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THE IEEE GLOBAL INITIATIVE ON ETHICS OF EXTENDED REALITY (XR) REPORT

EXTENDED REALITY (XR) ETHICS AND DIVERSITY, INCLUSION, AND ACCESSIBILITY

Authored by

Dylan Fox

Isabel Guenette Thornton

Chapter Leaders

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THE IEEE GLOBAL INITIATIVE ON ETHICS OF EXTENDED REALITY (XR) REPORT

EXTENDED REALITY (XR) ETHICS AND DIVERSITY, INCLUSION, ACCESSIBILITY

ABSTRACT

This report is the result of work within the IEEE Global Initiative on Ethics of Extended Reality (XR), a multidiscipline group of industry practitioners, ethicists, academics, researchers, educators, and technology enthusiasts. It has been written to focus on a wide range of ethical issues related to XR within the medicine domain. This report builds on work outlined in the "Extended Reality" chapter of the IEEE's seminal ethics-focused publication *Ethically Aligned Design*. XR is a term used to broadly refer to a suite of immersive technologies including virtual reality, augmented reality, and spatial computing. The scope of this report is the exploration of ethics-related issues to support the development, design, and deployment of XR applications in terms of diversity, inclusion and accessibility and the aim is to initiate expert-driven, multidiscipline analysis of the evolving XR Ethics requirements, with a vision to propose solutions, technologies, and standards in future updates. The set of recommendations within this report will hopefully contribute to industry conceptualization of socio-technological issues, highlight concreted recommendations, and lay the groundwork for future technical-standardization activities.

MONIQUE J. MORROW & MATHANA

CHAIR & VICE CHAIR

IEEE GLOBAL INITIATIVE FOR ETHICAL EXTENDED REALTY

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1. BACKGROUND

XR allows for novel interactions and a never-before-seen level of immersion in a digital medium, but these bring with them new accessibility challenges. XR systems must be created accessibly and affordably, lest people with disabilities and other marginalized populations be left behind and face increased discrimination and inequity in access to technology.

Discrimination and a lack of equity are also problems for XR beyond the issue of access. XR systems must be created inclusively in order to avoid the tendency of new technologies to reflect existing social biases and power relations and reproduce or exacerbate inequalities [1].[1] Instead, inclusive XR must provide fair opportunities and equitable experiences for users.

1.1. DISCRIMINATION IN TECHNOLOGY ACCESS

People with disabilities have long faced discrimination in regard to their access to information technology. With much new technology being created by predominantly able-bodied [2] white men [3], it tends to reflect their needs and abilities. This is a problem for people who do not fit into those two categories. While accessibility features like captions and keyboard input are helpful for all users, they make all the difference for many people with disabilities who might not be able to access technology without these features. They run the risk of being excluded from the digital world. Inaccessibility is not the only cause of discrimination in technology access. Poverty, discrimination due to race or gender, and lack of access to electricity and internet infrastructure can also deepen the divide [4].

1.2. DISCRIMINATION IN TECHNOLOGY USER EXPERIENCES AND EFFECTS

While equity in access to new technologies such as XR is a crucial concern, it is also necessary to examine whether the experience and effects of using these technologies are discriminatory, reproducing rather than ameliorating inequalities for marginalized populations. Tressie McMillan Cottom, a sociologist with an expertise in digital technology and racial capitalism, suggests that "digital divides may not go far enough to capture the various intersections of privilege, access, and power that operate online and offline simultaneously and which can also be mutually constitutive." [5] McMillan Cottom finds that

[1] Numbers in brackets refer to publications list in Section 4.

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internet technologies tend to have "amplified and reworked existing social relations" rather than providing new paths to equity [6]. This problem is discussed in this paper as a particularly relevant concern for XR. Of course, this discussion does not represent the entire scope of challenges for inclusion and diversity in XR—a scope that this body plans to increase and further develop in future work.

