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*Article*

# Enhancing the User Experience (UX) Development Life Cycle to Support Underrepresented Groups

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**Abstract:** This paper addressed critical gaps in traditional User Experience (UX) development life cycles that had systematically marginalized underrepresented groups—specifically individuals with disabilities, older adults, linguistic minorities, and those with limited digital literacy. As digital systems increasingly mediated access to essential services, this exclusion perpetuated social inequities and technological disenfranchisement. The study proposed a multidimensional framework to integrate inclusive design principles across all phases of the UX lifecycle, emphasizing stakeholder expansion, participatory design, intersectional analysis, and long-term engagement with marginalized communities. Furthermore, the paper introduced a structured gap analysis methodology to evaluate the disparity between a function's criticality and its accessibility across diverse user profiles. It advocated for adaptive interfaces, modular systems, and AI-assisted personalization as viable design strategies to meet heterogeneous user needs while maintaining coherence. The research also explored the evolving role of UX in supporting mission-critical domains such as banking, healthcare, and government services, mapping progress alongside persistent exclusion patterns. It concluded with foresight into future UX challenges posed by emerging technologies such as spatial computing, ambient intelligence, and brain-computer interfaces, and stressed the necessity of institutional transformation, ethical AI design, and continuous community involvement to ensure digital equity. This study repositioned inclusive UX not merely as a compliance requirement, but as a moral and design imperative aligned with the principles of human-centered computing and technological justice. Through critical analysis of BBC's Global Experience Language (GEL) and Microsoft's Inclusive Design Toolkit, the paper illustrated how embedding accessibility and flexibility from the outset enabled scalable, sustainable inclusion. These examples demonstrated the effectiveness of embedding inclusive design principles early in development, utilizing flexible design components, and continuously engaging diverse users. By learning from these approaches, this study advocated for a UX framework that prioritizes diverse user needs throughout the design lifecycle.

**Keywords:** user experience; UX; inclusive design; accessibility in UX; underrepresented users; UX development lifecycle; intersectional user research; adaptive interfaces; digital equity; participatory design; accessibility gap analysis; ethical technology design; human-centered computing

## 1. Introduction

### *1.1. Background*

As digital technologies increasingly support essential life functions, ensuring these systems are accessible and usable by all individuals is a matter of equity and inclusion. Traditional user experience (UX) design often centers on so-called typical users, unintentionally excluding underrepresented groups such as people with disabilities, older adults, linguistic minorities, individuals from low socioeconomic backgrounds, and those with limited digital literacy.

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Growing awareness of digital divides and technological inequalities highlights the need for more inclusive UX practices. Persson et al. [1] stated that integrating UX design with agile development presents challenges and opportunities for addressing these disparities. However, current UX methodologies often fail to meet marginalized communities' unique needs.

This paper explores strategies to enhance the UX development life cycle to better support underrepresented groups. We focus on expanding user analysis, adopting inclusive design practices, and establishing frameworks for assessing and addressing accessibility gaps.

Emerging technologies such as voice interfaces, artificial intelligence, and virtual reality bring both risks and opportunities. Without deliberate attention to diverse user needs, these tools may amplify existing exclusions. However, they can increase access and participation for marginalized populations when inclusively designed from the start.

As digital systems increasingly mediate critical services like healthcare, education, finance, and government access, inclusive UX becomes a design priority and a matter of social justice. The COVID-19 pandemic accelerated digitalization, often without sufficient consideration for diverse needs, further emphasizing the urgency of inclusive design approaches.

In the following sections, we outline a framework for improving UX practices to serve underrepresented groups better, covering user research, inclusive design methods, accessibility assessment, community engagement, and future directions in UX.

### *1.2. Research Questions*

According to the background, this study proposed the following research questions:

(1) What techniques can be used to expand user analysis in order to discover all relevant user categories and understand the specific needs of each group?
(2) What design approaches can efficiently address the diverse needs of underrepresented users while maintaining system usability and coherence?
(3) What methods can help measure the gap between how critical a given function is and how accessible it is to different user groups?
(4) How can user-centered design (UCD) be enhanced to meaningfully involve members of minority groups throughout the engineering and design life cycle?
(5) How has technology support evolved for mission-critical life functions such as banking, healthcare, and government services, and what accessibility gaps remain?
(6) Which characteristics make specific underrepresented groups vulnerable to technological change, and how can UX design reduce these vulnerabilities?
(7) What can be learned from successful inclusive systems, and how can these insights be applied to broader UX strategies for accessibility and equity?
(8) What user experiences, interfaces, and design processes will emerge in the future, and how can UX practices evolve to support digital inclusion in these contexts?

## 2. RQ1: Expanding User Analysis to Discover All Relevant Categories

Traditional user research often relies on convenience sampling and demographics that fail to capture the full spectrum of potential users. To develop truly inclusive technology, UX professionals must expand their analysis to identify all relevant user categories and understand their unique needs.

### *2.1. Comprehensive Stakeholder Mapping*

A critical first step in inclusive UX design is comprehensive stakeholder mapping that extends beyond primary user groups. This approach systematically identifies secondary and tertiary users, including those who might interact with the system unexpectedly or through assistive technologies.

For instance, when designing a health information system, stakeholders might include not only patients and healthcare providers but also caregivers with varying levels of technical proficiency, individuals with various impairments who use assistive technologies, and those who speak

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languages other than the dominant one. This expanded mapping helps ensure that diverse perspectives are considered from the earliest design stages [2].

Comprehensive stakeholder mapping requires going beyond typical user categories to consider individuals who might interact with the system in edge cases or unusual circumstances. For healthcare applications, this might include patients and doctors, family caregivers, medical interpreters, healthcare proxies, and emergency contacts who might need to access information in crisis situations.

For financial applications, relevant stakeholders might include not just account holders but also authorized representatives, financial advisors, assistants acting on behalf of individuals with disabilities, and support personnel who might need to help users navigate complex transactions.

The mapping process should also consider potential future users who might not currently use similar systems due to accessibility barriers. By imagining who might benefit from a service if barriers were removed, designers can identify currently excluded populations and develop strategies to include them. This forward-looking approach helps break the cycle where underrepresented groups are excluded from research because they are not current users, perpetuating their exclusion from future designs.

### *2.2. Contextual Inquiry Across Diverse Communities*

Contextual inquiry—observing users in their natural environments—provides rich insights into how different populations interact with technology. To capture diverse experiences, contextual inquiry should be conducted across various communities, including those historically underrepresented in technology research.

This approach might involve spending time with older adults navigating digital healthcare portals, observing how low-income families access government services online, or understanding how individuals with cognitive impairments use navigation applications.

Conducting contextual inquiry across diverse communities requires additional planning and sensitivity. Researchers must build trust with communities that may have experienced exploitation or harm from research in the past. They must be willing to meet participants in locations where they feel comfortable, adapt research protocols to accommodate different cultural norms and communication styles, and ensure that their presence and observations don't create additional burdens for already marginalized individuals.

### *2.3. Participatory Design Workshops*

Participatory design workshops involving members of underrepresented communities as co-designers rather than merely research subjects can generate insights that might otherwise remain hidden. These workshops create space for marginalized individuals to directly shape technology rather than having their needs interpreted by designers who may not share their lived experiences [2].

For example, when designing educational technology, workshops might bring together students with learning disabilities, English language learners, and those from under-resourced schools to collaboratively identify barriers and co-create solutions. This approach shifts power dynamics and centers the expertise of those most affected by design decisions.

Effective participatory design workshops require careful planning to ensure meaningful participation from diverse groups. This includes considering logistical factors such as location accessibility, accommodating different work schedules and family responsibilities, providing necessary accommodations such as interpreters or assistive technology [3], and creating environments where participants feel safe expressing their perspectives.

