the Commission and the Member States to consult with relevant stakeholders on a regular basis."*

In the following strategies, Germany:1 uses a strategy along with multiple norms to outline concrete guidelines to ensure accessibility concerning both German Sign Language and plain language,

> *"The following guidelines apply to the provision of information in German Sign Language on the Internet or intranet:*
> *1. Shadows on the actor's body should be avoided. Facial expressions and mouth movements must be clearly visible.*
> *2. The background should be static. A black or white background should be avoided.*
> *3. The background, the clothing and the hands of the actor or actress contrast with each other. The clothing should be dark and plain.*
> *4. The video is marked with the logo for German Sign Language. The color design of the logo can be adapted to the respective design of the appearance."*

> *"The following requirements apply to the provision of information in plain language on the Internet or intranet:*
> *1. Abbreviations, hyphenation at the end of lines, negations as well as subjunctive, passive and genitive constructions should be avoided.*
> *2. The readers should be addressed personally, as far as the content makes sense.*
> *3. Terms are to be used consistently in the same way.*
> *4. Short, common terms and phrases should be used. Abstract terms and foreign words should be avoided or explained using concrete examples. Compound nouns should be separated by hyphens.*
> *5. Short sentences with clear sentence structure should be formed.*
> *6. Special characters and spaces in brackets should be avoided.*
> *7. Content should be structured logically using paragraphs and headings. Lists with more than three points should be structured using lists.*
> *8. Important content should be presented first.*
> *9. Clear fonts with clear contrast and a font size of at least 1.2 em (120 percent) should be used. Important information and headings should be highlighted. A maximum of two different fonts should be used.*
> *10. Texts are left-aligned. Each sentence begins on a new line. The background is light and plain.*
> *11. Meaningful symbols and images should be used.*
> *12. Addresses should not be written as continuous text.*
> *13. Tables should be designed to be clear."*

From the level of detail and quality of these guidelines, the coders believed the lawmakers had consulted researchers and practitioners in the software accessibility domain before drafting this law.

Overall, the coders expected more strategies than what was actually there in the accessibility laws: *"[C2] I feel like a lot of EU countries just focus on the norm statement more overall. I wonder why they do not put in more strategy."*

5.4.3 Norms (N=1,393)

Norms are most common (N=1,393) in the laws, often found with deontics such as "shall," "should," and "must," as well as hedging such as "may," "can," and "will," yet without an enforcement mechanism.

EU Country Laws Implementing EU Directive 2016/2102

When a country has both an EU Directive implementation and an earlier independent law, the former was often deemed more effective and well-versed by the coders. When coding two laws by Finland, one coder commented, *"[C2] This one [Finland:2] is a bit more authoritative than the previous one [Finland:1]. They are trying to impose something this time. There are more definitions here. More clear to the designers."*

In EU:1, there are a lot of norms as guidelines for member countries to make their own laws. In the EU countries' laws that implemented EU Directive 2016/2102, norms are used to state requirements in various aspects of software accessibility, adding to the clarity of the laws.

Take Malta:1, a clearly structured implementation of EU Directive 2016/2102, as an example. Norms are used in key definitions across the regulations.

The following norm defined stakeholders, which included people with disabilities and entities representing their interests,

> *"'stakeholders' shall include persons with disabilities, organisations representing the interests of persons with disabilities and of the elderly, social partners, industry involved in the creation of accessibility software relating to websites and mobile applications, and civil society;"*

Norms are used to outline exceptions of software and content types to the accessibility requirements, e.g.,

> *"These regulations shall not apply to the following content of websites and mobile applications:*
> *(a) office file formats published before 23 September 2018, unless such content is needed for active administrative processes relating to the services performed by the public sector body concerned;*
> *(b) pre-recorded time-based media published before 23 September 2020;*
> *(c) live time-based media: [...];*
> *(d) online maps and mapping services, as long as essential information is provided in an accessible digital manner for maps intended for navigational use;*
> *(e) third-party content that is neither funded nor developed by, nor under the control of, the public sector body concerned: [...];*
> *(f) reproductions of items in heritage collections that cannot be made fully accessible because of either: [...];*
> *(g) content of extranets and intranets, meaning websites that are only available for a closed group of persons and not to the public in general, published before 23 September 2019, until such websites undergo a substantial revision;*
> *(h) content of websites and mobile applications qualifying as archives, meaning that such websites and mobile applications only contain content that is neither needed for active administrative processes nor updated or edited after 23 September 2019."*

The following norm lists requirements for the accessibility of websites and mobile applications, borrowing the four key accessibility principles from WCAG:

> *"Public sector bodies shall take the necessary measures to make their websites and mobile applications more accessible by making them:*
> *(a) perceivable, meaning that information and user interface components are presentable to users in ways they can perceive;*
> *(b) operable, meaning that user interface components and navigation are operable;*

(c) understandable, meaning that information and the operation of the user interface are understandable; and
(d) robust, meaning that content must be robust enough to be interpreted in a reliable manner by a wide variety of user agents, including assistive technologies."

Norms are used to recommend ways to comply with the accessibility requirements without imposing a disproportionate burden:

"In order to assess the extent to which compliance with the accessibility requirements set out in regulation 4 imposes a disproportionate burden, public sector bodies shall take account of relevant circumstances, including the following:
(a) the size, resources and nature of the public sector body concerned; and
(b) the estimated costs and benefits for the public sector body concerned in relation to the estimated benefits for users, in particular but in no way limited to persons with disabilities, taking into account the frequency and duration of use of the specific website or mobile application."

Norms are used to enumerate presumptions of conformity with the accessibility requirements, e.g.,

"Content of websites and mobile applications that meets harmonised standards or parts thereof, the references to which have been published by the European Commission in the Official Journal of the European Union in accordance with Regulation (EU) No 1025/2012, shall be presumed to be in conformity with the accessibility requirements set out in regulation 4 that are covered by those standards or by parts thereof."

Publishing accessibility statements is mandated through norms:

"Public sector bodies shall provide and regularly update a detailed, comprehensive and clear accessibility statement on the compliance of their websites and mobile applications with these regulations."

The standard components of the accessibility statements are further provided,

"The accessibility statement shall include:
(a) an explanation concerning those parts of the content that are not accessible, and the reasons for that inaccessibility and, where appropriate, the accessible alternatives provided for;
(b) a description of, and a link to, a feedback mechanism enabling any person to notify the public sector body concerned of any failure of its website or mobile application to comply with the accessibility requirements set out in regulation 4, and to request the information excluded pursuant to subregulation (3) of regulation 3 and regulation 5; and
(c) a link to the enforcement procedure set out in regulation 9 to which recourse may be had in the event of an unsatisfactory response or of a lack of a response to the notification or the request."

The following concrete norm states the time within which a public sector body must reply to a notification or a request:

"Where a public sector body receives a notification or a request pursuant to sub-regulation (4)(b), it shall provide an adequate response to such notification or request within fifteen (15) working days."

As seen in this norm, public sector bodies are asked to respond to complaints about inaccessible websites and mobile applications in a timely manner.

Requirements for training programs and awareness-raising efforts are listed in the following two norms:

> *"The Authority shall promote and facilitate training programmes relating to the accessibility of websites and mobile applications for relevant stakeholders and staff of public sector bodies, designed to train them how to create, manage and update the accessible content of websites and mobile applications."*

> *"The Authority shall take the necessary measures to raise Raising awareness. awareness of the accessibility requirements set out in regulation 4, of their benefits to users and to owners of websites and mobile applications, and of the possibility of giving feedback in the case of any failure by public sector bodies to comply with the requirements of these regulations as set out in this regulation."*

As we can see, both public sector bodies and users are targets of such education and awareness-raising efforts, suggesting a comprehensive endeavor to ensure software accessibility.

Monitoring and reporting requirements are listed in several norms, e.g.,

> *"The Authority shall periodically monitor the compliance of websites and mobile applications of public sector bodies with the accessibility requirements set out in regulation 4, on the basis of the monitoring methodology that may be established through implementing acts adopted by the European Commission."*

Other norms list the timeline for report submission and the required components of the report.