1.3. CHALLENGES OF XR ACCESSIBILITY

XR technologies are especially at risk for the exclusion of people with disabilities based on their immersive nature. For example, consider an adventure game with a sword-wielding hero. With a traditional 2D interface, a player might press a button to swing their sword; in an XR version, they might physically swing their controller, an act requiring much more physical dexterity. If the designers do not consider an accessible alternative, many disabled gamers would be excluded.

XR also requires rethinking existing accessibility features for immersive formats. Features like captions are well understood on rectangular 2D screens but present many new challenges in XR. For example, how should a user be cued to a speaker behind them? Should captions appear at a set distance and risk being occluded by other content, or render in front and risk disorienting the user? Groups such as the W3C Immersive Captions Community Group [7] and XR Access [8] are actively formulating best practices to answer these questions.

1.4. CHALLENGES OF XR EQUITY

There are many reasons why XR technologies are at particular risk for problems relating to equity, including: the immersive and often social nature of XR; its affordances for individualized experiences and as a platform for prosumption or for social engineering; and its dependence on the collection, algorithmic analysis, and rapid use of a wide range of personal data, including biological data. Many of these challenges also represent opportunities for the medium. The immersive nature of XR is such that XR worlds are often shaped in a totalizing way. XR worlds define the "field of the possibles" [9] for an XR user and have the potential to reflect and manifest biases and inequalities, causing harm to users. While the capacity to develop individualized experiences may mitigate this, it may also introduce other challenges if individualized experiences are not thoughtfully built for a diversity of individuals, communities, and cultures; at the same time, differences in individualized experiences may also prove discriminatory.

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Another challenge for equity in XR is predatory inclusion, “the logic, organization, and technique of including marginalized consumer-citizens into ostensibly democratizing mobility schemes on extractive terms.” [6]. For example, XR applications include some form of “prosumption” practices in which “consumers collaborate with companies or with other consumers to produce things of value.” [10] For example, users may build virtual assets such as avatars, avatar accessories, and virtual objects and spaces, or may create virtual events and performance that bring value to an XR platform or product. There is a danger that this uncompensated labor is done by marginalized users, whose work is appropriated by other users and platforms themselves, such has been found on social media sites like TikTok and Twitter [11]. XR applications that depend on prosumption practices are merely one example of how users may be included in ways that are extractive, and risk reproducing and exacerbating existing social inequalities.

The use of XR for social engineering, such as for human resources training at work or an immersive experience putting the user in the shoes of a disaster victim, may explicitly intend to reduce biases and discrimination and promote compassion. However, despite these intentions, social engineering or prosocial XR projects may instead center and empathically invest in XR makers’ experiences, rather than the experience of marginalized subjects [12]. A paucity of research on the prosocial potential of XR and flawed assumptions of universality on the part of makers contribute to the challenge of developing XR for effective and equitable prosocial purposes.

Lastly, XR technologies’ reliance on collecting, analyzing, and using personal data, introduces various challenges, many of which are described elsewhere in this report. However, XR applications’ collection of data, including biological data like eye-, hand-, and head-tracking, and the accumulation of user data from other social media platforms, introduces particular concerns for equity. Firstly, because marginalized populations have historically been disproportionately affected by privacy concerns, and secondly because the data collection, analysis, and use processes in XR technologies are likely to be obfuscated as well as vast. As stated by Tressie McMillan Cottom: “obfuscation privatizes information by making it inaccessible in practice. Information is the vessel for social actions and social facts. If information is inaccessible, the objects of everyday life are too.” [6] While a potential obfuscation of personal data and its uses are a problem for all users, a lack of transparency is a particular concern for marginalized groups, as it provides what McMillan Cottom calls a situation where “decision making can be veiled from democratic inquiry” [6] and therefore remain unexamined for issues of equity, inclusion and bias.