Participatory design should extend beyond initial research to include ongoing involvement throughout the development process. This might include design reviews, prototype testing, and feedback on implementation. By maintaining relationships with community members throughout

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the development lifecycle, designers can ensure that insights gathered during initial workshops are accurately translated into final products and that new issues that emerge during development are addressed appropriately.

### *2.4. Intersectional Analysis*

An intersectional approach recognizes that individuals simultaneously belong to multiple identity categories, producing experiences that cannot be understood by combining separate category effects. For instance, an older Black woman with low vision navigating telehealth platforms experiences distinct challenges compared to a young white man with low vision.

UX researchers should apply intersectional analysis to understand how different identity dimensions interact, creating unique user experiences and needs. This approach prevents homogenization of diverse groups, highlighting the complexity of user experiences across contexts. Intersectional analysis moves beyond single-dimensional demographics to explore intersections of age, gender, race, socioeconomic status, geographic location, and disability, revealing unique patterns in technology use and barriers.

Intersectional analysis incorporates both quantitative and qualitative methods. Quantitative analyses identify correlations between intersecting demographics and technology usage patterns. Qualitative approaches examine how users navigate technology amidst overlapping discrimination and exclusion systems. Implementing intersectional analysis in UX research necessitates sophisticated protocols to capture complex identity interactions without overwhelming participants or reinforcing stereotypes.

Hinderks et al. [4] emphasize the importance of integrating inclusive design strategies throughout the development lifecycle, suggesting multiple UX management approaches applicable at various stages of development [4].

### *2.5. Longitudinal Engagement with Marginalized Communities*

Beyond discrete research activities, UX professionals should establish sustained relationships with marginalized communities to understand how their needs evolve over time and in response to technological changes. This longitudinal engagement provides more profound insights than can be gained from short-term studies and helps build the trust necessary for authentic participation.

Longitudinal engagement might take the form of community advisory boards that provide ongoing input into design decisions, regular research activities with the same cohort of participants over time, or embedded research approaches where UX professionals spend extended periods immersed in particular communities. These sustained relationships allow researchers to observe how technology use evolves, how users adapt to new systems and features, and how changing life circumstances affect technology needs [2].

This approach also facilitates greater reciprocity between researchers and communities. Rather than extracting insights from communities without apparent benefit, longitudinal engagement creates opportunities for mutual exchange. Researchers might provide technology training, advocacy for community needs within organizations, or documentation of community perspectives that can be used in advocacy contexts beyond the specific product being designed.

Establishing meaningful longitudinal engagement requires an institutional commitment beyond typical project timelines and budgets. Organizations must allocate resources for community relationship building that may not yield immediate product outcomes but create foundations for more inclusive design in the long term. They must also be willing to engage with broader social and political issues affecting communities' relationships with technology rather than focusing on specific product features.

## 3. RQ2: Design Approaches to Efficiently Address Diverse Needs

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Once diverse user needs have been identified, designers face the challenge of efficiently addressing these needs without creating unwieldy or fragmented experiences. Several approaches can help designers accommodate diversity while maintaining coherence and usability.

### *3.1. Universal Design Principles*

Universal Design principles aim to create products that are usable by all people, to the greatest extent possible, without needing adaptation or specialized design. These principles include equitable use, flexibility, intuitive and straightforward operation, perceptible information, tolerance for error, low physical effort, and appropriate size and space for approach and use [5].

By incorporating these principles from the outset, designers can create products that accommodate diverse users without requiring separate specialized versions. For example, a universally designed mobile banking application might include customizable text sizes, multiple authentication options, and clear, jargon-free language—features that benefit users across a spectrum of abilities and backgrounds.

Implementing Universal Design principles requires challenging assumptions about normal users and recognizing the broad spectrum of human abilities, knowledge, and preferences. It involves identifying aspects of standard designs that might create barriers for specific populations and developing solutions that work for a broader range of users without compromising functionality for any group.

Universal Design goes beyond minimum compliance with accessibility standards to create truly inclusive experiences. While accessibility standards provide important baselines, they often focus narrowly on technical requirements rather than holistic usability for diverse populations. Universal Design takes a more comprehensive approach, considering not just whether a function is technically accessible but whether it provides an equitable and dignified experience for all users [6].

The efficiency of Universal Design lies in its ability to address diverse needs through a single coherent design rather than creating separate specialized versions for different populations. This reduces development and maintenance costs and avoids the stigmatization and segregation resulting from separate accessible versions that often receive less attention and updating than mainstream products.

### *3.2. Flexible User Interfaces*

Adaptive and responsive interfaces that allow users to customize their experience based on their specific needs can efficiently accommodate diversity without requiring separate designs for each user group. These interfaces might include customizable display options, multiple input modalities, adjustable complexity levels, language switching, translation features, and options to replace text with icons or audio for users with different literacy levels [7].

Too many options can overwhelm users, particularly those with cognitive impairments or limited digital literacy, while too few options may not adequately address diverse needs. Designers must carefully select which interface aspects should be customizable based on research into user needs and pain points [7].

Flexible interfaces should also incorporate intelligent defaults that work well for most users while making customization accessible for those who need it. This approach recognizes that many users, particularly those with limited technology experience or cognitive impairments, may not explore customization options unless prompted. By providing strong defaults with clear pathways to customization, designers can serve both those who need specialized configurations and those who prefer simplicity.

Implementing flexible interfaces also requires considering how user preferences are stored and applied across devices and sessions. Cloud-based preference management can provide consistency across devices but raises privacy considerations. Local storage provides greater privacy but may

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require users to reconfigure interfaces on each device. Designers must balance these considerations based on the specific context and user needs.

### *3.3. Modular Design Systems*

Modular design systems separate content, presentation, and behavior, enabling efficient adaptation for diverse user needs while maintaining consistency. For instance, a modular news app might decouple article content from its presentation, allowing delivery as text, audio, or summaries based on preferences.

Such systems comprise reusable components with defined interfaces and behaviors, assembled in various ways to meet different requirements. They include technical architecture (e.g., code components, APIs) and design elements (e.g., visual styles, interaction patterns) that ensure adaptable yet consistent experiences [8].

Their effectiveness relies on designing components with built-in accessibility—supporting screen readers, keyboard navigation, multiple input methods, content types, languages, and cultural norms. Documentation is also critical, offering implementation guidance, technical specifications, design rationale, and instructions for edge cases that impact inclusion.

Though requiring initial investment, modular systems improve efficiency over time and support consistent interaction patterns, benefiting users with diverse needs.

### *3.4. AI-Assisted Personalization*

Emerging artificial intelligence (AI) technologies offer promising methods for automatically adapting interfaces based on individual user behaviors and needs. AI systems analyze user interactions to suggest or implement personalized adjustments, enhancing usability. For example, an AI-enhanced browser could automatically adjust text size for users who frequently enlarge text or provide simplified alternatives if patterns of user confusion are detected.

AI personalization involves collecting and analyzing user behavior data to identify beneficial interface adaptations. This approach particularly aids users who lack the knowledge, confidence, or ability to customize interfaces manually. However, implementing AI personalization necessitates careful ethical considerations. Privacy concerns arise from collecting sensitive user data, requiring robust privacy protections, transparent data practices, and user control over data usage.

User agency and transparency are essential, as users must understand and control suggested or automatic adaptations. Systems lacking user awareness or consent could diminish autonomy, especially among users with cognitive impairments or limited digital literacy. Additionally, AI systems trained predominantly on majority-user data risk overlooking unique patterns and needs of marginalized groups, potentially suggesting unsuitable adaptations.

Nevertheless, responsibly designed AI-assisted personalization significantly enhances inclusion, reducing user burdens by offering adaptive interfaces while preserving user agency and transparency.