In addition to submitting monitoring reports to the European Commission, the Authority (in this law, the Authority means the Malta Communications Authority established under the Act") is further required to investigate incompliance and address complaints,

> *"The Authority shall initiate investigations on the website or mobile application of a public sector body where he has reason to believe that such public sector body has acted or is acting in breach of these regulations."*

After using rules to substantiate consequences of incompliance, i.e., name publishing and fines, norms are used to elaborate on the right of appeal:

> *"The public sector body concerned or the complainant as the case may be, may lodge an appeal before the Tribunal from a decision of the Authority issued pursuant to these regulations. "*

Methods of service, i.e., how the Authority should convey decisions to public sector bodies, and time constraints of the regulation application, are explained at the end of the law with norms.

Other EU countries have parallel implementations of EU Directive 2016/2102 with similar document structures and minor differences in content.

Examples of Good Norms

Although many EU countries implemented EU Directive 2016/2102, some laws stand out with more actionable and concrete implementations.

Germany:1 stood out for its emphasis on including the voices of multiple stakeholders, particularly people with disabilities, and concrete recommendations for designers. Below is an example of a concrete recommendation for designers to follow, *"Clear fonts with clear contrast and a font size of at least 1.2 em (120 percent) should be used."*

Germany:1 mandates the reporting of the inclusion of people with disabilities in the process of ensuring accessibility,

> *"In addition to the mandatory information, the report shall in particular contain information on: 1. the use of the enforcement procedure pursuant to Section 12b Paragraph 2 Number 3 in conjunction with Section 16 of the Equal Opportunities for People with Disabilities Act, 2. the use of the exemption regulation according to Section 12a Paragraph 6 of the Disability Equality Act, and 3. Results of consultations with associations and organizations of people with disabilities."*

Additionally, it includes the voices of people with disabilities in the monitoring process,

> *"When selecting the websites and mobile applications to be monitored, the monitoring body shall consult the associations and organisations of persons with disabilities and take into account their assessments of individual websites and mobile applications."*

Further, it includes the voices of a wide range of people in the committee for accessible information technology:

> *"The committee shall consist of expert representatives from the monitoring body, from the state monitoring bodies, from associations of people with disabilities and from the business world, as well as other expert persons, in particular from academia and from public bodies within the meaning of Section 12 of the Equal Opportunities for People with Disabilities Act."*

Portugal:1 provides actionable monitoring procedures, including automatic and manual procedures, as well as "usability testing with people with disabilities."

> *"For websites, the entities referred to in Article 2 must adopt the following monitoring procedures:*
> *a) Simplified automatic or semi-automatic procedure, corresponding to an automatic assessment of a sample of website pages consisting of, at a minimum, by the entry page and all linked pages to the home page and contemplating, whenever possible, the various types of templates used, using a automatic or semi-automatic accessibility validator web commonly used in the market;*
> *b) Simplified manual procedure, corresponding to a manual expert evaluation of a sample of pages that allows responding to the diversity of elements contained in the checklist for websites published in website www.acessibilidade.gov.br;*
> *c) Usability testing with people with disabilities, of which they must be part of the object of analysis, by least, one task and one type of users."*

The coders appreciated the spirit of community-driven design. It was believed that the legislators had consulted domain experts before writing the law. This law also has better guidance to make the accessibility statement more accessible and usable, providing technical solutions:

> *"The accessibility statement relating to websites web must be published on the respective website, on page with the URI address ending in «/accessibility», and be hyperlinked to the home page and, whenever possible, to the footer of all pages on the site."*

Poland:1 also has some interesting implementations and extensions of the EU directive. For example, it has specific control of the budget relating to accessibility compliance:

"In the event of exceeding or risking exceeding the maximum expenditure limit adopted for a given budget year specified in paragraph 1 and if, during the period from the beginning of the calendar year to the date of the last assessment, the part of the annual limit falling proportionally to this period is exceeded by at least 10%, a corrective mechanism shall be applied consisting in reducing the state budget expenditures being the financial consequence of this Act by limiting:
1) information activities referred to in art. 12 item 4;
2) the number of websites or mobile applications of public entities subject to monitoring referred to in art. 12 item 2."

Such content was not found in other laws implementing EU Directive 2016/2102. The law also distinguishes between mobile applications and websites regarding accessibility requirements,

"The accessibility declaration of a mobile application shall additionally include an indication of the electronic address where the mobile application can be downloaded and installed."

Further, the law provides more details for the accessibility statement, including alternative access to information for people with disabilities (e.g., sign language interpretation):

"The accessibility statement shall also include:
1) the date of publication of the website or mobile application;
2) the date of the last update of the website or mobile application, following a significant change in its content, in particular a change in the appearance or structure of the information presented or a change in the manner of publishing information;
3) information or a link to information on the method of assessing digital accessibility;
4) contact details of the registered office of the public entity, together with the contact details of the person designated to handle matters related to digital accessibility in that public entity;
5) information on keyboard shortcuts created on the website or in the mobile application for moving around the elements of the website or mobile application and launching the functions available on them;
6) information on the architectural accessibility of the registered office of the public entity for disabled persons;
7) information on the availability of a sign language interpreter via electronic means of communication, together with information on the methods enabling the use of this function or information on its absence;
8) a link to the declaration of accessibility of the mobile application, if the public entity has a mobile application;
9) information on the possibility of notifying the public entity of the lack of digital accessibility;
10) a link to the website of the Commissioner for Human Rights."

Italy:1 was enacted in 2004, yet provided many insights for EU Directive 2016/2102. Its concepts regarding raising accessibility awareness and training may have been borrowed by the later EU directive. For example, it states,

"The administrations referred to in Article 3, paragraph 1, within the available budget, shall provide professional refresher courses on accessibility."

Similarly, the following norm echoes the concepts of disproportionate burden in the later EU regulations:

"Public employers shall implement paragraph 4, within the scope of budget availability."

Norway:1 was enacted before EU Directive 2016/2102 and has a broader scope for disproportionate burden, encompassing privacy, economics, and technological considerations:

"A disproportionate burden may be due to considerations of privacy, economics, technological possibilities or where the development process for a procurement cannot be adapted to the deadlines."

Taiwan:1 has some interesting and actionable recommendations for ensuring website accessibility. The following norm suggests using a certification system to incentivize website developers to comply with accessibility requirements,

"After the website passes the test and self-assessment, the website developer can submit the assessment results to the certification body to apply for the certification mark, and download the website accessibility certification mark corresponding to each test level from the official website related to this specification based on the test level passed by the website, and place the certification mark and instructions in the appropriate position of the web page in accordance with the prescribed method."

Another example of concrete technical recommendations is seen in the following norm,

"For example, you should use web page structure tags and form presentation appropriately, and you should not mix inappropriate tags for the sake of convenience or aesthetics."

China:1 heavily relies on WCAG principles while including some localized revisions, e.g., accompanying uncommon written characters with pinyin, the spelled sounds in Mandarin:

A mechanism should be provided to add pinyin to uncommon Chinese characters and explain their meaning.

US accessibility laws are sometimes found with more detailed procedures. For example, **US:3** is rather detailed regarding establishing the Advisory Committee and subcommittees. This law also details a co-design approach to survey people with disabilities:

"Within 1 year after the completion of the member appointment process by the Chairman of the Commission pursuant to subsection (b), the Advisory Committee shall conduct a national survey of individuals with disabilities, seeking input from the groups described in subsection (b)(2), to determine the most effective and efficient technologies and methods by which to enable access to emergency services by individuals with disabilities and shall develop and submit to the Commission recommendations to implement such technologies and methods, including recommendations—
(1) with respect to what actions are necessary as a part of the migration to a national Internet protocol-enabled network to achieve reliable, interoperable communication transmitted over such network that will ensure access to emergency services by individuals with disabilities;
(2) for protocols, technical capabilities, and technical requirements to ensure the reliability and interoperability necessary to ensure access to emergency services by individuals with disabilities;
(3) for the establishment of technical standards for use by public safety answering points, designated default answering points, and local emergency authorities;
(4) for relevant technical standards and requirements for communication devices and equipment and technologies to enable the use of reliable emergency access;

(5) for procedures to be followed by IP-enabled network providers to ensure that such providers do not install features, functions, or capabilities that would conflict with technical standards;
(6) for deadlines by which providers of interconnected and non-interconnected VoIP services and manufacturers of equipment used for such services shall achieve the actions required in paragraphs (1) through (5), where achievable, and for the possible phase out of the use of current-generation TTY technology to the extent that this technology is replaced with more effective and efficient technologies and methods to enable access to emergency services by individuals with disabilities;
(7) for the establishment of rules to update the Commission's rules with respect to 9–1–1 services and E–911 services (as defined in section 158(e)(4) of the National Telecommunications and Information Administration Organization Act (47 U.S.C. 942(e)(4))), for users of telecommunications relay services as new technologies and methods for providing such relay services are adopted by providers of such relay services; and
(8) that take into account what is technically and economically feasible."