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These are only some of the challenges that may arise in the development of equitable XR. Interdisciplinary collaboration across diverse user-stakeholders, developers, and policy-makers, aided by further research, is needed in order to further articulate and discover these challenges and develop mitigations and best practices. With XR rapidly moving from a novel entertainment tool to an essential technology for communication, education, medicine, and telework, it is vital to further consider, and ideally resolve these and other challenges to ensure that people with disabilities are not left behind, and that XR can serve all users equitably.

1.5. OPPORTUNITIES FOR XR

The potential benefits of XR for remote work, education, training, medicine, and communication are substantial, and must be made accessible and equitable for a diverse range of users. If developed equitably, XR technologies may afford particular opportunities for marginalized groups. The ability to customize and individualize experiences for safety, privacy and accessibility, or, in the case of avatar customization, to allow users to more inclusively represent themselves are common examples, as is the potential benefit of new community building, collaboration, and communication using XR technologies [13].

While equal and equitable access for mainstream applications remains an ethical priority, the opportunities for XR applications specifically aimed at people with disabilities should not be overlooked. XR has proven to be effective in arenas such as treating phantom limb pain [14], teaching communication skills to children with autism spectrum disorders [15], or helping blind people navigate unfamiliar spaces [16]. Additionally, XR technology can make a difference in issues with which people with disabilities and other groups have historically struggled. For example, XR training and telework can open up new routes to employment [17] for people with disabilities, which is important considering that only 17.9% of people with disabilities were employed in 2020 compared to 61.8% of those without [18]. It could also help combat the social isolation [19] that afflicts many people with disabilities.

Finally, while it is always dangerous to equate a brief demonstration with lived experience [20], XR could create more empathy [21] among able-bodied people for the discrimination that people with disabilities and other groups face every day. While offering new opportunities for perspective taking, it is worth noting that the social engineering potential of XR is highly dependent on the context and execution of

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pro-social and anti-bias applications, which may also have adverse effects [13], and more research is needed to develop the opportunities and challenges of XR used in this way.

For additional information, read "Current and Potential Uses of AR/VR for Equity and Inclusion" by Ellysse Dick of the Information Technology and Innovation Foundation [1].

2. RECOMMENDATIONS

2.1. RECOMMENDATIONS FOR POLICY MAKERS

"Principles and Policies to Unlock the Potential of AR/VR for Equity and Inclusion" [13] by Ellysse Dick of the Information Technology and Innovation Foundation offers an excellent list of suggestions for policy makers and other decision makers. Excerpts are repeated here.

2.1.1. REVIEW AND CLARIFY ACCESSIBILITY, ANTI-DISCRIMINATION, AND PRIVACY LAWS FOR IMMERSIVE TECHNOLOGIES

While immersive technologies will not require new technology-specific regulation around equity and access, it is still uncertain how current laws written with 2D interfaces in mind will apply to them. Clarifying this uncertainty could increase adoption and experimentation with XR applications.

2.1.1.1 ENSURE ACCESSIBLE TECHNOLOGY

The Department of Justice should review compliance requirements for entities subject to Title II and Title III of the American Disabilities Act, and Section 508, including "effective communication" rules to ensure people with vision, hearing, or speech disabilities can effectively receive audiovisual information, to determine when and how these requirements apply to AR/VR devices and applications.

2.1.1.2 PREVENT DISCRIMINATION

The EEOC should issue guidance on how existing laws apply to AR/VR devices and applications used in hiring, training, and other workplace functions, including employer obligations to provide reasonable accommodations for candidates and employees with disabilities and on how to mitigate discrimination and harassment within multi-user virtual experiences that would be illegal in physical space.

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2.1.1.3 PROTECT CONSTITUTIONAL RIGHTS

AR applications raise concerns about reasonable expectations of privacy in public space, as they cannot only record audiovisual information, but also process and aggregate data about a user's surroundings in real time. This information gathering may present special considerations for bystander privacy, especially when government and law enforcement use the technology. To address potential concerns, the Department of Justice should issue guidelines for law enforcement development and implementation of AR/VR solutions to ensure they maintain First and Fourth Amendment rights protections for the communities in which they deploy this technology.