### *3.5. Cross-Platform Consistency with Adaptive Variations*

Users with diverse needs often navigate multiple platforms and devices to accomplish their goals. Designing for cross-platform consistency while incorporating adaptive variations for different contexts can help users transfer their knowledge and skills across environments while addressing platform-specific challenges.

Cross-platform consistency involves maintaining consistent mental models, interaction patterns, and terminology across web, mobile, desktop, voice, and other interfaces. This consistency helps users build transferable skills and reduces cognitive load when switching between contexts. At the same time, adaptive variations recognize that different platforms have distinct constraints and affordances that may require different approaches to accessibility and inclusion.

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For example, a banking service might maintain consistent terminology, information architecture, and security models across platforms while adapting authentication methods to leverage platform-specific capabilities such as fingerprint recognition on mobile devices or security keys on desktop browsers. Similarly, navigation patterns might maintain conceptual consistency while adapting to the different interaction modes of touchscreens, keyboards, voice commands, or screen readers.

This approach also requires close collaboration between platform-specific design teams and a shared understanding of inclusive design principles. Organizations should establish design systems and pattern libraries that document cross-platform constants and platform-specific adaptations, with clear rationales for each decision considering diverse user needs [9].

By balancing consistency with appropriate adaptation, designers can create ecosystems of products that accommodate diverse needs across contexts while minimizing the learning burden for users navigating between platforms.

## 4. RQ3: Measuring the Gap Between Function Criticality and Accessibility

To prioritize improvements and measure progress toward inclusion, organizations need frameworks for assessing the gap between how critical a given function is and how accessible it is for different user groups.

### *4.1. Function Criticality Assessment Framework*

A function criticality assessment framework helps organizations systematically evaluate how essential different features or tasks are to users' ability to achieve their goals. This assessment might consider factors such as whether the function is legally required or mandated, whether the function relates to essential needs, the frequency with which users need to perform the function, the consequence of being unable to perform the function, and whether alternatives exist if the digital function is inaccessible.

Functions can then be categorized as critical (essential for basic participation), important (significantly enhances the quality of life), or enhancing (provides additional benefits but is not essential).

Developing a function criticality assessment framework begins with a comprehensive inventory of all functions provided by a digital product or service. This inventory should be user-centered, focusing on tasks from the user's perspective rather than technical implementations. For example, rather than listing "form validation" as a function, the inventory might include "correcting errors in submitted information" as a user task.

Legal requirements represent a baseline measure of criticality, as functions mandated by accessibility laws or regulations must be accessible to comply with legal obligations. However, legal compliance alone is insufficient for true inclusion, as laws often establish minimum standards rather than optimal experiences.

Beyond legal requirements, criticality should be assessed based on the function's relationship to fundamental human needs and rights. Functions that provide access to healthcare, financial security, education, civic participation, social connection, or personal safety have inherently high criticality regardless of legal mandates. The assessment should consider both immediate and long-term consequences of function inaccessibility, recognizing that seemingly minor barriers can have cumulative effects on life opportunities and outcomes.

The frequency and timing of function use also affect criticality. Functions that are used regularly or that must be accessed during time-sensitive situations may have higher criticality than those used only occasionally or in non-time-critical contexts. Similarly, functions that serve as gateways to other capabilities may have higher criticality than standalone features, as inaccessibility can block access to entire categories of functionality.

The availability of alternatives should also be considered but evaluated critically. Alternatives should provide truly equivalent experiences regarding dignity, independence, efficiency, and

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outcome quality. For example, a telephone alternative to a web form might be considered equivalent only if it provides similar convenience, privacy, and efficiency without creating additional barriers such as limited hours of availability or long wait times.

### *4.2. Accessibility Measurement Across User Groups*

For each identified function, organizations can then assess accessibility across different user groups, considering factors such as whether users can independently discover and access the function, understand how to use the function without specialized training, successfully complete the function without assistance, complete the function efficiently and without undue stress, and whether there are specific barriers that prevent certain groups from using the function.

These assessments should be conducted through expert evaluation using established accessibility guidelines, automated testing, and—most importantly—usability testing with members of underrepresented groups.

Accessibility measurement should go beyond technical compliance with standards such as WCAG (Web Content Accessibility Guidelines) to consider the holistic usability of functions for different groups. While technical compliance provides an important foundation, it doesn't guarantee that users can effectively accomplish their goals. For example, a form might comply with technical accessibility requirements for keyboard navigation and screen reader compatibility but still present barriers through complex language, cognitive load, or time constraints that disproportionately affect specific populations.

Comprehensive accessibility measurement requires evaluation across multiple dimensions of access, including sensory (visual, auditory), motor, cognitive, linguistic, and technical (device, bandwidth, digital literacy) factors. Each function should be assessed for how well it accommodates users with different abilities and constraints across these dimensions.

The measurement process should also distinguish between different levels of accessibility: technical accessibility (can the function be perceived and operated by different users?), usable accessibility (can users effectively and efficiently accomplish their goals?), and equitable accessibility (does the function provide an equivalent experience in terms of dignity, independence, and quality of outcome?).

To ensure measurement validity, accessibility evaluations should involve both expert analysis and direct testing with diverse users. Expert evaluations using established heuristics and guidelines can efficiently identify common issues, while usability testing with members of underrepresented groups reveals barriers that might not be captured by guidelines alone [10]. This combination provides both breadth of coverage and depth of insight into the lived experience of diverse users.

### *4.3. Gap Analysis and Prioritization*

By mapping function criticality against accessibility for different user groups, organizations can identify the most significant gaps and prioritize improvements. Critical functions with low accessibility represent the highest priority for remediation, while enhancing functions with high accessibility may be lower priorities.

This gap analysis provides a data-driven approach to prioritizing inclusive design efforts and measuring progress over time. It also helps organizations communicate about inclusion efforts to stakeholders, regulators, and advocacy groups by demonstrating a systematic approach to addressing accessibility barriers.

The gap analysis process involves creating a matrix that plots function criticality against accessibility for each user group of interest. This visualization helps identify patterns of exclusion that might otherwise remain hidden, such as consistent barriers for particular user groups across multiple functions or specific types of functions that present challenges across user groups.

This analysis can reveal opportunities for strategic improvements that address multiple gaps simultaneously [11]. For example, implementing a consistent approach to error handling might

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address accessibility gaps across multiple critical functions, providing greater impact than addressing individual functions in isolation. Similarly, focusing on foundational components of the user interface that affect multiple functions can create efficiencies in remediation efforts.

The gap analysis also facilitates more nuanced prioritization than approaches based solely on either criticality or accessibility. Rather than simply addressing the most critical functions first, organizations can consider the size of the gap, the number of users affected, the technical feasibility of improvements, and the potential for strategic solutions that address multiple gaps simultaneously.

Gap analysis should be integrated into ongoing product management processes rather than conducted as a one-time exercise to be most effective. By regularly updating assessments of both criticality and accessibility, organizations can track progress over time, identify emerging gaps as products evolve, and focus on inclusion throughout the product lifecycle.

Hinderks et al. [4] suggest that UX management comprises a UX goal, strategy, and resources. This framework can be applied to measuring accessibility gaps by establishing clear goals for reducing critical function gaps, developing strategies to address them, and allocating appropriate resources for implementation.

### *4.4. Continuous Monitoring and Feedback Mechanisms*

Beyond initial gap analysis, organizations should establish mechanisms for continuously monitoring accessibility and gathering ongoing feedback from diverse users. This continuous approach recognizes that accessibility is not static but can change as products evolve, user needs shift, and technologies change.

Continuous monitoring might include automated testing integrated into development pipelines to detect regressions in accessibility [12], regular manual assessments of key user journeys, periodic usability testing with diverse participants, and analytics that track usage patterns and completion rates across different user groups. These approaches provide early warning of emerging gaps and help maintain focus on inclusion throughout the product lifecycle.