Examples of Bad Norms

Vague norms will lead to confusion for website developers. For example, Austria:1 borrows principles from WCAG, but the following norm is written in a vague and general manner, without explaining what being perceptible, operable, understandable, and robust implicates,

> *"The legal entities named in Section 2 Paragraph 1 Items 1 and 2 must make their websites and mobile applications more accessible by designing them perceptible, operable, understandable and robust."*

One of the coders commented on how this law sacrifices usefulness for brevity, *"[C2] Pretty general. This law sacrifices usefulness for brevity. What is accessible is up to people's interpretation. This leaves leeway when people implement accessibility."*

None of the EU laws implementing EU Directive 2016/2102 has an easily understandable definition of the disproportionate burden. Take Portugal:1 as an example. The norm that defines factors in assessing disproportionate burden reads:

> *"The entities referred to in Article 2 must comply the provisions of the previous article in accordance with the principle of proportionality, insofar as for them it is not result in the imposition of a disproportionate burden, considering:*
> *a) The size, resources and nature of the entity in question; and*
> *b) The estimate of costs and benefits for the entity compared to the estimated benefits to people with disabilities, taking into account the frequency and duration from the use of the website or mobile application."*

The coders were confused as to what counts as a small-sized entity, what counts as a high cost, what counts as a high benefit, and so on, having more questions than clarifications. US:3 provides a better example with a specific threshold,

> *"Such regulations may provide an exemption from the regulations for cable systems serving 20,000 or fewer subscribers."*

However, the coders again deemed this exemption criterium weird without knowing the rationale for setting the threshold at 20,000 subscribers.

One common drawback of the EU country laws implementing EU Directive 2016/2102 is that they do not make much effort to differentiate regulations of websites and mobile applications – mobile applications may impose additional accessibility challenges with the small screens of smartphones.

5.4.4 Rules (N=21)

Only sporadic rules (N=21) were identified in the legal documents, defining the punishment in the form of fines or name-calling, sometimes both. For example, Malta:1 used a combination of these two punishments for entities that are not compliant with accessibility requirements,

> *"Subject to the provisions of regulation 9(6), where a public sector body does not comply with any of its obligations pursuant to these regulations, then the Authority may in the first instance publish the name of the public sector body and the decision of the Authority taken pursuant to regulation 9(5) in any such manner as it considers appropriate in the circumstances."*

> *"If notwithstanding the publication of the name of the public sector body and of the decision of the Authority as provided for in sub-regulation (6), the public sector body persists in not complying with the aforesaid decision, the Authority may then impose an administrative fine in accordance with the provisions of regulation 11."*

Rules Are Often Vague Or Assumes Too Much Audience Knowledge

Some rules are written in a vague manner without substantiating the punishment for violating accessibility requirements. For example, in Argentina:1, it writes,

> *"ARTICLE 9º — Failure to comply with the responsibilities assigned to public officials by this law will give rise to the corresponding administrative investigations and, where appropriate, to the relevant complaint before the courts."*

While this statement claims the consequence of non-compliance, i.e., court complaints, it does not impose fines or specific punishments on entities that fail to ensure web accessibility.

Laws such as Norway:1 do not mention a specific fine amount when discussing penalty,

> *"A penalty payment shall only be imposed where it is deemed necessary for the order to be complied with within a reasonable time and shall be of such a size that it provides an incentive to comply with the order."*

Some countries assume one understands the rest of their legal code when making accessibility laws. For example, Finland:2 refers to another law when discussing fines, presenting another type of vagueness (Note: the following quote is not a rule, but is used for comparison):

> *"Provisions on conditional fines are provided for in the Act on Conditional Fines (1113/1990)."*

Italy:2 adopts a similar wording when it comes to fines (Note: the following quote is not a rule, but is used for comparison),

> *"Failure to comply with the provisions of this article, including failure to publish the objectives referred to in paragraph 7: a) is relevant for the purposes of measuring and evaluating the individual performance of the responsible managers; b) entails managerial and disciplinary liability pursuant*

to Articles 21 and 55 of Legislative Decree no. 165 of 30 March 2001, and subsequent amendments, without prejudice to any criminal and civil liability provided for by the provisions in force."

When coding such rules, the coders did not consider them the best way to convey the consequences of violations. Without sufficient clarity, relevant parties will have difficulty realizing the severity of incompliance and will be confused when receiving a considerable fine later on.

Romania:1 mentions the fine amount but in a confusing way (Note: the following quote is not a rule, but is used for comparison),

> *"The following acts constitute a contravention and are sanctioned as follows:*
> *a) with a fine of 4 to 5 points, failure by the public sector body to publish the accessibility statement provided for in art. 6 ;*
> *b) with a fine of 1 to 2 points, failure by the public sector body to update the accessibility statement, according to the provisions of art. 6 paragraph (1) ;*
> *c) with a fine of 1 to 5 points, omitting to include in the specifications the products or services for the creation or modification of websites or mobile applications to be purchased, in compliance with the provisions of Law no. 98/2016 on public procurement, with subsequent amendments and supplements, in order to ensure the accessibility of websites and mobile applications, provided for in art. 9 paragraph (3) ;*
> *d) with a fine of between 5 and 10 points, failure by public sector bodies to meet the accessibility requirements of websites and mobile applications according to the provisions of art. 3 ."*

The coders suspected that Romania utilized a point/scale system for the penalty and agreed that the law should be made clearer so that foreign entities could comply without contextual knowledge.

Throughout the coding process, the coders speculated that vagueness might be intentionally designed. One coder [C2] commented on the vagueness in this particular rule: *"I guess it's good for the government. They get more money then [if companies are confused about the penalty system]."*

A better example can be seen in Croatia:1:

> *"(1) A public sector body responsible for a misdemeanor shall be fined in the amount of HRK 2,000.00 to 50,000.00 if:*
> *a) has not taken all necessary measures to make websites and software solutions for mobile devices more accessible by making them observable, operable, understandable and stable, in accordance with Article 6 of this Act*
> *b) has not made an initial assessment of the extent to which achieving compliance with accessibility requirements imposes a disproportionate burden on that body in accordance with Article 8, paragraphs 1 and 2 of this Act*
> *c) does not regularly publish or update on its website in an accessible format the Accessibility Statement for the website or software solutions for mobile devices if it is not downloaded when downloading the software solution in accordance with Article 9, paragraphs 1 and 3 of this Act*
> *d) has not published a link that would allow all users to notify the authority of any non-compliance with accessibility requirements and to request information about parts of the content that are not accessible in accordance with Article 9, paragraph 2, subparagraph 2 of this Act*
> *e) did not publish a link to the inspection that could be initiated in the event of an unsatisfactory response to a user's notification or request in accordance with Article 9, paragraph 2, subparagraph 3 of this Act*

f) fails to respond to a user's notification or request within 15 days of receipt of the notification or request, or within a subsequent period in accordance with Article 9, paragraph 6, of this Act."

"(2) For the violation referred to in paragraph 1 of this Article, the responsible person in the public sector body shall be fined in the amount of HRK 500.00 to 5,000.00."

Here, specific fines are imposed on public sector bodies and responsible persons. The two coders agreed that holding responsible persons in the public sector bodies accountable was a particularly helpful way to ensure accessibility. In contrast, in most laws, no single person was held accountable.

In France:1, the authority that decides the exact amount of penalty is clearly defined,

"III.-Failure to bring an online public communication service into compliance with the obligations set out in II shall be subject to an administrative penalty, the amount of which, which may not exceed €5,000, is set by the decree in the Council of State mentioned in IV."

Rules May Not Be Strict Enough

Although some laws state the specific penalty amount, the coders thought the relatively small fines may not be able to force companies or public entities to comply. For example, Slovenia:1 imposes a fine of 200 to 2,000 euros on the responsible person of the liable party,

"A fine of 200 to 2,000 euros shall be imposed on the responsible person of the liable party if:
- does not ensure the accessibility of websites and mobile applications in accordance with Article 5 of this Act,
- fails to make an assessment of the disproportionate burden referred to in Article 6 of this Act,
- fails to publish an accessibility statement in accordance with Article 7 of this Act,
- does not provide a link for sending feedback information referred to in the first paragraph of Article 8 of this Act, or
- does not respond to the user in accordance with the second paragraph of Article 8 of this Act."