2.1.2. INVEST IN RESEARCH AND DEVELOPMENT OF AN INCLUSIVE AR/VR ECOSYSTEM

Government investments in relevant research and innovation—including implementing inclusive AR/VR solutions within government—will help to form a strong foundation for equity and inclusion in AR/VR more broadly.

2.1.2.1 ACCELERATE RESEARCH AND INNOVATION IN INCLUSIVE AR/VR

Government agencies should provide funding for projects and initiatives that build a robust knowledge base around both the ways in which AR/VR can promote equity and inclusion as well as the potential risks or barriers that AR/VR solutions might raise for underserved communities.

Perhaps the most immediate need is greater research into accessible and inclusive design, as knowledge of what is possible and effective is needed before policymakers and industry actors can put standard practices in place. To address this knowledge gap, the National Science Foundation should dedicate funding to establish research projects and programs that explore creative solutions to designing immersive experiences that create value for users with disabilities. In addition, Congress should provide funding to the U.S. Access Board to develop federal standards for accessible AR/VR so each agency does not have to resolve these questions independently.

Some experts in the corporate Diversity, Equity, and Inclusion (DEI) space hope that AR/VR tools could reduce instances of implicit bias and discrimination by creating immersive trainings or simulations that let participants take on the perspectives of others. However, other equity and inclusion advocates have cautioned that such interventions could have adverse consequences. Flagship research investments

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should engage the Department of Education, the Department of Justice, and the Department of Health and Human Services to determine whether AR/VR-based empathy interventions could reduce instances of bias in education, law enforcement, and health or other public services.

2.1.2.2 IMPLEMENT INCLUSIVE AR/VR SOLUTIONS ACROSS GOVERNMENT

In addition to facilitating greater understanding of equity and inclusion in VR, policymakers should strive to put this research into practice by introducing inclusion-oriented AR/VR solutions across government activities. This would create more demand for inclusive AR/VR innovations, encouraging these approaches in both the development and implementation of AR/VR solutions in other sectors beyond government use.

Government agencies should explore possible uses of AR/VR solutions to recruit, train, and engage a diverse federal workforce. Inclusive workforce development efforts should also maintain a high standard of accessibility and inclusion to encourage innovation and set expectations for workplace development solutions in other sectors beyond government.

The ability to overcome challenges of physical space would also allow government agencies to make public services more easily available to individuals or communities with limited access due to distance or other physical barriers; for example, conducting remote inspections using AR, offering virtual skills assessments for driving or operating equipment, and establishing VR alternatives for services such as mental health counseling.

For AR/VR to become mainstream, it will need to be made available to more than those who currently have the resources, physical ability, and technical knowledge necessary to take advantage of them. Government agencies should include initiatives to mitigate both technical and non-technical barriers to access whenever they implement public-facing AR/VR solutions. At the most basic level, this means ensuring more potential users have access to the necessary AR/VR devices and high-speed Internet. One way to affordably expand access in an equitable way is to expand community access to these devices, through public libraries, schools, or community labs.

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2.1.3. ESTABLISH STANDARDS FOR EQUITY AND INCLUSION IN AR/VR EXPERIENCES

Policymakers should work with industry as well as stakeholder communities to develop robust and actionable guidelines and clear standards for inclusive AR/VR.

2.1.3.1 GOVERNMENT PROCUREMENT AND AUDITING

Federal agencies should establish baseline standards for accessible and inclusive AR/VR by including these parameters in procurement and auditing processes. The GSA should work with stakeholders to develop guidelines for developing and implementing AR/VR solutions that include and exceed the basic accessibility and equity requirements required by law.