Feedback mechanisms should provide multiple channels for users to report accessibility issues, request accommodations, and suggest improvements. These channels might include feedback forms integrated into products, direct communication with support teams trained to recognize and escalate accessibility concerns, community forums, social media monitoring, and partnerships with advocacy organizations representing underrepresented groups.

To be effective, feedback systems must collect information and ensure it reaches decision-makers and influences product development. This requires transparent processes for routing accessibility feedback to appropriate teams, accountability for addressing reported issues, and transparency about how feedback influences product decisions.

By combining structured gap analysis with continuous monitoring and feedback mechanisms, organizations can accurately understand accessibility gaps over time and respond proactively to emerging needs and challenges.

## 5. RQ4: Enhancing User-Centered Design (UCD) to Include Minority Groups

Traditional UCD methodologies must be enhanced to incorporate members of minority groups throughout the engineering lifecycle meaningfully. This section explores approaches for making UCD more inclusive and representative.

### *5.1. Recruiting Diverse Research Participants*

Meaningful inclusion begins with recruitment practices that reach beyond convenient or majority populations. Organizations should develop relationships with community organizations, advocacy groups, and service providers that work with underrepresented communities to facilitate recruitment.

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Recruitment materials should be accessible in multiple formats and languages, and compensation should account for additional barriers participants might face (such as transportation, childcare, or assistive technology compatibility). Research schedules should accommodate diverse work patterns, religious observances, and family responsibilities.

Logistically, organizations must consider factors such as the accessibility of research locations, the timing of sessions, the availability of necessary accommodations, and appropriate compensation for participants' time and expertise. These considerations should be integrated into research planning from the outset rather than treated as afterthoughts once recruitment challenges emerge.

Beyond logistics, organizations must address social and historical factors that might create mistrust or reluctance to participate among marginalized communities. Many underrepresented groups have experienced exploitation, misrepresentation, or harm through previous research efforts, leading to justified skepticism about participating in new studies. Overcoming this mistrust requires building genuine relationships with communities over time, demonstrating respect and reciprocity, and ensuring that research contributes to rather than extracts from community resources [13].

Recruitment should also consider the diversity within underrepresented groups rather than treating them as monolithic. For example, the experiences of older adults vary significantly based on factors such as socioeconomic status, education, cultural background, and health status. Similarly, people with disabilities represent a highly diverse population with varying needs and perspectives. Recruitment should aim to capture this internal diversity rather than relying on a small number of participants to represent entire populations.

Organizations should also recognize that some individuals may belong to groups that are particularly difficult to reach through traditional recruitment methods. This includes people who are institutionalized, homeless, or living in rural areas with limited connectivity; those who don't speak dominant languages; those with severe disabilities that affect communication; and those who avoid technology entirely due to past negative experiences. Creative approaches such as snowball sampling, community-based participatory research, or in-context observation may be necessary to include perspectives from these highly marginalized groups.

### *5.2. Creating Safe and Accessible Research Environments*

Physical and virtual research environments should be designed to be accessible and culturally sensitive. This involves ensuring physical accessibility, appropriate accommodations, and psychologically safe spaces, encouraging participants to share their experiences [14]. Researchers should be trained in cultural competence, disability etiquette, and trauma-informed methods. Sessions should recognize power dynamics and allow participants to engage on their terms.

Safe and accessible environments must address both physical and psychological needs. Physical considerations include sensory-friendly settings, flexible seating for mobility devices, adequate lighting, and reduced background noise for participants with interpreters or hearing impairments. Virtual environments require compatibility with assistive technologies, captioning, transcription, video-off options, and alternatives for those without stable internet. Organizations should build capacity for inaccessible remote methods and offer technical support.

Psychological safety involves creating a respectful space where participants feel valued and free from judgment. This includes accessible informed consent, clear confidentiality practices, and participant control over engagement, such as skipping questions or withdrawing without penalty.

Cultural sensitivity requires adapting communication and protocols to community norms, such as storytelling over direct questioning and recognizing taboos or technology perceptions shaped by culture. For sensitive topics or marginalized groups, involving community members as co-researchers can enhance trust and interpretation through shared lived experiences.

### *5.3. Adapting Research Methods for Diverse Participants*

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Traditional research methods may need to be adapted to be effective with diverse participants. Visual methods like card sorting might be adapted for screen reader users, while interview protocols might be modified for participants with cognitive impairments or language differences.

Researchers should be flexible and prepared to adapt their approaches based on participant needs and preferences. This might include providing questions in advance, allowing more time, using interpreters, or incorporating cultural practices that create comfort and trust.

Adapting research methods requires both methodological flexibility and thoughtful preparation. Rather than assuming that standard methods will work for all participants, researchers should proactively consider potential barriers and develop alternatives before beginning research. This preparation might include developing multiple versions of research materials in different formats and complexity levels, preparing alternative activities that capture similar insights through different modalities, and training research teams to adapt their approaches based on participant responses dynamically.

Method adaptation should consider multiple dimensions of diversity, including sensory, motor, and cognitive abilities; language proficiency; cultural background; educational level; and technology familiarity. Researchers should identify potential barriers in standard methods for each dimension and develop appropriate adaptations that preserve the research objectives while accommodating diverse needs [15].

For example, traditional think-aloud protocols that ask participants to verbalize their thoughts while completing tasks might be modified for participants with speech impairments by allowing written or typed responses, for those with cognitive impairments by breaking tasks into smaller steps with reflection points, or for non-native language speakers by allowing expression in their preferred language with interpretation.

Similarly, usability testing protocols might be adapted for participants with motor impairments by allowing more time for task completion or providing alternative input methods, for those with cognitive impairments by simplifying instructions and reducing the number of tasks, or for those with limited technology experience by providing more contextual information and reassurance about the testing purpose.

Researchers should also consider how data collection and analysis methods might need to be adapted to capture diverse perspectives accurately. Standard metrics such as time-on-task or error rates might not meaningfully reflect users' experiences with different abilities or constraints. Alternative measures such as perceived effort, satisfaction with outcomes, or comparative performance against personal baselines might provide more meaningful insights for diverse participants.

Successful adaptation requires striking a balance between flexibility and research integrity. While methods should be adapted to accommodate diverse participants, adaptations should preserve the core research objectives and allow for meaningful participant comparisons where appropriate. Researchers should document adaptations made for different participants and consider how these adaptations might affect data interpretation and findings.

### *5.4. Including Minority Group Members on Design Teams*

Organizations should implement comprehensive diversity strategies that address each stage of the employee lifecycle from recruitment through advancement. This includes developing diverse candidate pipelines through partnerships with educational institutions and community organizations, implementing inclusive hiring practices that evaluate potential rather than just traditional credentials, creating mentorship and professional development opportunities that support underrepresented team members, and establishing clear pathways for advancement that recognize diverse contributions and leadership styles.

Beyond representation, organizations must create environments where minority team members can meaningfully influence decisions. This requires addressing both explicit and implicit power

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dynamics that might minimize or marginalize diverse perspectives. Strategies might include establishing clear processes for incorporating diverse viewpoints into decision-making, implementing practices that ensure all team members have opportunities to contribute, and providing training for team leaders in recognizing and addressing biases in collaboration and decision processes.

Organizations should recognize that increasing diversity often requires examining and changing fundamental aspects of workplace culture and practice that have evolved in predominantly homogeneous environments [16]. This might include reconsidering traditional work schedules that conflict with family responsibilities, communication norms that privilege certain cultural styles, physical environments that present barriers for people with disabilities, or social activities that exclude certain groups. These changes benefit not only minority team members but also create more humane and flexible workplaces for all employees.