According to one coder [C2], *"this is a slap on the wrist for public entities, governments, or giant companies like Google."*

A heavier fine was found in US:3, which states,

"(F) Subject to paragraph (5) of this section, if the violator is a manufacturer or service provider subject to the requirements of section 255, 716, or 718, and is determined by the Commission to have violated any such requirement, the manufacturer or provider shall be liable to the United States for a forfeiture penalty of not more than $100,000 for each violation or each day of a continuing violation, except that the amount assessed for any continuing violation shall not exceed a total of $1,000,000 for any single act or failure to act."

One coder [C2] noticed the heavier fine in US accessibility laws compared to their EU counterparts. I, however, noted that rich entities might just pay for 10 days of inaccessibility and stay so, given the maximum penalty outlined in this law.

Overall, the coders expected more rules in the current accessibility laws. When coding US:2, one of the coders commented, *"[C2] Mostly norms. It seems like they want to standardize the practice, but there are no consequences for breaking these laws."* This would, in turn, lead to people's lack of motivation to stay compliant with the accessibility requirements, *"[C2] There's not a consequence here. Why would people care if there's not a consequence? I wouldn't follow it."*

5.5 Discussion

Implications of this work will serve to inform future governance, suggest where current laws can be improved, and direct improved compliance and operationalization of existing governance over accessibility.

5.5.1 Summary of Results

From a descriptive lens, only a few laws (N=6) apply to private sector entities, limiting their applicability. Most laws (N=29) utilized WCAG in some way. Many of the analyzed laws (N=27) are implementations of EU Directive 2016/2102. Norms (N=1,393) are most common in the laws, followed by strategies (N=143) and rules (N=21).

Strategies are used to define the scope of the laws, clarify other aspects of accessibility regulation, and recommend good practices to ensure accessibility.

Norms are used to clarify key aspects of the accessibility laws. EU Directive 2016/2102 provides many helpful guidelines in the form of norms, leading to effective implementations in EU countries at both structure and content levels. Good accessibility laws have characteristics such as the inclusion of the voice of people with disabilities, concrete guidelines and recommendations for software designers to follow, providing details related to budget control and other procedural aspects, and distinguishing between different types of content and devices (e.g., mobile applications vs. websites), often in the form of norms. On the contrary, bad laws leave more questions than clarifications.

Rules are sporadic in laws. Rules can be vague or assume too much of the audience's knowledge of the legal system. As a result, the rules may not be easily understandable by software creators.

5.5.2 Governance Recommendations

I have the following governance recommendations for future legislation of software accessibility.

First, some helpful strategies in the accessibility laws can be formalized as norms or rules. For example, in EU countries' laws implementing EU Directive 2016:2102, strategies tend to be used to define disproportionate burdens for public entities. These could be developed into norms or rules that more clearly delineate when and under what conditions the laws are in effect.

Second, future legislation around software accessibility should build on some good norms and rules. Germany:1 and Poland:1, among others, stand out for their emphasis on centering the voice of people with disabilities, actionable enforcement mechanisms and administrative procedures, providing training for accessibility awareness, and providing technical recommendations for compliance with accessibility requirements. Rules, in particular, should be clear and should not rely on people's legal knowledge when trying to comply. For example, without understanding Romania's point/scale system for punishment, software creators will have difficulty interpreting the consequences of inaccessibility. The details of the consequences should be explicitly stated.

Third, future legislation should avoid the bad regulative statements identified in the analysis. Some laws are overly brief without providing a sufficient level of detail. When borrowing principles from guidelines such as WCAG, legislators should explain the principles, e.g., robust and perceptible, so that software practitioners can have a better understanding when trying to comply. Laws should also provide more definite clarifications on what counts as a disproportionate burden when complying with accessibility requirements. For example, are entities with 50 employees called small entities? Does a budget of $10,000 cause a burden for an entity? Without thresholds, the laws leave too much discretionary space for people and are hardly enforceable.

Fourth, it is worthwhile to reconsider the most effective incentives for public and private entities to comply with accessibility requirements. The laws that do have rules tend to use financial penalties and name-publishing as punishments. However, the punishments may not be sufficient to force the companies, especially rich companies, to comply. The companies may pay the fine, which has a cap ranging from a few thousand to a million dollars, then keep being inaccessible. Name-publishing may work well for companies that rely on reputation to grow, but not as much for companies with products that people have to use on a daily basis, such as Google search engine or Amazon. More adaptive rules pairing the size of punishment with the capacity of companies are recommended.

Lastly, future legislation should draw more insights from academic research or guidelines such as WCAG. Currently, the laws read more like bureaucratic documents with procedural and normative content. Substantive technical guidelines are lacking. Taiwan:1 suggests a certification system to incentivize website developers to comply with accessibility requirements. Germany:1 has specific guidelines regarding the accessibility and usability of sign language. Such implementations are plausible and should appear more in future software accessibility laws.

5.5.3 Implemenation and Compliance Recommendations

From the perspective of software developers and companies, complying with software accessibility requirements requires a deep and contextual understanding of the laws regulating software development. This is not an easy job from multiple angles. First of all, complying with software accessibility requires dedicated knowledge of accessible and inclusive design. If not trained in terms of awareness and knowledge of software accessibility, one may find it difficult to implement guidelines outlined in WCAG, which are emphasized by many EU countries' laws implementing EU Directive 2016/2102. Second, many laws are written in a vague manner and require knowledge of the legal system in the respective country. For companies that are not equipped with a capable legal team, software developers need to be well-versed in laws to comply.

From a realistic perspective, ensuring compliance with the WCAG guidelines is a feasible start, as many accessibility laws emphasize being Perceivable, Operable, Understandable, and Robust, the four principles of WCAG, as their core. W3C provides a comprehensive list of Web accessibility evaluation tools.[3] Software designers and developers can use these tools to remain compliant with WCAG, which, at most times, should lead to compliance with software accessibility laws.

5.5.4 Implications for Governance Research

Several implications for governance research emerged in the process of evaluating software accessibility laws.

First, reading through laws is a time-consuming and often tedious process. Many EU countries' laws implementing EU Directive 2016/2102 are almost identical in structure yet have nuanced differences in content. These nuanced differences may lead to drastically different interpretations and enforcement outcomes, necessitating a closer examination. Tools have been developed to leverage large language models to automate the annotation of legal documents under the governing knowledge commons and contextual integrity (GKC-CI) framework [214]. However, these tools are more helpful in differentiating strategies, norms, and rules and less

[3] https://www.w3.org/WAI/test-evaluate/tools/list/

helpful in generating themes and a high-level understanding. This is why I took a conventional approach to code the lengthy laws manually.

Second, legal and computer science researchers should dedicate more efforts to researching existing software accessibility laws, which currently lack depth and concrete technical recommendations. Past research has presented case studies to understand how well the accessibility laws worked [205], [207], However, limited research focused on evaluating the laws themselves. Although policy comments are a common way to exercise researchers' impact on the legislation process, a retrospective look at existing laws can identify good and bad practices in legislation and suggest better governance practices in the future.

Third, a sizable gap exists in understanding the alignment between software accessibility laws, non-binding guidelines, and software accessibility research. Legislation is a lengthy process, often finding difficulty in catching up with latest technological trends. Without a more efficient and decentralized legislation process, it is hard to incorporate emerging accessibility challenges into laws and mandate new assistive technologies and accessible practices.

Lastly, future research should focus on understanding compliance, i.e., how companies comply with software accessibility laws and navigate the balance between accessibility and shipping speed. Having such insider perspectives can help shape better enforcement mechanisms in future software accessibility laws.

5.6 Conclusion

In this chapter, I examined governance approaches to software accessibility by evaluating software accessibility laws worldwide. The distribution of strategies, norms, and rules revealed a lack of enforceability. Both good and bad characteristics of accessibility laws were identified to inform better governance in the future.

After reporting three empirical chapters on design, education, and governance approaches to software accessibility, I will comprehensively synthesize the three approaches in the upcoming chapter.