2.1.3.2 INDUSTRY STANDARDS AND BEST PRACTICES

In addition to establishing parameters for equity and inclusion in government use of AR/VR, policymakers should facilitate the development of both technical standards and more broadly defined best practices to ensure equity and inclusion is at the center of AR/VR design and implementation across sectors. Policymakers can draw from efforts such as the Cyber XR Coalition, the Partnership on Employment and Accessible Technology (PEAT), the World Wide Web Consortium (W3C), and the XR Access Initiative. Policymakers should strengthen existing efforts to develop standards and guidelines for accessible design in AR/VR. A multistakeholder effort should consider the best ways to take advantage of the highly customizable nature of AR/VR applications to optimize these experiences for users with disabilities or temporary impairments and reduce the need for after-the-fact accommodations or additional hardware. The Department of Commerce should form a working group to allow civil society, government, and industry actors to collaborate toward best practices for user protections in immersive experiences as well as responses to instances of harassment and abuse, particularly in multi-user experiences that are managed by employers, educators, or public service providers. A framework could include identifying real-world risks and harms that could translate into immersive experience; developing robust codes of conduct; establishing privacy settings and real-time safety tools; and providing guidance on content monitoring and moderation.

Finally, best practices should extend beyond baselines for accessibility, privacy, and safety to provide more specific guidance for government agencies, businesses, and service providers who are considering implementing AR/VR solutions. Agencies that oversee the areas of greatest potential impact should put

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forward additional guidelines that build on these multi-stakeholder efforts.

2.2. RECOMMENDATIONS FOR XR CREATORS

From the conception phase to user testing to post-launch, XR creators should actively, consistently, and iteratively consider and include the needs and feedback from underrepresented communities, people with disabilities and others that may be impacted by the product [13]. Ideally, this work will discover and establish industry best practices, which may help reduce the actual or perceived opportunity costs [13] of future equitable development. During development, it is important to keep in mind values such as transparency, safety, privacy, self-determination of data, and access (both for people with disabilities and for users who may not have access to high-speed internet, equipment, or private spaces in which to use XR tools). A full description of the current best practices for accessible and inclusive XR is out of the scope of this document. However, an excellent list is available from XR Association's Developer's Guide, Chapter Three: Accessibility & Inclusive Design in Immersive Experiences [22]. A brief list of best practices is repeated in 2.2.1. Additional recommendations can be found here:

- XR Access Resources Page [23]
- W3C XR Accessibility User Requirements [24]
- Oculus "Designing Accessible VR Experiences" [25] and Accessibility VRCs [26]
- Game Accessibility Guidelines [27]

Note that open-source repositories of accessible code snippets demonstrating how to implement these features are still under development by organizations such as XR Access and the XR Association.

2.2.1. GENERAL BEST PRACTICES (REPEATED FROM THE XR ASSOCIATION DEVELOPER'S GUIDE, CHAPTER THREE)

2.2.1.1 BEST PRACTICES FOR INCLUSIVE DESIGN

Provide comparable experiences for all users. Give users control of their experience by providing them with various options for how to complete tasks and/or how to alter their XR environment to fit their needs or desires.

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2.2.1.2 REMOVING OR REDUCING BACKGROUND DETAILS AND AUDIO

Those who are visually impaired or have cognitive or intellectual disabilities may have difficulty discerning the most important experience options or tasks amidst rich background visuals. Similarly, for people with hearing loss or those with cognitive or intellectual disabilities, background audio that is not essential to the experience could be confusing or disorienting. By providing users the option to remove or reduce background visual and audio detail, users may better distinguish the most important activities or tasks in the application.

2.2.1.3 UNDO/REDO FUNCTIONS

Regardless of disability, all people make mistakes when using XR platforms and apps. Allowing users to undo or redo actions they have made in error or because of imprecision would aid all users but is especially helpful to improve the experience for users with physical, cognitive, visual, or auditory disabilities. For example, users who have physical dexterity disabilities, perhaps tremors or a broken finger, may be more likely to inadvertently make imprecise choices when using certain hardware. Additionally, users with disabilities may also benefit from a function that requires them to confirm an action before it happens, so they can correct an error that otherwise would be irreversible.