It is important to note that advocating for inclusion should not fall solely on team members from underrepresented groups. Organizations should establish structures that distribute responsibility for inclusive practices across all team members, particularly those in positions of privilege and power. This prevents the exhausting minority tax, where underrepresented team members are expected to perform their regular duties and serve as informal diversity consultants or advocates.

### *5.5. Compensating for Expertise and Lived Experience*

When engaging people from minority groups as consultants, advisors, or expert reviewers, organizations should fairly compensate them for their expertise and lived experience. Too often, individuals from marginalized communities are expected to provide this expertise for free or for minimal compensation, which perpetuates inequitable power dynamics.

Organizations should develop fair compensation structures that recognize the value of lived experience and expertise from navigating systems not designed for one's needs. This compensation should extend beyond research participation to include ongoing advisory roles, expert reviews, and consultation throughout development.

Fair compensation for expertise and lived experience recognizes that knowledge gained through navigating barriers and developing adaptation strategies represents a valuable form of expertise that contributes significantly to inclusive design. This expertise is often undervalued because it is typically acquired outside formal educational or professional contexts. However, it provides insights that cannot be gained through academic study or professional training alone.

Compensation models should consider both monetary and non-monetary forms of recognition, depending on the context and the preferences of those involved. Monetary compensation should be commensurate with the specialized knowledge and experience being contributed rather than minimum wage standards or token payments. Organizations should develop transparent rate structures that value lived experience expertise like other specialized consulting or advisory services.

In some contexts, non-monetary compensation might be appropriate in addition to financial payment, such as opportunities for skill development, networking, professional recognition, or specific accommodations that enhance access to education or employment opportunities. However, these should supplement rather than replace fair financial compensation.

When engaging with communities rather than individuals, compensation might include community-level benefits such as investments in community infrastructure, support for community-led initiatives, or shared ownership of intellectual property developed through collaboration. These approaches recognize that expertise often emerges from community contexts and that benefits should flow back to communities rather than just individuals.

Fair compensation practices should also recognize the additional labor that people from marginalized groups often perform in making their expertise accessible to majority organizations [17]. This includes the emotional labor of explaining experiences of discrimination or exclusion, the

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cognitive labor of translating between different cultural contexts, and the physical labor of navigating inaccessible environments to participate in research or advisory activities.

### *5.6. Building Institutional Knowledge and Practices*

Beyond individual projects or initiatives, organizations should build institutional knowledge and practices that support the inclusion of underrepresented groups across the organization's work. This institutional approach ensures that inclusive practices become embedded in organizational culture rather than dependent on individual advocates or temporary initiatives.

Building institutional knowledge involves documenting insights about diverse user needs, successful inclusive design approaches, and lessons learned from previous projects. This documentation creates an organizational memory that persists even as team members change and helps prevent repeating past mistakes or continually rediscovering the same insights [18].

Institutional practices include established processes for including diverse perspectives throughout the design lifecycle, checklists and templates incorporating inclusive design considerations, and governance structures holding teams accountable for inclusion outcomes. These practices make inclusion a standard part of how work is done rather than an exceptional effort requiring special advocacy.

Leadership commitment is essential for building effective institutional knowledge and practices. When leaders consistently communicate the importance of inclusion, allocate resources to support inclusive practices, and hold teams accountable for inclusion outcomes, they create the conditions for institutional change. Conversely, when leaders treat inclusion as optional or secondary to other objectives, institutional knowledge and practices are unlikely to take root or persist over time.

## 6. RQ5: Mission-Critical Life Functions and Technology Support Evolution

Certain mission-critical life functions are essential for full participation in modern society. Understanding how technology support for these functions has evolved can provide insights into both progress and persistent gaps in inclusion.

### *6.1. Financial Management and Banking*

Access to financial services is essential for economic participation and stability. The evolution of technology support for banking illustrates both progress and ongoing challenges in inclusion.

Early digital banking systems emerged in ATMs and telephone banking in the 1980s and 1990s. These systems provided convenience for many users but presented significant barriers for those with visual impairments, mobility limitations, or cognitive disabilities. ATMs initially relied heavily on visual interfaces without audio alternatives. At the same time, telephone banking systems used complex menu structures that could be disorienting for users with cognitive impairments or those not fluent in the dominant language.

The transition to online banking in the late 1990s and early 2000s created new opportunities and challenges. Web-based banking interfaces expanded access for some users with mobility impairments who could now conduct banking from home, but created new barriers for screen reader users when sites were not designed with accessibility in mind. While important for protecting accounts, security features such as CAPTCHAs and complex password requirements often present disproportionate barriers for users with various disabilities.

Mobile banking applications introduced in the 2010s further transformed the landscape. These applications offered unprecedented convenience for many users. However, they created new barriers for older adults unfamiliar with smartphone interfaces and users with various disabilities when apps were not designed with accessibility features. The gradual implementation of biometric authentication, while simplifying access for many users, created complications for those whose physical differences made fingerprint or facial recognition unreliable.

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More recently, voice banking through smart speakers and enhanced screen-reader compatibility has improved access for some users with visual impairments. AI-powered services have simplified complex transactions for users with limited financial literacy, while chatbot interfaces have provided alternative interaction methods for those who struggle with traditional form-based interfaces.

Many financial applications still present challenges for users with cognitive impairments, who may struggle with abstract financial concepts or complex authentication procedures. Digital-only banking tends to exclude those without reliable internet access, appropriate devices, or the digital literacy necessary to navigate evolving interfaces. Automated systems may fail to accommodate the unique circumstances or needs of users who do not fit standard patterns, such as those with non-traditional sources of income or complex financial situations.

The banking sector's evolution illustrates several key patterns. First, each new technology wave tends to create both opportunities and barriers, often improving access for some populations while creating new challenges for others. Second, accessibility features typically lag behind mainstream feature development, with inclusive design incorporated reactively rather than proactively. Third, the increasing reliance on digital-only services without maintaining alternative access channels can exclude populations that cannot easily adapt to digital transitions, creating a form of technological redlining.

Future developments in financial technology should focus on true multimodal interactions that provide equivalent experiences across different interaction methods, maintaining non-digital access channels for those who cannot use digital options and designing for users with cognitive and financial literacy limitations who may struggle with complex financial concepts and interfaces.

### *6.2. Healthcare Access and Management*

Technology is increasingly central in healthcare access and information management, with important consequences for individual and public health.

Early electronic health records (EHRs) from the 1990s and early 2000s primarily served provider needs, digitizing clinical and administrative data without offering patient access. This provider-centric model maintained significant information asymmetries, especially disadvantaging patients with limited health literacy, language barriers, or disabilities.

Patient portals introduced in the mid-2000s improved access by allowing users to view records, message providers, and manage appointments. However, early portals posed usability challenges for older adults, individuals with low digital literacy, and users with disabilities. Complex language and inaccessible design limited effective use for many.

The COVID-19 pandemic accelerated the adoption of telehealth, revealing significant accessibility gaps. Many platforms lacked captioning or screen reader compatibility features, while high-bandwidth requirements excluded users with limited connectivity or older devices [19].

Wearables and health-tracking apps support self-management and preventive care but often assume digital literacy, specific physical abilities, and cultural norms not shared across all user groups.

Healthcare technologies remain fragmented, requiring patients to use multiple systems with inconsistent interfaces and processes. This creates barriers, particularly for those with cognitive impairments or complex care needs.

Future systems should prioritize integrated accessibility in telehealth, plain language for medical content, broader language support, and culturally inclusive design. Maintaining multiple access channels—including digital, phone, and in-person options—is essential, as is enabling caregiver or proxy access for dependent users.