6

Discussion

Human-centered ICT depends on the integration of a deep understanding of humans and society, value-centered design, and governance. The constant failure to design inclusive ICT can be partly attributed to the disconnection between efforts from academics and practitioners/educators/policymakers. Through this dissertation, I argue that, with research taking a central role, synthesizing pragmatic insights from research for education practitioners, software designers, and policymakers is a viable way to impact real-world software accessibility.

Design, governance, and education approaches to software accessibility have their own advantages and limitations. Below, I will reflect on lessons learned from three parallel empirical studies and discuss how to combine the three kinds of interventions toward an integrated approach to accessibility.

6.1 A Pragmatic Approach: Research at the Center

As illustrated in Figure 1.1, research sits at the center of the pragmatic, human-centered approach to accessibility. Research can impact design both directly and through education or governance. From a pragmatic perspective, what researchers can do is to (1) formulate design guidelines for designers, (2) translate research into policy recommendations, and (3) translate research into education outreach.

I showed the potential effectiveness of education and design approaches through education outreach and talking to vulnerable populations, respectively. Regarding the governance approach, as Managing Attorney of the D.C. Office Mara Youdelman argued,[1] the Administration has to consider all the comments submitted during a public comment period by law: “The agency really has to review all the comments. While it does not have to explain why it did (or did not) make changes suggested by the comments, it does need to address significant issues that commenters raise. The agency will also need to explain the types of comments it received and whether it made any changes to its proposed rule based on those comments.”

6.1.1 Solution 1: Research Impacts Design Through Design Guidelines

HCI researchers have proposed numerous accessible designs or assistive technologies for people with disabilities. One disillusionment is that these designs are hardly turned into practical products that average people can

[1] https://healthlaw.org/resource/do-my-comments-really-matter-demystifying-the-public-comment-process/

utilize. Zhou et al. found that haptic and visual music devices developed in academia are hardly used by deaf or hard-of-hearing people [215]. Cao et al. identified a huge gap between the publication of academic papers and citations by industrial patents [72].

Instead of waiting to be cited, researchers should develop new ways to convey their research insights. A potentially more useful approach is to turn research insights into actionable design guidelines, which software designers can directly utilize in their design process. HCI researchers should not expect software designers to dig design guidelines from tedious academic papers. They should have a dedicated section in their papers, e.g., “designers' takeaways”, or alternatively translate research into actionable insights in popular/scientific press facing the public, such as Information Matters.

In Chapter 3, I used a formative study to formulate design guidelines and design features that can be implemented in software for cancer survivors with impairments. Software designers can directly use these insights as the first step toward accessible design. This is more time- and resource-efficient than conducting co-design workshops with cancer survivors with various impairments whenever an app is developed [160]. Even those designers who tend to skip or de-emphasize user studies (which is not a good practice by itself) can utilize these design recommendations to make their designs more accessible.

6.1.2 Solution 2: Research Impacts Design Through Education

Educating next-generation software designers/developers about accessibility [24] and ethics [42] is a profound way to instill computational thinking, design thinking, and responsible design/development principles. This way, more accessible and ethical technologies will be designed when accessibility- and ethics-literate designers enter the IT workforce.

In Chapter 4, I integrated research advancement, i.e., simulation games [25], [27], [123] into teaching materials and taught accessibility to high schoolers. The students gained knowledge and awareness of accessibility and empathy for disabilities. Hopefully, they can use the knowledge learned to conduct accessible design practices one day.

6.1.3 Solution 3: Research Impacts Design Through Governance Recommendations

Keeping industrial stakeholders compliant with disability and anti-crimination laws is important since they often lack a financial incentive to make their products accessible – enough money can be earned even without catering to the needs of people with disabilities. However, governance approaches may not always keep pace with technological advancement, failing to regulate emerging technologies such as generative AI and blockchain and emerging challenges such as accessibility and LGBTQ rights.

Empirically driven policy-making is really important and academics can be more directly involved in standardization processes, e.g. NIST privacy standards and CI researchers as a good example. I argue that researchers should impact the governance process by identifying where anti-discrimination and disability laws fall short. Then, by submitting policy comments, researchers can inform policymakers of their research insights, accelerating and optimizing the legislation process. New or updated laws can then better regulate industrial products.

In Chapter 5, through a comprehensive institutional analysis, I identified where accessibility laws and guidelines fell short and recommended how they should be. If such research insights are submitted to policymakers in the form of policy comments, they may be used to update or draft new legislation, in turn impacting design practices in the industry.

6.2 *Evaluating and Comparing Three Approaches*

Design, education, and governance approaches to software accessibility have pros and cons and should be leveraged together to complement each other.

6.2.1 *Design*

In theory, design approaches are most effective in directly impacting industrial practices. It is natural to think that if researchers come up with an accessible feature or an assistive technology, industrial practitioners will follow suit. This is hardly the case in reality. A drastic disconnection was seen between the prevalent assistive technologies in academia and the scarce products for DHH individuals to use to listen to music [215]. A sizable gap exists in translating designs in top HCI conferences into industrial practices in terms of patents [72].

In empirically evaluating the three approaches to accessibility, I discussed with ChatGPT why HCI research in accessibility design is hard to translate into industrial practices, and it insightfully provided several reasons. First, there is a "mismatch between research goals and industry needs." Academic research tends to prioritize innovation and long-term impact, while companies tend to prioritize profitability, scalability, and user adoption – all short-term goals.

Second, there is "a lack of immediate practicality" in academic research. ChatGPT states, "Industry often needs ready-to-deploy solutions, whereas academic research typically offers conceptual frameworks or prototypes that require further development." This speculation aligns best with my thoughts when writing this dissertation and conducting design research. Containing portions of academic papers that practitioners can practically leverage is necessary.

Third, "limited industry-academia collaboration" exists. In other words, academic research and industrial practices are often siloed. ChatGPT gave an example, "Tech giants (e.g., Google, Microsoft) conduct in-house HCI research tailored to their business needs, often ignoring broader academic findings." The lack of motivation from industrial practitioners to leverage academic findings necessitates lightweight communication of academic insights. Ultimately, ChatGPT recommended having "flexible, incremental innovation that aligns with business realities."

My empirical exploration, reflection, and interaction with ChatGPT are not to discourage any accessible design research in academia but to encourage more research into developing and assessing better ways to convey research insights.

In Chapter 3, I extracted accessibility design principles and design features to help software designers come up with more accessible designs. The principles, e.g., "avoiding too many options," are easily implementable, aligning with ChatGPT's recommendation for "flexible, incremental innovation."

I have to acknowledge that whether such guidelines and features are effective in transforming practitioners' practices is unknown without empirical assessment and talking to software designers and developers. Future research should consider expanding my research and talking to different stakeholders in the software industry regarding the best way to convey accessibility design research.

One limitation of the design approach is its voluntary nature, making it less enforceable. If accessibility design principles do not align with corporate goals, they will not be utilized by software designers. This is where governance approaches can step in. Third parties, such as non-profits that promote the rights of people with disabilities, can use accessibility auditing to nudge companies to comply, given the reputational incentive. The authorities can use software accessibility laws to sanction companies that refuse to comply. These are more enforceable ways to ensure the accessibility of software products.

Another limitation of the design approach is that ensuring software accessibility requires domain knowledge in accessible computing, yet this aspect is often overlooked or siloed from design research. Most software practitioners are not trained in accessible computing and may not have the skills and awareness to make software accessible. This is where education approaches to software accessibility can step in by either providing training to software practitioners or teaching next-generation software practitioners accessibility in K-12 and university courses.

6.2.2 Education

Education approaches to accessibility are fundamental in terms of awareness raising and knowledge equipment for software designers. I have taught software accessibility in a wide range of educational settings, including:

- Teaching web accessibility in high school (Chapter 4) [216];
- Teaching web accessibility to K-8 kids [217];
- Teaching mobile accessibility to Information Science majors [218].

Game-based education was well received by different student bodies and praised by students, teachers, and parents for being engaging, informative, and thought-provoking. I further argued teaching accessibility in non-CS courses, such as courses in design and medicine [219].

Despite being promising in promoting a mindset of accessibility, education approaches to software accessibility have several limitations.

First, accessibility education may not have a prompt effect on software accessibility. If a software designer receives some accessibility design principles from an academic paper, they may make a product more accessible in a few days. However, accessibility education, particularly that for K-12 or university students, will only exhibit its effect after the students enter the IT workforce. Such long-term effects are unpredictable [120] and need further investigation.