2.2.1.4 REDUCING SPEED AND SETTING UP ACTION SEQUENCES

Users may at times have difficulty quickly and accurately reacting to prompts, experience options, and/or physical or reflex challenges due to mobility, vision, auditory, or cognitive disabilities. To enable user progress, it may be helpful to allow users to reduce the speed of the app or to increase the time allotted for making decisions or completing challenges. Similarly, allowing users to pause the app or game to set up action sequences for tasks that require several steps may aid them in ensuring they can accurately respond to each challenge.

2.2.1.5 BYPASS FUNCTIONS

XR experiences that include physical or reflex challenges and/or complex puzzles or other decision-making tasks may be taxing for some users with physical or cognitive disabilities. Additionally, timed tasks put pressure on users who cannot move or make decisions quickly. Adding a bypass function would permit users to skip challenging or timed experiences while still allowing them to progress in the app. Other users with visual or hearing loss may also want to bypass tasks that prove frustrating or time-consuming.

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2.2.1.6 SAVE PROGRESS

Users benefit from being allowed to save their progress in an XR experience for a variety of reasons, such as unexpected real-world interruptions, difficulty completing tasks in the app, or just because they are ready to end the experience. For users with disabilities, having to end the experience and restart later may require them to repeat experiences that may have been challenging for them to complete in the first instance. Therefore, it is recommended that platform and app developers include a function that allows users to save their progress at any time to avoid the need to repeat challenging actions or simply to allow them to pick up where they left off on the experience. Developers also should allow users to skip challenging actions or reduce the difficulty of challenging tasks.

2.2.2. VISUAL ACCESSIBILITY

2.2.2.1 ALTERING THE SIZE OF OBJECTS, ELEMENTS, AND TEXT

There are several ways developers can allow users to control the visual elements in an app that would aid low vision users in completing tasks and/or enhancing their experience. These include allowing users to:

- Magnify or reduce objects and text to make them larger or smaller
- Change fonts for more easily readable text
- Add contrasts or edge enhancements to highlight objects and text
- Change foreground or background colors of text
- Change the brightness levels in the app
- Employ peripheral maps to show objects outside of the field of vision

2.2.2.2 AUDIO AUGMENTATION AND TEXT-TO-SPEECH

Audio augmentation is an important feature that should be available to users with vision loss. Text-to-speech (TTS), also known as “read aloud,” programs may work especially well to ensure that users who otherwise cannot read text instructions, labels, or other written elements in an app are able to understand and interact with the app effectively. TTS is already a built-in feature of operating systems for computers, smartphones and tablets, and developers should consult existing software solutions when designing their own XR TTS technology and/or build their platform to natively support an existing TTS technology. Developers also should include optical character recognition as a feature of TTS, so that words included in images that may be used in XR apps can be deciphered by low vision users. In addition to TTS, audio augmentation elements should include labeling objects or elements and allow users to

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have those objects audibly identified as they encounter or explore those objects in the platform or app.

2.2.2.3 COLOR FILTERS AND SYMBOLS

To support users that cannot discern color, developers should either allow users to recolor the interface and objects, provide shapes or symbols alongside meaningful colors, or provide textures on objects or elements to help distinguish information in-app. These methods allow users to comprehend information in the app communicated by color.

2.2.2.4 SCRIM OR SCRIM-LIKE OVERLAYS

A scrim is a translucent gradient layer that aids in making text more readable against background pictures, colors, objects, and other elements that might affect a user's ability to read it. Where other methods of making text more readable—such as blurring underlying images or using text boxes—can obscure background information and elements, a scrim's semitransparent layer still allows the user to see the image or object behind it, while providing text that is readable.

For programs that require readable texts and/or captioning for deaf or hard of hearing users, using a scrim-like overlay is a potential solution for developers to help ensure all users can read and understand the text display. However, it is important to also ensure that scrims or scrim-like overlays do not introduce color gradients that may make the text unreadable by users with vision loss, create other difficulties in reading the text, or prevent the user from otherwise experiencing the virtual environment

2.2.3. DEAF AND HARD OF HEARING

2.2.3.1 CAPTIONING AUDIO FEATURES

One of the most common ways to make XR accessible to the deaf and hard of hearing is by providing captions or subtitles for audio features. However, there are several considerations developers should consider when providing captions to ensure the captions are readable given the dynamism of XR technology.

