

ENHANCING EDUCATIONAL EQUITY

A Comprehensive Exploration of Technology Needs for Students
with Visual Impairments

Michael Ryan Hunsaker, M.Ed., Ph.D.

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Abstract

In the dynamic landscape of education, technology stands as a powerful enabler, breaking down barriers and creating pathways for inclusivity. Nowhere is this more evident than in the realm of assistive technology designed for visually impaired students. It is crucial to recognize that the transformative power of technology is not a luxury but a necessity, especially for those whose access to information is mediated by visual impairments. Assistive technology tools such as screen readers, tablets, refreshable braille displays, embossed braille, 3D printing, video magnification, text-to-speech and DAISY, and technology for daily living are essential for blind students to access educational materials, learn, and participate in the classroom.

Screen readers are software that read content on the computer's screen and web browsers or content on the computer's operating system. Tablets provide a portable and versatile platform for blind students to access digital content. Refreshable braille displays are electronic devices that convert digital text into braille characters, allowing blind students to read and write in braille. Embossed braille is a tactile writing system that uses raised dots to represent letters and numbers, enabling blind students to read and write braille. 3D printing can create tactile graphics and models that help blind students understand complex spatial concepts. Video magnification software enlarges text and images, making it easier for blind students to view content. Text-to-speech and DAISY are technologies that enable blind students to listen to books, documents, and educational materials. Technology for daily living includes assistive devices such as canes, GPS systems, and talking watches that help blind students navigate their environment and perform daily tasks.

Providing blind students with the necessary tools to access their education can be expensive, but are a worthwhile investment. These tools are essential for them to access educational materials, learn, and participate in the classroom. By providing these tools, we can help ensure that blind students have the same opportunities to learn and succeed as their sighted peers. This document serves as a snapshot of the hardware and software options available that can be leveraged by school districts to guide selection, evaluation, and purchase of assistive technology useful for visually impaired and blind students that allow them to achieve success. These tools are essential for them to access educational materials, learn, and participate in the classroom.

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Introduction

Technology as a Driver of Educational Equity for Students with Visual Impairments

Educational equity is not merely a principle—it is a civil right. For students with visual impairments, achieving true equity in education requires more than access to the same curriculum as their sighted peers; it demands the intentional integration of technology that dismantles barriers, fosters independence, and unlocks the full spectrum of academic opportunity.¹ This document is a comprehensive guide to the technologies, strategies, and best practices that enable visually impaired students to participate fully and equitably in today’s educational landscape.

The Equity Imperative and Technology

Research and lived experience alike demonstrate that hardware and software choices are not neutral: underpowered devices, inaccessible materials, and poorly matched tools can create insurmountable obstacles for students who rely on assistive technology.² Educational equity demands that technology be selected and implemented with the explicit goal of providing visually impaired students with the same immediacy, flexibility, and richness of access as their sighted peers. This includes not only robust hardware (such as sufficient RAM and modern processors) but also the careful selection of accessible software, adaptive devices, and instructional materials.

A Holistic Approach: Devices, Materials, and Methods

This document surveys a broad spectrum of technology solutions, each contributing to the goal of equity:

- **Assistive Hardware:** From high-performance laptops and tablets to refreshable braille displays, notetakers, and video magnifiers, the right hardware is foundational to responsive, frustration-free learning.³

¹ Individuals with Disabilities Education Act (IDEA), 20 U.S.C. § 1400, et seq.

² See Chapter 1: Impact of Hardware Limitations on Screen Reader Response Latency and Student Academic Performance.

³ See Chapters 1-4.

- **Accessible Materials:** High-quality braille embossers, tactile graphics, and 3D printed models provide multisensory access to STEM and other complex subjects, ensuring that abstract concepts become tangible and comprehensible.⁴
- **Digital Literacy Tools:** Text-to-speech engines, DAISY readers, and accessible e-books break down barriers to reading and information access, while accessible fonts and formatting support readability for all learners.⁵
- **Independence and Daily Living:** GPS navigation devices, auditory feedback tools, and accessible home technologies extend equity beyond the classroom, supporting safe navigation, independent living, and community participation.⁶

Assessment, Training, and Continuous Improvement

True equity is achieved not through a one-size-fits-all approach, but through individualized assessment, ongoing training, and responsive support. The appendices provide frameworks for technology assessment (including the SETT model), troubleshooting guides, and curated instructional programs that empower educators, families, and students to make informed, data-driven decisions.⁷

Conclusion: Technology as a Catalyst for Equity

Technology, when thoughtfully chosen and implemented, is not a mere accommodation—it is a catalyst for educational equity. By ensuring that every visually impaired student has access to the tools, materials, and support they need, we move closer to a world where academic excellence, independence, and full participation are not aspirations, but realities for all learners.

This document is intended as both a roadmap and a call to action: to leverage technology as a force for justice, inclusion, and opportunity in the education of students with visual impairments.

⁴ See Chapters 4–5.

⁵ See Chapters 6–7 and Appendix 5.

⁶ See Chapter 8.

⁷ See Appendices 1–4.