Second, it is hard to mandate accessibility education in the CS curriculum, both before and after college, without a consensus among teachers regarding the importance of this topic. This approach is even more volatile with the interference of conservative politics [220]. For example, teachers "had to fill out a Freedom of Information Act request from a conservative Super PAC concerning whether the school's curricula included 'critical race theory"' [42]. Accessibility education may face similar challenges.

Third, more tools should be developed for teachers who are not tech-savvy to teach accessibility. I used games to teach software accessibility, which was perceived as a promising way by the high school teachers. More research should happen in this domain.

6.2.3 Governance

Both design and education approaches to software accessibility are voluntary to some extent – designers may not cooperate, and students may not be willing to learn.

Governance approaches have more enforceability. Performing poorly in accessibility auditing creates a bad impression for companies, and violating software accessibility laws may lead to financial and reputational penalties. When companies fail to see an alignment between accessibility and other corporate priorities, laws are the last line of defense to ensure software accessibility.

Like any approach, governance approaches are far from perfect. First, despite being enforceable in theory, real-world laws are not that enforceable. In my evaluation of software accessibility laws, they are often found vague, failing to define key aspects of software accessibility; they have limited rules and stay at the level of social norms instead of enforcement. Better laws should be made to ensure software accessibility.

Second, governance approaches tend to fix issues instead of preventing issues. In this sense, design and education approaches can better curate a culture of accessibility in the industry and society.

Third, it is worthwhile to think about governance beyond laws, such as organizational or agency policies, and sociotechnical governance. The prevalence of norms rather than enforceable rules echoes other areas of tech policy around bias and fairness. Nevertheless, norms are still helpful in shaping a culture of accessibility, especially when united with education approaches.

An integrated approach to software accessibility should combine design, education, and governance interventions. Design research works by directly impacting industrial software practices. Education research works by increasing practitioner preparedness and curating a culture of accessible computing. Governance research works by sharpening accessibility laws to force public and private entities to comply.

7

Conclusion and Future Work

7.1 Summary of Contributions

This dissertation uses three parallel studies to uncover the complementary relationship between design, education, and governance interventions for software accessibility.

Chapter 3 makes two main contributions:

1. I gauged the lived experiences and challenges of cancer survivors interacting with software through a comprehensive formative study combining interviews, a survey, and a diary study.

2. I proposed design principles and features for software designers to follow when designing software for cancer survivors.

Chapter 4 makes two main contributions:

1. I taught software accessibility to a group of high school students through games, exercising a direct impact on them in terms of awareness, knowledge, and empathy regarding accessibility.

2. I suggested the feasibility of teaching the topic of software accessibility before post-secondary education in both CS and non-CS curricula.

Chapter 5 makes two main contributions:

1. I examined a large collection of software accessibility laws around the world to understand the status quo of legislation efforts in ensuring software accessibility.

2. I identified issues in existing laws on software accessibility and suggested ways to improve the governance of software accessibility.

Through a synthesis and reflection on the three empirical chapters, I identified the complementary nature of the design, education, and governance approaches, each with its advantages and limitations.

In particular, the design approach is most effective in directly impacting software practitioners on the premise that researchers convey their ideas and recommendations in an approachable manner. Though there is no empirical evidence, it is hard to imagine software practitioners referring to HCI or computer accessibility papers regularly to inform their design practices. To exercise the impact of research on industrial practices, researchers should extract takeaways from their co-design studies or empirical studies in the form of actionable design principles and design features, so that software practitioners can leverage the research advancements in a seamless manner in their routine work. Possible outlets for conveying such insights include public-facing e-journals such as Information Matters, where researchers summarize their research and provide takeaway messages of around 1,000 words.

The downside of the design approach is that industrial practitioners draw insights from academia on a voluntary basis. Industrial patents have been found delayed in citing academic work in human-computer interaction [72]. Without the incentive of generating patents, software designers may be even less willing to learn from academic efforts to ensure accessibility, especially if they have not been well-equipped to cope with software accessibility challenges in terms of skills and mindset.

The education approach to software accessibility is most effective in preparing the next generation of software designers and developers to design software accessibly. To be realistic, it is barely possible for researchers to go into companies and hold training sessions for their employees in software accessibility. It is more feasible to teach software accessibility in one's own course or collaborate with local K-12 teachers or university colleagues to deliver software accessibility education. This, in fact, already covers a considerate population. Students majoring in computer science, information science, or other STEM-related disciplines are very likely to become involved in the software industry in different roles, from software designers and developers to managers and infrastructure builders. Even university students in seemingly irrelevant majors or high schoolers can still contribute to a more accessible software infrastructure by creating accessible content online, helping people in need around them use software, and in other ways. Equipping students with awareness, knowledge, and empathy regarding accessibility will enable them to think of accessibility as a priority instead of an afterthought in their future software development, design, and use practices.

One major downside of the education approach is that its long-term effect on students' awareness, knowledge, and empathy regarding accessibility is hard to measure. Students may exhibit too optimistic of an increase in knowledge or awareness of accessibility in a short time, just for the sake of a higher grade in the course. Teachers and researchers should come up with more objective and enduring assessments to evaluate the effectiveness of accessibility education. Other limitations of the current education interventions to software accessibility include a lack of presence in non-computing curriculums [219] and a lack of demonstration tools for people without disabilities to experience the difficulty of interacting with software.

Lastly, the governance approach to accessibility is most effective in forcing companies to comply with software accessibility requirements, which often echo the four principles in WCAG: Perceivable, Operable, Understandable, and Robust. Companies often lack an incentive to ensure accessibility, as it does not directly increase revenues or expand the user base. Therefore, it is important to use some enforcement to have them comply.

The governance or legal approach is effective in theory but hardly works in reality. Several reasons may explain the ineffectiveness of the governance approach, according to my research. First, structurally, there are way fewer rules and strategies than norms in accessibility laws. Therefore, they lack an enforcement mechanism and ways to comply with social norms that are largely present in the laws. Secondly, content-wise, accessibility laws are often written in a vague manner or require too much contextual legal knowledge for people to comply. Legislators should make accessibility laws more usable by:

1. Including the voice of people with disabilities in the legislation process;

2. Providing concrete guidelines and recommendations for software designers to follow;

3. Providing details related to budget control and other procedural aspects; and
4. Distinguishing between different types of content and devices (e.g., mobile applications vs. websites).

It is believed that if and only if design, education, and governance approaches are utilized, the enduring issue of software accessibility can be improved.

7.2 Future Research Directions

Given the breadth of the dissertation, there are multiple research directions I intend to pursue regarding design, education, and governance approaches to software accessibility.

7.2.1 Design Approaches to Accessibility

As argued in the dissertation, accommodating the software needs of people with different disabilities requires dedicated studies and design efforts. My ongoing and future design research will center on different populations and work with them to develop accessible designs.

First, Chapter 3 spotlights cancer survivors' software accessibility challenges and software needs. My ultimate goal is to develop a chatbot-based application to help cancer survivors socialize and seek a healthy lifestyle with co-design approaches.

Second, beyond the population of cancer survivors, a significant portion of the older adult population has issues with digital banking due to physical limitations, technical challenges, and distrust of online media. However, there are limited training resources and technological interventions to help older adults overcome these issues. In my ongoing interventional study, I envision improving financial literacy, reducing financial vulnerability, and improving the self-efficacy of older adults with the help of a finance simulator that teaches older adults to accomplish digital banking and e-commerce tasks and learn ways to guard against online security threats, with the aid of helpful challenges, training videos, troubleshooting assistance, and community forum support.

Third, as my research revealed, deaf and hard-of-hearing people had difficulty accessing assistive music devices, such as those leveraging haptic or visual senses [221]. Informed by the formative study, I am currently designing an affordable wearable music device combining haptic and visual (e.g., color) cues to improve DHH people's music experience.

7.2.2 Education Approaches to Accessibility

In my past efforts in teaching software accessibility, I have largely focused on students who will potentially become software practitioners, such as undergraduate students and high schoolers who were taking CS courses.