### *6.3. Government Services and Civic Participation*

Access to government services and civic participation are fundamental citizenship rights, yet technology implementations often create barriers for underrepresented groups. Early e-government

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initiatives (1990s–2000s) typically digitized paper-based bureaucratic processes without significant user-centered redesign, neglecting language barriers, accessibility needs, and varying user familiarity with government systems.

Subsequent e-government advancements improved accessibility and usability but depended on digital literacy and reliable internet, excluding elderly individuals, technology-limited groups, homeless individuals, and rural populations. Mobile-optimized services from the 2010s enhanced access, benefiting lower-income and immigrant communities with higher smartphone usage. However, complexities in completing processes on small screens introduced challenges for visually impaired and motor-limited users.

Evolving voting technologies aimed to improve accessibility but sometimes introduced complications. Electronic voting machines, despite accessibility promises, faced issues related to implementation, security, and inconsistent interfaces, causing confusion and reduced access. Online voter registration simplified the process for many but disadvantaged users lacking reliable internet or required digital documentation.

Identity verification systems in government contexts frequently disadvantage immigrants, homeless individuals, transgender populations, and those with non-traditional life circumstances. Digital verification methods reliant on stable addresses, credit histories, or specific technologies further marginalize these groups.

Increasing reliance on digital civic participation platforms, such as online consultations, comment systems, and social media engagement channels, often excludes diverse communication styles, language needs, and accessibility requirements. This can disproportionately amplify certain voices while marginalizing others.

Future government technology should emphasize plain language, multi-channel access (in-person and telephone options), inclusive identity verification methods, and designs sensitive to community trust levels based on historical experiences. Persson et al. [1] highlighted that integration through mutual adjustments is essential in evolving these critical systems, progressively enhancing inclusivity despite ongoing gaps.

## 7. RQ6: Characteristics of Underrepresented Groups Vulnerable to Technology Evolution

Different underrepresented groups face unique vulnerabilities as technology evolves. Understanding these characteristics can help designers create more inclusive experiences.

### *7.1. Older Adults*

Older adults exhibit diverse technological experiences, capabilities, and attitudes. Specific aging-related changes heighten their vulnerability to technological evolution. Physical changes, such as presbyopia, reduced contrast sensitivity, increased glare sensitivity, hearing loss (particularly at higher frequencies), and reduced motor control, affect interactions with standard digital interfaces. Cognitive changes, including working memory limitations, slower processing speed, and reduced divided attention capabilities, complicate the use of complex or multitasking interfaces.

Generational differences significantly impact older adults' technological mental models, often causing difficulty with interfaces intuitive to younger users. Socioeconomic constraints, such as fixed incomes and social isolation, restrict access to contemporary technology and informal support networks.

Additionally, older adults often face compounded accessibility issues due to multiple chronic conditions or medication effects that fluctuate throughout the day. Major technological transitions, from command-line interfaces to touchscreens and voice commands, require substantial learning efforts that older adults may find challenging without adequate support [20].

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Future design strategies should emphasize consistency, predictability, redundant interaction methods, integrated learning supports, and recognition of older adults' diverse capabilities and needs.

### *7.2. People with Disabilities*

Technological advancements have differently impacted individuals based on disability types. Users with visual impairments initially benefited from text-based interfaces compatible with screen readers; however, graphical and touchscreen interfaces lacking tactile feedback introduced new barriers. Emerging visual technologies, such as augmented reality, risk further exclusion if not designed with non-visual access in mind.

For hearing-impaired individuals, inconsistent caption quality, inadequate sign language support, and reliance on auditory cues without alternatives limit technology usability. Voice-controlled interfaces rarely support sign language or speech differences resulting from hearing impairment.

Motor impairments complicate interaction with precise touchscreen targets, gesture-based interfaces, and virtual reality environments requiring specific physical movements. Cognitive impairments, including learning disabilities, autism, and brain injuries, increase difficulties with complex interfaces, abstract navigation systems, and rapid interface changes requiring constant relearning. Voice interfaces frequently exclude users with speech impairments due to recognition systems trained on normative speech patterns.

Compound disabilities pose unique challenges, as accessibility features for single disabilities may conflict or fail when combined. Multimodal interfaces providing equivalent experiences across diverse interaction methods are thus crucial [21]. Future design should consistently implement accessibility features, allow customization for complex disability combinations, and involve diverse disability groups throughout development.

### *7.3. Linguistic and Cultural Minorities*

Technological barriers faced by linguistic and cultural minorities extend beyond interface translation issues. Limited interface availability in minority languages, incomplete translations of advanced functionalities, and unreliable machine translation create unequal user experiences. Cultural contexts, such as differing date formats, naming conventions, measurement systems, and social roles, often lack adequate accommodation, causing confusion or offense.

Western-oriented iconography and color symbolism create additional cognitive burdens for users from non-Western cultures. Information categorization based on dominant cultural structures can appear illogical or irrelevant to culturally diverse users, particularly in healthcare or government services. Standardized identity verification systems that assume stable documentation exclude many from minority backgrounds.

Although visual and voice interfaces partially mitigate linguistic barriers, they frequently embed deeper cultural assumptions, posing challenges for non-native speakers and those with regional accents. Future designs should prioritize cultural adaptability, thorough community-validated translations, diverse categorization approaches, and culturally inclusive testing throughout development [22].

## 8. RQ7: Case Studies of Exceptionally Good Systems

Examining examples of systems that successfully accommodate diverse users can provide valuable insights into practical inclusive design approaches.

### *8.1. Case Study: BBC's GEL (Global Experience Language) Design System*

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The BBC's Global Experience Language (GEL) system [23] represents an exemplary approach to inclusive design that accommodates diverse users while maintaining a coherent design language.

The GEL system emerged from the BBC's public service mandate to serve all audiences in the United Kingdom, including those with disabilities, older adults, and linguistic minorities. Rather than treating accessibility as a separate concern, the BBC integrated inclusive design principles throughout its design system from its inception, creating a foundation for consistent accessibility across its digital products.

The system is built on robust accessibility guidelines that exceed minimum standards, incorporating both technical requirements for compatibility with assistive technologies and usability considerations for diverse user needs. These guidelines address not only permanent disabilities but also situational limitations and preferences that might affect how users interact with BBC content across different contexts and devices.

GEL incorporates research with diverse audiences throughout its development and evolution. The BBC conducts regular testing with older adults, people with various disabilities, and those with limited digital literacy to validate the effectiveness of design patterns and identify potential barriers. This research informs both the core components and the guidance provided to implementation teams.

A key innovation of the GEL system is its provision of flexible components that adapt to user needs across platforms. Rather than creating separate "accessible versions" of components, GEL components are designed to respond appropriately to different contexts, user preferences, and assistive technologies. For example, navigation components work effectively with keyboard navigation, touch interfaces, screen readers, and voice control without requiring separate implementations for each interaction method.

The system includes detailed guidance for designers and developers that goes beyond technical specifications to explain the rationale behind accessibility requirements. This comprehensive documentation helps implementation teams understand what to do and why specific approaches are necessary for inclusive experiences. By educating teams about diverse user needs, the documentation builds organizational capacity for inclusive design beyond simply providing reusable components.

The BBC regularly tests GEL components with diverse users to validate their effectiveness and identify areas for improvement. This continuous evaluation recognizes that accessibility is not a static achievement but an ongoing process that must evolve as technologies, user needs, and content requirements change. The testing includes controlled usability studies and real-world monitoring of components' performance across the BBC's digital ecosystem.

Key lessons from the BBC's approach include integrating accessibility as a core design principle rather than an afterthought, developing reusable components that encapsulate inclusive practices, creating clear guidance that helps implementation teams understand the rationale behind requirements, continuous testing with diverse users throughout the development process, and treating inclusivity as an ongoing journey rather than a compliance checkbox.

