A Review of Assistive Technology (AT) - Innovations, Accessibility, and the Future of Inclusion

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Abstract:
The rapid advancement of assistive technology (AT) has created significant opportunities to improve the lives of individuals with disabilities by enhancing functionality, independence, and participation across sectors such as education, employment, and daily living. This review explores the development of AT, including its historical foundations, legal definitions, and the shift from device-centric to user-centric models like the Human Activity Assistive Technology (HAAT) framework. It highlights key themes, such as the integration of AT in education and workplaces, the convergence of assistive and mainstream technologies, and ongoing challenges like affordability, access disparities, and insufficient training. Additionally, the review evaluates the transformative potential of emerging technologies, including artificial intelligence, robotics, and advanced manufacturing, while addressing ethical and equity concerns. By identifying research gaps, such as the lack of standardised taxonomies, inconsistent adoption in low-resource settings, and limited long-term studies, this review underscores the need for interdisciplinary research, inclusive design, and innovative strategies. It provides a deeper understanding of AT's critical concepts and categories and emphasizes the importance of bridging the gap between innovation and equitable access to foster a more inclusive and accessible future.

Keywords: Assistive technology, accessibility, user-centric models, Human Activity Assistive Technology (HAAT), emerging technologies, inclusive design, equity, affordability, policy frameworks, education, mainstream technology, innovation, access disparities, disability inclusion, interdisciplinary approaches.

Policy and historical perspective

Assistive technology (AT) policies, such as the 1988 Tech Act in the U.S., provide a foundational framework, emphasizing AT devices and services to enhance independence and functionality. However, these policies often overlook challenges in implementation, including funding gaps and disparities in access. Broader definitions, like those from the World Health Organisation (WHO) and the UK government, highlight AT's role in improving well-being and inclusion but fail to address systemic barriers such as affordability, cultural adaptability, and stigma, particularly in low-resource settings.

While the person-centred approach advocated by Cook, Polgar, and Encarnacao (2019) is promising, there is limited focus on how user input influences policy and design. Additionally, overlapping definitions from various scholars reiterate core themes but lack synthesis, missing opportunities to analyse the evolution of AT in response to technological and societal changes. To bridge the gap between policy and practice, AT frameworks must prioritize user-driven innovation, equitable access, and inclusive design, addressing the socio-political and economic factors that hinder widespread adoption. A more dynamic and global perspective is essential to ensure AT meets the diverse needs of individuals with disabilities.

Assistive Technology (AT)-Functionality and Participation

Assistive technology (AT) aims to empower individuals with disabilities by enhancing participation in education, employment, and daily living. However, implementation often faces challenges. The WHO (2024) defines AT as health technology that improves functioning and well-being, but critics highlight its failure to address disparities in access, affordability, and cultural adaptability, particularly in low-resource settings (Cook and Hussey, 2002; Okolo and Bouck, 2006; Chmilliar, 2007). Similarly, the UK Parliament underscores systemic barriers like inadequate training and institutional biases that hinder AT adoption. To realise AT's transformative potential, solutions must prioritize affordability, equitable access, user training, and culturally adaptable designs, ensuring inclusion and well-being for all.

Furthermore, Young and MacCormack (2020) praise the transformative impact of assistive technology (AT) on students with disabilities but fail to address the uneven adoption in underfunded schools where budget constraints and lack of teacher training limit its utility. Without equitable access, the promise of AT remains unrealized for many students. Zallio and Ohashi (2022) highlight the evolution of AT influenced by technological advances and the Assistive Technology Act of 2004, promoting inclusive design. However, this focus often neglects those with severe disabilities who require specialized solutions. Recent innovations primarily benefit individuals with mild or moderate impairments, raising ethical concerns about resource allocation. Critics argue that prioritizing commercially viable technologies risks marginalizing those with greater needs but less purchasing power. Addressing these gaps is crucial for ensuring AT enhances participation for all students.