However, as I argued in the ASSETS workshop proposal [219], teaching accessibility is crucial for students across many disciplines, not just those in computing education. For example, if journalism and media students are trained in accessibility, they will be more willing and able to produce accessible media content after they enter their professions. Training medical and nursing students in accessibility equips them to better meet the diverse needs of patients with disabilities. In the long run, I plan to integrate game-based accessibility education into a broader range of disciplines and conduct long-term and short-term classroom experiments, in collaboration with colleagues in various disciplines.

7.2.3 Governance Approaches to Accessibility

In this dissertation, I report my research on evaluating software accessibility laws from a qualitative lens. In the future, I will leverage natural language processing techniques to assess accessibility laws, as well as policies, at scale. This will deliver a holistic view of the accessibility governance landscape and generate more generalizable results.

Another underexplored aspect of governance approaches to software accessibility is the ad-hoc, voluntary regulation initiated by non-governmental parties such as crowdsourcing workers or end users. Echoing my past research on AI Incident Database [141], I plan to build an Accessibility Incident Database that documents real-world incidents regarding accessibility, such as inaccessible videos and poorly labeled or unlabeled mobile apps. The incidents will be added by crowd workers or end users interacting daily with websites and mobile apps. This database can potentially inform policymakers and industrial designers to make software more accessible.

7.2.4 Broader Research Implications

Besides my own research agenda, future research on improving design, education, and governance approaches should focus on two additional aspects.

First, there is a lack of understanding and evaluation of the best practices for conveying accessibility research. My dissertation suggests potential ways such as eliciting design guidelines, conducting education outreach, and generating governance insights. Future research should empirically evaluate the effectiveness of such approaches by working with designers, teachers, and policymakers in formative or longitudinal studies.

Second, there is a lack of understanding of the connection between the three approaches to accessibility. For example, how can education help software designers better adopt accessible design guidelines? How can designers' perspectives impact legislators' practices, given an effective communication channel between them? Investigating these fundamental questions can help inform better, unified approaches to accessibility in the future.

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A

Materials for Chapter 3

A.1 *Recruitment Message and Survey Questions for Cancer Survivors*

[Recruitment message when distributing the survey through email or on X (formerly Twitter)]
With [another researcher on the team], we're conducting a research study examining best practices for software design for cancer survivors. If you are a cancer survivor who has experienced challenges (such as chemo brain), please take this survey and you will be compensated with a $10 gift card: [survey link that is no longer active].

1. Email
2. Gender
3. Age
4. Race
5. Highest level of education
6. What type of cancer were you diagnosed with? (If you were diagnosed multiple times, select all.)
    - Bladder
    - Bone or soft tissue
    - Brain
    - Breast
    - Cervical
    - Colorectal
    - Eye
    - Head and neck
    - Kidney
    - Leukemia

- Liver
- Lung
- Lymphoma
- Melanoma and related skin cancers
- Myeloma
- Ovarian
- Pancreatic
- Prostate
- Stomach and esophageal
- Testicular
- Thyroid
- Prefer not to say
- Other

7. What stage of cancer were you first diagnosed with?
   - Stage 1
   - Stage 2
   - Stage 3
   - Stage 4
   - I'm not sure
   - Prefer not to say
   - Other

8. Current stage of cancer:
   - No evidence of disease
   - Partial remission
   - Complete remission
   - Same stage as above
   - Cancer has progressed to Stage 2
   - Cancer has progressed to Stage 3
   - Cancer has progressed to Stage 4
   - I'm not sure
   - Prefer not to say
   - Other

9. How many years ago were you diagnosed?

10. Optional comments about diagnosis if you need to clarify anything (including multiple diagnoses).

11. What types of treatment did you receive?
    - Surgery
    - Radiation
    - Chemotherapy
    - Hormonal treatment
    - Other
12. Prior to your diagnosis, did you experience difficulties with any of the following?
    - Visual
    - Hearing
    - Cognitive
    - Physical/motor/dexterity
    - Anxiety/depression
    - Fatigue
    - Other
13. Please explain the nature of these difficulties. If you did not have prior to diagnosis, enter N/A.
14. After your cancer diagnosis and treatment, did you experience any new difficulties in any of these areas?
    - Visual
    - Hearing
    - Cognitive (including chemo brain)
    - Physical/motor/dexterity
    - Anxiety/depression
    - Fatigue
    - Other
15. Please explain the nature of your (new) difficulties. If you do not have any, enter N/A.
16. If you had a cancer-related impairment, how long did the effects last? (Select for multiple impairments as necessary and explain in the next question.)
    - The impairment is still ongoing.
    - I had the impairment for $<$ 6 months.
    - I had the impairment for $<$ 1 year.
    - I had the impairment for $<$ 2 years.
    - I had the impairment for $<$ 3 years.
    - I had the impairment for $<$ 4 years.
    - I had the impairment for $<$ 5 years.

- I had the impairment for < 10 years.
- I had the impairment for 10 years or more.
- Prefer not to say.
- Other

17. If you answered for multiple impairments, please explain.
18. If you had chemotherapy, did you experience the cognitive fog known as “chemo brain"? If so, please describe how it felt and how long it lasted.
19. If you had a cancer-related impairment, did it pose any specific challenges in the use of software (e.g., websites, apps)? (5-point Likert scale – Never to Very often)
    - I had/have difficulty reading text on websites/apps (because it is too small or blurry).
    - I had/have difficulty seeing images/icons on websites/apps.
    - I had/have difficulty hearing audio on websites/apps/videos/podcasts.
    - I had/have difficulty typing.
    - I had/have difficulty manipulating or selecting (e.g., scrolling, zooming, clicking on buttons) on websites/apps.
    - I had/have difficulty following the instructions on websites/apps.
    - I frequently found/find navigating on websites/apps (e.g., finding the correct option or page) to be difficult or confusing.
    - I was/am frequently distracted or had a hard time focusing while using websites/apps.
    - I frequently found/find myself frustrated or annoyed while using software, more than before cancer diagnosis/treatment.
20. Did you experience any difficulties using websites or apps that are not listed above? Please explain.
21. Please provide descriptions of the difficulties faced while using websites or apps - elaborate on the choices above.
22. Which features of website/app design made the use easier?
23. Which features of website/app design made use more challenging?
24. Which websites/apps/programs were particularly easy to use? Why?
25. Which websites/apps/programs were particularly difficult to use? Why?
26. Were there any strategies, technologies, or tools that you used to mitigate the effects of the impairments on software use?
27. Do you have any comments that you'd like to share?
28. Do you consider the impairments that you experienced as a result of cancer and/or its treatment to be a “disability"? Please explain your thoughts.

29. In your experiences with your cancer-related impairment(s), in what ways did you find that technology/software helped with the challenges you faced, and in what ways did technology/software make them more difficult?
30. Thank you for completing the survey! Would you be open to further questions, surveys, or interviews? (Additional compensation would be provided.)

A.2 Interview Script for Cancer Survivors

1. Could you tell me a bit about yourself?
2. Do you have any impairments as a result of cancer and its treatment?
   (a) Can you tell me a little more about it?
3. What types of technology do you use? (Computer, Laptop, Gaming Consoles, Tablets, etc.)
   (a) Is some technology easier to use than others? What makes technology use challenging?
4. What software do you often use? (Social media, learning, job search, food delivery, games, etc.)
   (a) For each type of software
      i. What challenges do you experience when using it?
      ii. Could you give me an example?
      iii. What do you think are some possible solutions to these challenges?
5. Do you use any assistive technology for support when using software? How is it used to help?
   (a) Have you found any techniques to be helpful to you in certain types of software?
6. Do you feel comfortable asking other people for help if you have difficulty accessing/using software?
7. What types of games do you play on your mobile device or computer?
   (a) Has the type of games you play changed since cancer?
   (b) What features made them easy or difficult to play with?
8. How often do you generally exercise per week?
   (a) Has this changed since having cancer?
   (b) What kind of software do you think can help you exercise?
9. Has your social life been impacted by cancer?
   (a) If yes, explain how.
   (b) What kind of software do you think can help your social life?
10. What hobbies do you have?
    (a) Has this changed since cancer?
    (b) What kind of software do you think can support your hobbies?
11. Is there anything else you would like to tell me that could help my study on accessible software for cancer survivors?

A.3 Diary Template for Cancer Survivors

The template starts on the following page.

Please fill out this diary over the course of **a week**, keeping an eye out for **accessibility issues/challenges** that arise when you use digital devices and software/websites. We will compensate you with a $10 gift card for the completion of the diary, with a $5 bonus if it contains at least 7 events and another $5 for the quality of the entries.