For example, developers may want to consider allowing users to choose where to place captions and allow users to move them to ensure other visual aspects of the app are observable. Developers also should allow users to change the font as well as the colors of captions and their background to make them easier to read if the background colors in the interface dynamically change.

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If a feature in the app involves more than one speaker, the captions should clearly indicate or label which speaker is talking. In addition to the previous recommendations, there are many useful guides that are publicly available for how to ensure high-quality captions that meet industry standards, which have been developed over decades for captioning of television audio. While there are no standard captioning guidelines specifically for XR, television broadcast captioning guidelines may prove helpful to XR developers. As a starting point, developers should consult captioning guidelines, which provide information on the recommended number of characters per line, characters per second, and standards for punctuation, among other things. Some government agencies, such as the U.S. Federal Communications Commission, have published specific recommendations for broadcast captioning, and the WCAG 2.1 has guidelines and resources for online accessibility and captioning that may be helpful in developing captioning for XR.

While standard two-dimensional captioning for media is relatively straightforward, developing three-dimensional captioning for XR poses an added challenge, given the difficulty in predicting where a user may look or turn at any given moment.

2.2.3.2 USING ICONS TO IDENTIFY AUDIO FEATURES

Developers should use icons or other indicators to identify for users how they should move their heads or reorient their focus to ensure they are able to see the direction from which verbal and non-verbal audio features are emanating.

Additionally, developers may want to use icons or captions to indicate background sounds or other non-speech indicators, but they should ensure such indicators specify the source or direction from which the sound is coming. In gaming, for example, this may include indicating the direction of incoming gunfire or approaching characters.

When creating icons for XR, however, it is important to remember that there is no standardized iconography across geographic regions or cultures. Developers should ensure when creating icons that those icons are culturally and geographically sensitive and do not evoke different, or even offensive, connotations in different cultures and regions of the world.

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2.2.3.3 SIGN LANGUAGE

Developers may want to consider augmenting their captions with an option to persistently display sign language interpretation within the app. Just as with captioning, developers should allow users to control the placement of the sign language visual to ensure other visual information is not obscured.

Whatever features developers include, they also should provide a way for users to turn these various features on or off—such as captions, sign language, background noise icons, etc., so that users can customize their experience and choose the information that best suits their needs.

2.2.3.4 MONO AUDIO

Users with hearing loss in only one ear may not be able to hear everything in a stereo recording, which splits audio into left and right channels, particularly when using headphones. Platform developers should include a feature that allows users to switch from stereo to mono audio so both stereo channels can be heard in either ear. Keep in mind mono audio will no longer contain information on the directionality of an audio source so the directionality will need to be communicated using other methods, such as with icons or other indicators. For reference, a "mono audio" feature is already included on most smartphones as an accessibility feature.

2.2.4. MOBILITY DISABILITIES

2.2.4.1 SETTINGS AND MENU OPTIONS

Being able to configure usability preferences when initially setting up their XR experience is an important feature for those with mobility disabilities, as is allowing users to save those preferences for future interactions with the program. Some of those preferences should include:

- Allowing users to choose to have the app assist them in navigating the interface and in helping them to complete any tasks, such as might occur in workplace training programs or in gaming.
- Allowing users to receive assistance in some aspects of the program by enabling a separate controller or sensor.
- Allowing users to access the experience from a seated, reclining, or stationary position, if the application otherwise would require standing or body movements to access its full content.

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If the XR design requires users to use multiple buttons or controllers to navigate through the program, there are several ways a developer can make it easier for those with mobility issues to experience the application:

- Allowing users to automate some actions to reduce the number of physical actions they must make within an app.
- Allowing users to map several actions to a single controller button or action to be able to complete complex multi-step actions or choices in a sequence.
- Allowing remapping of controls onto alternate controllers, sensors, or keyboards.
- Allowing remapping of controls on the standard controller to ensure the user can reach the necessary controls.