Shift from Device-Centric to User-Centric Models

The evolution of assistive technology (AT) is shifting from device-centric to user-centric approaches, emphasizing the user's needs, goals, and context, as seen in the Human Activity Assistive Technology (HAAT) model. However, practical implementation often falls short due to systemic barriers like inadequate user involvement and limited adaptability in diverse settings. Lee et al. (2022) call for integrating biophysical and social theories in AT research to address users' experiences and quality of life, though interdisciplinary research faces feasibility issues. The interdependence-HAAT (i-HAAT) model which merges the HAAT

framework with interdependence theory aims to modernize AT outcomes but may not fully address real-world complexities, especially in underserved communities.

Despite the HAAT model's focus on user-context interplay, it often overlooks socio-political and economic factors such as stigma and funding inequities that impact AT adoption. Without tackling these broader issues, user-centric models remain theoretical. Laurenco, DeJesus, and Steiner (2024) trace AT's evolution, noting its role in social inclusion. However, they risk overgeneralizing benefits without addressing challenges like accessibility and affordability. AT enhances quality of life, but uneven availability limits its universal impact. The perspective that AT empowers individuals assumes supportive infrastructure and policies, which are often lacking in schools and workplaces, creating barriers to social integration. Hiremath and Nirmala (2023) outline AT's historical development, but their focus on market-driven innovation overlooks equitable access, and systemic gaps continue to hinder AT's full potential.

AT trends and emerging technologies

The distinction between assistive technology (AT) and mainstream technology is blurring, raising questions about inclusivity, access, and equity. Mainstream devices now include built-in accessibility features, but these often do not meet the specialized needs of individuals with severe disabilities (Ludlow, 2014). This convergence can overlook the unique requirements of these users. The commodification of accessibility complicates matters further. Features like speech-to-text and GPS benefit many but are often embedded in premium devices, making them inaccessible to those who need them most, widening the digital divide. Young and MacCormack (2014) highlight AT's diversity from low-tech to high-tech solutions but fail to address how this aligns with users' socioeconomic realities. High-tech solutions are often impractical in underfunded schools or resource-poor regions.

In addition, Hiremath and Nirmala (2023) emphasize AT's broad applicability but overlook systemic barriers that hinder access. The Assistive Technology Industry Association (ATIA) (2024) defines AT broadly but neglects the role of advocacy and policy in making these products accessible and affordable. while merging assistive and mainstream technologies holds promise, it presents significant challenges. Ensuring these technologies are accessible and affordable for all is crucial for greater inclusivity. On the other hand, merging assistive technology (AT) with mainstream technology normalizes accessibility, it also poses significant risks. Mainstream solutions can lead to one-size-fits-all designs that do not address the unique needs of all disabilities. Often, the responsibility for accessibility falls on individuals to adapt, rather than on developers to create inclusive designs from the outset.

However, emerging technologies like artificial intelligence (AI), advanced human-computer interfaces, improved sensors, robotics, 5G networks, and additive manufacturing offer promising, personalized, and adaptive AT solutions (Abdi et al., 2021). AI can enhance device capabilities, while natural language processing and machine learning open new possibilities for accessibility. Sensor technology provides real-time data for tailored solutions,

and robotics, combined with AI, can support daily activities. 5G networks enable remote healthcare and virtual rehabilitation, while additive manufacturing and advanced materials allow for customizable, durable devices. Nevertheless, these advancements are often expensive and require technical expertise, limiting their availability in low-income regions and underserved communities, potentially exacerbating existing inequalities.

Also, the World intellectual property Organisation (WIPO) Tech Trends (2021) report highlights the shift from conventional to emerging AT, such as AI-powered speech recognition and robotic exoskeletons. These technologies significantly improve quality of life but face implementation challenges due to resource constraints and infrastructure limitations. Rapid technological advancements risk prioritizing sophistication over usability and accessibility. For AT to reach its full potential, developers must engage with end-users throughout the design process, ensuring that solutions are practical, affordable, and contextually relevant. Bridging this gap is crucial to ensuring that the benefits of emerging AT are equitably distributed and truly inclusive for all users.