Please summarize the impairments that you experience
Vision (e.g. blurred vision, low vision, blindness, color blindness): __________
Physical/motor/dexterity: __________
Auditory (hard of hearing or deaf): __________
Cognitive or neurological (include chemo brain): __________

Number	**Date and time**	**Device used (e.g. desktop computer, laptop computer, mobile phone, ebook reader, etc.)**	**Name of software, app, or website (if website please also list the browser used)**	**Accessibility issue noticed: What was challenging/ difficult/impossible about the software interaction? If you have any ideas for solutions, please list them as well.**	**Identify any information that would have been helpful but was not included**
Example 1	3/4/2024 12 pm	Desktop computer	Website: abc.com, Browser: Chrome	Small font Solution: larger font	I use a magnifier on my computer to read small text
Example 2	3/5/2024 3:30 pm	Mobile phone	Chase banking app	I can't figure out the appropriate menu button for what I need to do Solution: more clearly labeled menu choices	No
1					

2					
3					
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19					
20					

A.4 An Example of Filled Diary Template

The filled table starts on the following page.

Please fill out this diary over the course of **a week**, keeping an eye out for **accessibility issues/challenges** that arise when you use digital devices and software/websites. We will compensate you with a $10 gift card for the completion of the diary, with a $5 bonus if it contains at least 7 events and another $5 for the quality of the entries.

Please summarize the impairments that you experience
Vision (e.g. blurred vision, low vision, blindness, color blindness): Blurred vision
Physical/motor/dexterity: None
Auditory (hard of hearing or deaf): None
Cognitive or neurological (include chemo brain): Chemo brain and related cognitive side effects.

Number	**Date and time**	**Device used (e.g. desktop computer, laptop computer, mobile phone, ebook reader, etc.)**	**Name of software, app, or website (if website please also list the browser used)**	**Accessibility issue noticed: What was challenging/difficult/impossible about the software interaction? If you have any ideas for solutions, please list them as well.**	**Identify any information that would have been helpful but was not included**
Example 1	3/4/2024 12 pm	Desktop computer	Website: abc.com, Browser: Chrome	Small font Solution: larger font	I use a magnifier on my computer to read small text
Example 2	3/5/2024 3:30 pm	Mobile phone	Chase banking app	I can't figure out the appropriate menu button for what I need to do Solution: more clearly labeled menu choices	No
Day 1	05/24/2024 7:16 am	Mobile Phone	SCPK Editor app	I find it difficult to view the writings because of its font size. Solution: Increase in application's text size	Incorporation of zooming gestures such as using two fingers to zoom in and out of the screen
Day 2	05/25/2024 5:57 pm	Mobile phone	Website: Chesstempo.com Chrome	Games like this cause pressure on me making thinking quite difficult for me and sometimes causing me headaches and mental instability.	Provision of opponent rank before playing games so as to play with someone at your level.

				Solution: Provision of adjustable game modes which should help reduce mental stress when gaming.	
Day 3	05/26/2024	Laptop with a gaming pad connected to the desktop	Need For Speed(Driving simulation game) from Google Playstore	I played this game in the evening for leisure. Initially, it was nice because the driving speed was okay and it was interesting when taking turns to another lane and dodging other cars on the road. As the game continued, it got faster and it affected my vision. Sooner I started having experiencing dizziness and cloudy mind. Solution: Controlled game experience and difficulty.	No
Day 4	05/27/2024 12:33 pm	Mobile phone	NovelUp	The app is for reading novels and books. I experienced difficulty in identifying some words because of the size of texts and choice of colors. Recognition of light yellow writings were difficult. Solution: I had to use magnifying glasses to view the written texts.	For the colouration, I had to put my phone on dark screen mode so as to reduce the brightness of the brightly coulored texts.
Day 5	05/28/2024 08:29 am	Mobile Phone	Soduko number game	Just as I try to strongly improve my word use, I also try out matching numbers. I found the Soduko game to be complicated and caused me headaches each time I try to push myself far. Solution: I had to adjust the game	Easy access to adjustments of gaming difficulties.

				difficulty to the easiest and made sure I mastered it before progressing to the next.	
Day 6	05/29/2024 12:30 pm	Laptop	Sketchbook app (For Sketches and graphic designs)	I use this app at leisure times when I'm not playing a game. It allows for incorporation of lines and curves to form meaningful objects. However, since after experiencing the side effects of chemotherapy, carrying out these actions have been challenging as I find it difficult to combine different lines and shade of colours to form meaningful objects. Also, some features looks like they require much attention and mastery to use, example are the kinds of paints available for use. Solution: I had to read reviews of the app again and also watch some YouTube videos to help me out	No
Day 7	05/30/2024 08:45 am	Mobile phone	Website: www.typingclub.com Chrome	As part of some form of re-entry into the community and the world at large, I learn typing online. I experience difficulties with quick typing of words and ability to focus on the keyboard on my phone. Solution: I changed my keyboard design to a picture of something I liked, for me it was picture of nature and foods. I felt more at ease when looking at them to type and it got my focus	Also, adjustment of text size to see what I was writing helped a lot, so that I could know and correct mistakes.

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B

Materials for Chapter 4

B.1 Pre-/Post-Game Survey for High School Students

1. Email
2. Grade in school
3. Gender
4. Race
5. I am currently taking this survey for the following class:
   - Computer Literacy
   - Study Hall
   - Coding Club
   - Digital Media Productions
   - Theatre Class
   - Stage Craft
   - Other
6. Do you know anyone personally who has a disability?
   - Yes, close friend/family
   - Yes, acquaintance/classmate
   - No
   - I'm not sure
   - Prefer not to say
7. Have you created coding projects? If so, describe some that you have done. What have you created? (open-ended)

8. Which languages did you use to create your project(s) (e.g. Scratch, Python, JavaScript)? (open-ended)
9. Who has played/watched/used your creation(s)? (open-ended)
10. Suppose you were coding a game and wanted to make sure that everyone could play it. Which sorts of people should you ask to try it out? (open-ended)
11. Suppose you were creating a voting booth for people to use in an election, and wanted to be sure that everyone could use it. Which sorts of people should you ask to try it out? (open-ended)
12. Please rate your level of agreement with the following statements: (5-point Likert scale – Strongly Disagree to Strongly Agree)
    - People with disabilities are as capable of living independently as people without disabilities.
    - Many current software applications are difficult for people with disabilities to use.
    - People with disabilities are interested in new technology.
    - A person with disabilities should not have to rely on someone around who can help.
    - Software developers should provide technology suitable for use by people with disabilities.
    - People with disabilities are likely to face challenges when interacting with many applications.
    - If I design applications, I will try to keep in mind people with disabilities.
13. For example: If I design applications, I will try ... (open-ended)
14. (Post-game survey) Thank you for participating! Please tell us what you think below.
15. (Post-game survey) Are there any improvements that you suggest making to these games?
16. (Post-game survey) Additional comments.

B.2 Discussion Guide For High School Students (After Game Playing)

1. Have you previously learned or thought about accessibility issues in computer software?
2. What are your current thoughts on the challenges people with disabilities have when using software?
3. How can software designers and developers make applications so people with disabilities can use them?
4. What did you think of the activity?
5. What did you think of the games?
   (a) Were the instructions understandable?
   (b) Was anything confusing?
   (c) Is there anything we should improve?
6. If you were to design a game to teach students about accessibility, how would you design it?
7. Any other comments for us?

B.3 Interview Script for High School CS Teachers

1. What courses do you teach? What grades do you teach?
2. What topics do you usually cover in your computer classes?
   (a) Do you teach any computing concepts in your course(s)? In what way? Could you give me an example?
   (b) Do you teach any social/ethical concepts in your courses(s)? In what way? Could you give me an example?
   (c) How do you balance the teaching of technical and social aspects of computers?
3. Have you taught digital accessibility to students in your classes?
   (a) (If Yes) In what way? What accessibility learning objectives do your courses cover? Could you give me an example?
   (b) (If No) If you do not currently teach about accessibility, would you be interested in teaching accessibility if you were given support? What would that support look like? Which teaching methods would interest you?
4. What barriers do you face (if any) to teaching about accessible design in your classes?
5. Have you previously learned about accessibility issues in computer software?
   (a) (If Yes) How well do you think you understand the concepts of digital accessibility?