The success of the GEL system demonstrates how systematic attention to inclusion can create superior experiences for all users while maintaining design coherence and efficiency. By building accessibility into the foundation of their design system, the BBC has created a scalable approach to inclusion that supports diverse products and content types while ensuring consistent quality of experience across their digital ecosystem.

### *8.2. Case Study: Microsoft's Inclusive Design Toolkit*

Microsoft's Inclusive Design Toolkit [24] and its implementation across its product ecosystem demonstrate how systematic attention to inclusion can drive innovation and improve products for all users.

Microsoft's approach is based on a methodology that recognizes "permanent, temporary, and situational" disabilities that affect everyone at different times. This framing moves beyond binary notions of disability to recognize that all users experience capability constraints in different contexts.

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For example, a person might experience a permanent limitation (blindness), a temporary limitation (eye infection), or a situational limitation (driving a car) that all result in an inability to view a screen. By designing for the constraints of permanent disabilities, products become more usable for everyone encountering similar limitations temporarily or situationally.

The company incorporates a persona spectrum approach that considers how designs for edge cases benefit mainstream users. Rather than treating accessibility as a specialized need affecting a small population, this approach recognizes that solutions developed for users with disabilities often benefit the user spectrum. For example, captioning developed for deaf users also benefits those watching videos in noisy environments, learning a language, or processing information better through reading than listening.

Microsoft has implemented adaptable interfaces across input methods, including keyboard, mouse, touch, voice, and eye tracking. This multimodal approach recognizes that users have different preferences and needs depending on their abilities, contexts, and tasks. By supporting equivalent experiences across these input methods, Microsoft's products accommodate diverse users while providing flexibility for changing circumstances and preferences.

A key strength of Microsoft's approach is the development of developer tools and resources that make implementing accessibility easier. By incorporating accessibility features into development frameworks, design tools, and code libraries, Microsoft has reduced the implementation burden for teams across their organization and external developers building on their platforms. These tools help mainstream accessibility practices that might require specialized expertise, making inclusion more achievable at scale.

Microsoft conducts regular usability studies with diverse users, including those with disabilities, to evaluate and improve its products. This research informs ongoing refinement of both specific products and the overall inclusive design methodology. By maintaining relationships with disability communities and advocacy organizations, Microsoft ensures its approach remains responsive to evolving needs and incorporates diverse perspectives.

Key innovations from Microsoft's approach include framing inclusion as a driver of innovation rather than a compliance requirement, creating tools that make inclusive design patterns easy to implement across large and complex product ecosystems, considering the full spectrum of abilities rather than binary notions of disability, developing consistent experiences across different interaction methods, and investing in research and development of new accessibility technologies that expand what is possible in digital inclusion.

Microsoft's implementation of inclusive design principles across its product ecosystem demonstrates the scalability of this approach even in large, complex organizations with diverse product lines. By establishing inclusion as a core design principle and providing the tools, resources, and methodologies to support implementation, Microsoft has created organizational capability for inclusion that transcends individual product teams or champions.

The BBC and Microsoft case studies highlight how systematic approaches to inclusion that center diverse users throughout development can create superior experiences for all users. They demonstrate that inclusion is not merely about compliance but creating better, more usable products for everyone. Investing in inclusive design infrastructure yields benefits across product ecosystems beyond individual accessibility features.

## 9. RQ8: Future Predictions for User Experience Design

As technology continues to evolve, user experience design faces both new challenges and opportunities for inclusion. This section explores predictions for the future of UX design and how it might better accommodate diverse users.

### *9.1. Future User Interfaces and Interactions*

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The nature of user interfaces will evolve significantly in the coming years, transforming how users interact with technology and creating new opportunities and challenges for inclusion.

Multimodal interfaces that seamlessly blend voice, gesture, touch, and visual interactions will become standard, allowing users to interact through their preferred modality. These interfaces will recognize that users have different capabilities and preferences in different contexts and that the optimal interaction method may change based on the task, environment, or user state. The increasing sophistication of natural language processing, computer vision, and sensor technologies will enable more intuitive and adaptive interactions that do not require users to learn specialized commands or gestures.

The convergence of these technologies will create opportunities for more inclusive experiences by offering multiple equivalent paths to accomplish the same tasks. Users with visual impairments might interact through voice and haptic feedback, while those with hearing impairments might use visual and gesture-based interactions. This redundancy will benefit not only users with permanent disabilities but also those experiencing situational limitations such as occupied hands or noisy environments.

Spatial computing and augmented reality will move interactions beyond screens into three-dimensional space, creating new information presentation and manipulation paradigms. These technologies can potentially create more intuitive and natural interactions by leveraging users' existing understanding of physical space and objects. For example, spatial interfaces might allow users to organize information in personal "spatial memory palaces" that leverage human spatial memory capabilities, potentially benefiting users with specific cognitive processing differences.

However, spatial computing also presents new accessibility challenges. Users with mobility impairments may struggle with interfaces that require specific physical movements, while those with spatial processing differences might find three-dimensional information arrangements confusing rather than clarifying. Ensuring that spatial interfaces include alternatives for users who cannot perceive or navigate 3D space will be essential for inclusion.

Ambient computing will distribute interactions across environments rather than discrete devices, creating interfaces that respond to presence, movement, and context without explicit commands. These systems can potentially reduce technology interaction's cognitive and physical burden by anticipating needs and providing assistance without requiring explicit requests. Ambient systems could provide unprecedented levels of independence and support for users with cognitive or physical impairments that make traditional interfaces challenging.

The distributed nature of ambient computing also creates new challenges for transparency, control, and privacy. Users need to understand what systems monitor them, what inferences are being made, and how to control or override automated behaviors. These challenges are particularly significant for users with cognitive impairments who might struggle to understand abstract system behaviors, or those with communication differences who might be misinterpreted by sensing systems trained on normative behaviors.

Brain-computer interfaces will emerge as a new interaction paradigm, potentially offering new opportunities for those with physical impairments. Direct neural interfaces that interpret intentions without requiring physical movement could revolutionize access for people with severe motor impairments, creating new possibilities for communication, creativity, and independence.

As with any emerging technology, brain-computer interfaces will raise significant ethical and practical questions about consent, privacy, security, and equitable access. Ensuring these technologies are developed with diverse users involved from the earliest stages will be essential for creating interfaces that respect autonomy, accommodate neurodiversity, and provide benefits beyond specialized medical applications.

These evolving interfaces will require UX designers to develop new paradigms for inclusion that account for diverse physical, cognitive, and sensory capabilities across multiple interaction modalities. The increasing complexity of technology ecosystems will demand more sophisticated

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approaches to ensuring equivalent experiences across different access methods, contexts, and user capabilities.

### *9.2. Future of UX Design Processes and Tools*

The practice of UX design will also evolve to support better inclusion, with new processes and tools making inclusive design more achievable and efficient.

AI-assisted design tools will help identify potential accessibility issues during the design process, making inclusion easier to implement before development begins. These tools will analyze designs for common accessibility issues such as insufficient color contrast, missing alternative text, or interaction patterns that might be challenging for keyboard or screen reader users. By providing real-time feedback during the design process, these tools will help designers address accessibility issues early when changes are less costly and more feasible.

As AI capabilities advance, these tools will move beyond technical compliance checking to provide more sophisticated usability analysis for diverse users. They might simulate how different users would experience an interface, identify potential cognitive load issues for users with different processing capabilities, or suggest alternative interaction patterns that might be more inclusive for specific user groups.

Simulation tools will allow designers to experience their interfaces as users with different abilities might experience them, building empathy and understanding of diverse user needs. These tools might simulate various visual impairments, cognitive processing differences, or motor limitations, helping designers identify barriers that might not be apparent from their perspective. By making the experiences of diverse users more immediately perceptible to designers, these tools will help bridge empathy gaps and make inclusive design more intuitive.