2.2.4.2 DYNAMIC FOVEATED RENDERING AND EYE TRACKING

Some XR hardware developers are working to incorporate eye tracking and dynamic foveated rendering features into their products to improve the performance of the hardware as well as the user's experience. Foveated rendering reduces the image quality in a user's peripheral vision while providing clear and detailed images at the eyes' focal point. Dynamic foveated rendering uses eye tracking to move the user's field of vision as the user's eyes move.

When developing apps or platforms for such hardware, software developers can use the built-in eye-tracking and foveated rendering features to create an option for users with significant mobility disabilities, such as paralysis or severe tremors, to select eye-tracking as their primary way of manipulating the interface and progressing through the app.

Eye tracking and foveated rendering techniques developers can use to increase accessibility include the following:

- Interface navigation
- Input selection
- Automatic scrolling
- Aim assistance
- Object selection

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- Text and fine details rendering quality
- Analytics and user research

2.2.4.3 CONTROLLER-FREE HAND TRACKING

With the advent of controller-free hand-tracking hardware, developers have the opportunity to design software to match the technology. This important accessibility feature can help address the difficulty in handling controllers that users with impairments to fine motor skills or the ability to grasp and press buttons may have.

A key design component of hand tracking software will be in allowing the user to have both absolute and relative interactions with the app to ensure that the user can both directly "touch" an object nearby (absolute) and control or manipulate objects farther away (relative). Some hardware developers with hand-tracking functionality have published guides for software developers to use when designing apps for such hardware.

2.2.5. COGNITIVE DISABILITIES

Just as with mobility disabilities, those with cognitive disabilities may want to save their settings and preferences for future use of the platform. Additional settings that would aid users with cognitive disabilities include the following:

- Providing on-demand functions that allow the user to receive assistance in orienting themselves in the experience or to receive more context about their progression in the app. Such options should provide information to users about where they are in the virtual space, what they can or should do next, what their current progress in the app is, etc.
- Providing in-app prompts, such as reminders, help topics, introductions to new features, among other things, to assist the user in progressing through the experience.
- Providing training opportunities for users to experiment with the interface and control configurations so they can learn the potential challenges they may face and choose their settings accordingly.
- If an app includes challenges or tasks that must be completed, allowing users to review their objectives—both completed and future—to reorient them in the application and

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ensure they can progress in the app effectively.

- Allowing users to hide distracting or noncritical interface components, including visual, audio and/or animated components, to ensure they are able to focus on the most essential information being communicated to them.
- If the design requires users to use separate controllers to accomplish tasks, allowing users to create control reviews for the interface to help the user navigate the controllers more accurately, and allowing users to reduce the number of controls in order to limit the number of things they have to do to accurately complete any objectives contained in the program.

3. CONCLUSIONS

XR technologies are already used in a variety of fields, many key to human wellbeing and flourishing, such as work, education, medicine, communication, and training. Therefore, it is vital that XR is developed inclusively, particularly in the early stages of industry development during which XR platforms set foundation and standard practices. As an immersive and visceral medium that often engages with large quantities of personal data, XR technologies may be complex and challenging to develop in an equitable, accessible, and inclusive way. The discussions in this report represent only some of the challenges that may arise in XR development. More research into these and other challenges, as well as potential resolutions and opportunities in XR development, is critically needed. Thoughtful research, along with transparency in development decision-making, consulting a diversity of user-stakeholders in the development process, robust and inclusive user testing at all stages of development, and interdisciplinary collaboration are all recommended to facilitate the discovery of new challenges as well as fruitful paths forward for policy and development alike. XR technologies' use in a variety of fields already provides an opportunity to take advantage of a variety of perspectives, and it is crucial to ensure that the voices of marginalized communities and people with disabilities are also at the forefront of XR development.

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