Functionality, Disability and Technological Categories

Assistive technology (AT) can be categorised by the specific functions or activities it supports, such as reading, writing, communication, mobility, vision, hearing, cognition, and daily living activities (Mavrou, 2011). This approach aligns with AT's core purpose of enhancing functionality and promoting independence. AT can also be categorised based on the type of disability it addresses, like physical disabilities, learning disabilities, visual impairments, and hearing impairments (Maor, Currie, & Drewry, 2011). While useful in educational settings, this method may inadvertently reinforce a medical model of disability. AT can be classified by its technological sophistication: low-tech (simple tools like pencil grips), mid-tech (battery-operated devices like audio recorders), and high-tech (advanced systems like speech recognition software and powered wheelchairs) (Wynne et al., 2016). This classification helps understand the range of AT solutions and the varying levels of support they provide.

Established Frameworks

-ISO 9999:2016: This standard classifies assistive products to help manufacturers, service providers, and policymakers.
-WHO International Classification of Functioning, Disability and Health (ICF): Provides a holistic view of disability by considering body functions, activities, participation, and environmental factors (WHO, 2024; Tochetto et al., 2016).
-Individuals with Disabilities Education Act (IDEA): US legislation mandating AT provision in educational settings (Lipkin et al., 2019).
-Comprehensive Assistive Technology (CAT) Model: Proposed by Hersh and Johnson (2008), this model categorizes AT systems by user characteristics, environmental factors, and technological features.

-Problem Manifestation, Underpinned Implication, Instructional Strategy and Cognitive Strength Developed (PISC) Framework: Focuses on AT for learning disabilities, examining the problems addressed, instructional strategies, and cognitive skills fostered (Thapliyal & Ahuja, 2023).

Conventional vs. Emerging Technologies

As mentioned earlier, WIPO (2021) classifies assistive technology (AT) into conventional and emerging types. Conventional AT includes well-established products like magnifiers, hearing aids, and walking aids that support functions such as cognition, communication, hearing, mobility, self-care, and vision. These technologies are widely available and provide essential support for individuals with disabilities. Emerging AT incorporates cutting-edge technologies such as artificial intelligence, robotics, and new materials. These advancements offer sophisticated and personalized solutions, including intraocular lenses, bionic eyes, smart eyewear, augmented reality devices, assistive robots, and mind-controlled hearing aids. Innovations like advanced prosthetics, exoskeletons, smart homes, and feeding assistant robots are enhancing the independence and quality of life for individuals with disabilities.

Challenges in Developing Comprehensive Taxonomies

Defining and classifying AT presents ongoing challenges. The rapid pace of technological advancements requires continuous updates to taxonomies. The diverse needs of users complicate the creation of universally applicable classifications. Additionally, the integration of AT with medical technologies and neuroscience adds complexity to the classification process. Despite these challenges, AT taxonomies are crucial for organizing and understanding the vast array of available technologies. They guide research, development, assessments, funding decisions, and the matching of AT to individual needs. As technology and our understanding of disability and accessibility evolve, these taxonomies must adapt to remain relevant and support inclusive, equitable access to AT for all individuals.

Gaps in the Literature on Assistive Technology Taxonomy

The literature on AT taxonomy reveals significant gaps. There is a lack of a widely accepted, comprehensive framework, complicating the comparison and synthesis of research findings. Current taxonomies are insufficient for emerging technologies like AI, robotics, and brain-computer interfaces, highlighting the need for further research. There is also a lack of documented evidence on the effectiveness and long-term impact of AT interventions. Studies often focus on short-term outcomes, leaving questions about long-term efficacy unanswered. Additionally, user experience and contextual factors, such as individual needs and environments, are not sufficiently considered in research. The field also lacks focus on low-incidence disabilities and relies on short-term interventions. Longitudinal studies are needed to track the long-term impact of AT on educational and life outcomes. Universal design principles are not adequately applied to AT, particularly emerging technologies. The absence

of consistent terminology hinders collaboration and impedes the development of a cohesive taxonomy.

Conclusion

Developing comprehensive and adaptable AT taxonomies is essential for promoting equitable access to technology. Understanding various categorisation methods and established frameworks helps in the effective assessment, implementation, and support of assistive technologies, ultimately enhancing independence and participation for individuals with disabilities.

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