Automated personalization will dynamically adapt interfaces based on individual user needs and preferences, reducing the burden on users to discover and configure accessibility settings. These systems will learn from user interactions to identify potential barriers and suggest or implement adaptations that improve usability. For example, a system might notice that a user frequently zooms in on text, automatically increasing default text sizes, or detecting confusion with certain interaction patterns and offering simplified alternatives.

Co-design platforms will enable remote collaboration with diverse users throughout the design process, making it easier to incorporate perspectives from users who might not be able to participate in traditional in-person research activities. These platforms will support asynchronous participation, multiple communication modalities, and accessible feedback mechanisms that accommodate diverse needs and preferences. By reducing logistical barriers to participation, these platforms will help ensure that diverse perspectives are represented throughout the design process, not just during formal research phases.

Standardized inclusion metrics will facilitate comparison across products and progress tracking over time. These metrics will go beyond binary compliance measures to assess the quality of the user experience for diverse populations, considering factors such as task completion rates, efficiency, error rates, and satisfaction across different user groups. By providing quantitative measures of inclusion, these metrics will help organizations set meaningful goals, track progress, and identify areas for improvement.

These tools will help mainstream inclusion practices requiring specialized expertise, making inclusive design more achievable for all UX practitioners. However, they will not replace the need for direct engagement with diverse users, as no automated tool can fully predict the complex and nuanced ways in which real people interact with technology in their specific contexts and with their unique combinations of abilities and preferences.

### *9.3. Institutional and Regulatory Evolution*

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Stronger regulatory frameworks will establish more precise requirements for digital accessibility across sectors. Building on existing frameworks like the Web Content Accessibility Guidelines (WCAG) and legislation like the Americans with Disabilities Act, future regulations will likely expand to address emerging technologies and interaction patterns not covered by current standards. These frameworks will increasingly focus not just on technical compliance but on meaningful usability and equivalent experiences for diverse users.

Regulations will likely evolve to address not only traditional disabilities but also broader considerations of digital equity, including accommodations for linguistic diversity, cultural differences, and socioeconomic constraints. This expanded scope will push organizations to consider inclusion holistically, addressing the full spectrum of barriers different populations might face.

Certification programs will create recognized standards for inclusive design expertise, helping organizations identify qualified professionals and incentivizing practitioners to develop specialized skills. These certifications will likely go beyond technical knowledge of accessibility standards to encompass competencies in user research with diverse populations, inclusive design methodologies, and implementation strategies across different platforms and technologies.

Academic programs will integrate inclusive design throughout curricula rather than treating it as a specialized topic. This integration will ensure that all design and development professionals enter the workforce with a fundamental understanding of diverse user needs and inclusive design approaches. By embedding inclusion throughout education rather than treating it as an optional specialization, these programs will help create a generation of practitioners for whom inclusion is a core professional value and competency.

Organizations will establish chief accessibility officers and inclusion teams that directly influence product strategy. These roles will elevate inclusion considerations to the executive level, ensuring that accessibility is considered in strategic decisions rather than treated as a technical implementation issue. By giving inclusion advocates organizational authority and resources, companies will create internal champions who can drive systemic change across product lines and teams.

Market demand for inclusive products will increase as demographics shift and awareness grows. Aging populations in many countries will create larger markets of users with age-related accessibility needs while growing recognition of disability rights and digital equity will increase expectations for inclusive experiences. Organizations that excel at inclusion will gain a competitive advantage through access to broader markets, a stronger brand reputation, and talent acquisition benefits from demonstrating social responsibility.

Industry collaborations will emerge to address common accessibility challenges, pooling resources and expertise to develop solutions that benefit the entire ecosystem. These collaborations might focus on developing accessibility standards for emerging technologies, creating shared resources for inclusive design, or researching underserved user groups that individual organizations might not have the resources to study comprehensively.

As noted by Kuusinen [25], collaboration between UX experts and development teams is crucial for successfully implementing inclusive design principles. When software developers take over, they are aware of the challenges and necessity of UX, suggesting that integrating inclusive design considerations throughout the development process will be essential for future systems.

### *9.4. Technological Evolution and Digital Equity*

The broader technological landscape will continue to evolve in ways that have significant implications for inclusion and digital equity.

Artificial intelligence will increasingly mediate user experiences, with both potential benefits and risks for underrepresented groups. AI systems could enhance inclusion by providing real-time accommodation, such as automatic captioning, visual description, or content simplification.

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However, AI systems trained on datasets that underrepresent specific populations risk perpetuating or amplifying existing biases, creating new forms of algorithmic discrimination.

Ensuring that AI systems are trained on diverse data, tested with diverse users, and designed with transparency and control mechanisms will be essential for leveraging their potential benefits while mitigating risks. Future UX designers must develop expertise in AI ethics and inclusive AI design to ensure these systems serve all users equitably.

Emerging hardware technologies will create new possibilities for inclusive interactions. Advances in haptic feedback, eye tracking, neural interfaces, and wearable technologies will provide new input and output channels that may benefit users with various disabilities. For example, sophisticated haptic systems might create tactile representations of visual information for blind users, while improved eye tracking could provide efficient input methods for users with motor impairments.

These hardware innovations will also create new design challenges, as teams will need to consider how to provide equivalent experiences across an expanding array of devices and interaction modalities. As the diversity of devices increases, the importance of platform-agnostic design principles and adaptive interfaces will grow.

The digital divide will evolve rather than disappear, with new technological inequality emerging even as basic access becomes more widespread. While internet connectivity and device ownership will likely increase globally, disparities in digital literacy, advanced device access, broadband quality, and technical support will continue to create barriers for specific populations.

Future digital inclusion efforts will need to address these evolving disparities, considering physical access to technology and the knowledge, support, and resources needed to use it effectively. UX designers will play a critical role in reducing these barriers by creating intuitive interfaces that require minimal training, function effectively on lower-end devices and limited bandwidth, and provide integrated learning supports for users with varying levels of digital literacy.

## 10. Conclusion

Enhancing the UX development life cycle to support underrepresented groups requires systematic changes in identifying users, designing solutions, measuring success, and structuring our teams and processes. By expanding our understanding of diverse user needs, developing flexible design approaches that efficiently accommodate these needs, measuring gaps between function criticality and accessibility, and meaningfully including members of underrepresented groups throughout the development process, we can create more inclusive and equitable technology.

The evolution of technology support for mission-critical life functions demonstrates both progress and persistent challenges in inclusion. By understanding the specific characteristics that make certain groups vulnerable to technological change and learning from exemplary systems that successfully accommodate diversity, we can develop design approaches that are more resilient and inclusive.

As user interfaces, design tools, and institutional contexts evolve, new opportunities will emerge to mainstream inclusive design practices. By embracing these opportunities and maintaining a commitment to serving diverse users, the field of user experience can help ensure that future technology supports full participation for all individuals, regardless of ability, age, language, culture, or other factors.

The future of UX design must balance innovation with inclusion, recognizing that new technologies can either exacerbate existing inequalities or help overcome them, depending on how they are designed and implemented. By integrating inclusive design principles throughout the development lifecycle, involving diverse users in meaningful ways, and creating accountability mechanisms for inclusion outcomes, organizations can create products that meet compliance requirements and truly support human flourishing across the full spectrum of user diversity.

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As technology becomes increasingly essential for participation in education, employment, healthcare, civic engagement, and social connection, ensuring that these systems are accessible to all users becomes not just a technical challenge but an ethical imperative. By enhancing the UX development lifecycle to support underrepresented groups better, we can help create a technological future that expands rather than limits human potential across diverse populations.

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