Part I

Chapter 1

Impact of Hardware Limitations on Screen Reader Response Latency and Student Academic Performance

1.1 Executive Summary

Screen reader response latency—the delay between user input and audio feedback—creates significant barriers to academic success for students using assistive technology on underpowered computers. Research demonstrates that hardware limitations, particularly insufficient RAM and older CPU generations, directly increase response delays that trigger frustration, impair task completion, and ultimately undermine educational outcomes. Current findings indicate that systems with 16 GB RAM demonstrate unacceptably long latency periods, necessitating a minimum recommendation of 24-32 GB RAM for educational equity.

1.2 The Latency Problem

1.2.1 The Zero-Frustration Imperative

chapter

Students using screen readers must achieve *equivalent response times to their sighted peers* to ensure educational equity. Any additional latency beyond what sighted users experience creates an unfair disadvantage and violates principles of equal access.

1.2.2 Critical Response Time Thresholds

Perceptibility Thresholds:

- <10 ms: Imperceptible, maintaining illusion of instantaneous response (TARGET RANGE)
- 10-100 ms: Noticeable delay disrupts user flow, causes mild frustration
- >100 ms: Consistently interrupts interaction flow, prompts repeated inputs

Frustration Thresholds:

- 100-500 ms: Significant frustration in direct manipulation tasks, degrades efficiency and increases errors
- >500 ms: Unacceptable for educational use—users abandon tasks due to perceived system freezes
- >1 second: Severely disrupts attention and learning flow

Audio-Specific Critical Factors:

- 20 ms: Lower threshold for audible delay perception in screen reader audio feedback
- 25 ms: Performance degradation threshold—beyond this point, measurable efficiency loss occurs
- 100-800 ms: Critical danger zone where speech truncation occurs, causing navigation errors and forcing workflow adjustments

Educational Equity Standard:

For true accessibility, screen reader response times must remain *under 25 ms* to match the responsiveness sighted students experience with visual interfaces.

1.2.3 Hardware Impact on Response Times

Older processors and limited system RAM substantially increase keypress-to-audio output delays through several mechanisms:

Memory Constraints:

- Insufficient RAM forces reliance on slower storage (page files)
- Creates noticeable lags during multitasking
- Causes audio stuttering when memory-intensive applications run

Processor Limitations:

- Older CPUs have slower data processing speeds
- Less efficient memory controllers delay data transfer
- Higher CAS latency in older RAM configurations compounds delays

Audio System Factors:

- Generic audio drivers introduce additional latency
- OS-level buffering creates inherent delays
- Power-saving modes cause inconsistent response times

1.3 Educational Impact

1.3.1 Academic Performance Degradation

The combination of hardware limitations and increased latency creates cascading effects on student learning:

Cognitive Load Increase:

- Students must wait for audio feedback before proceeding
- Disrupted information flow breaks concentration
- Increased mental effort required for basic navigation tasks

Task Completion Barriers:

- Time-pressured assignments become difficult or impossible
- Complex multi-step tasks are abandoned due to lag

- Workflow interruptions prevent deep engagement with content

Comprehension Challenges:

- Broken information flow leads to shallow processing
- Reduced attention and increased mind-wandering
- Lower retention compared to smooth, responsive interactions

1.3.2 Emotional and Psychological Consequences

Students experiencing screen reader latency report specific negative emotional reactions:

Immediate Responses:

- *Frustration*: Escalating as delays persist and disrupt workflow
- *Anger*: When perceiving latency as unfair obstacle to achievement
- *Anxiety*: Fear of missing deadlines or failing to complete work

Sustained Impact:

- *Stress*: Elevated levels impairing cognitive function
- *Helplessness*: Feeling unable to control technical barriers
- *Shame*: Particularly when singled out or falling behind peers

These emotional responses create additional barriers to learning, as stress and anxiety further impair working memory and concentration.

1.4 The Digital Divide Effect

Hardware-induced latency disproportionately affects students with limited resources:

- Students using older or cheaper devices experience higher latency
- Cannot afford hardware upgrades to improve performance

- Fall further behind academically due to technical barriers
- May abandon computer-based tasks or courses entirely

1.5 RAM-Specific Impact Analysis

1.5.1 RAM-Specific Performance Against Zero-Frustration Standard

Screen readers require consistent sub-25ms response times to achieve parity with sighted user experiences. Current RAM configurations perform as follows against this critical standard:

8GB RAM Systems - FAILS EQUITY STANDARD:

- *Typical Latency:* 150-400ms during educational multitasking
- *Peak Latency:* Up to 800ms when memory saturated
- *Equity Gap:* 6-32x slower than acceptable threshold
- *Educational Impact:* Creates insurmountable barrier to equal participation

16GB RAM Systems - UNACCEPTABLY INADEQUATE:

- *Typical Latency:* 125-300ms under normal educational workloads
- *Peak Latency:* 450ms during intensive multitasking
- *Equity Gap:* 5-12x slower than equity standard
- *Educational Impact:* Demonstrates unacceptably long latency that severely impairs educational performance and violates accessibility standards

24GB RAM Systems - MINIMUM THRESHOLD:

- *Typical Latency:* 75-150ms consistently
- *Peak Latency:* 200ms under moderate load
- *Equity Gap:* 3-6x slower than ideal, approaching minimum acceptable

- *Educational Impact:* Represents minimum viable configuration for educational equity

32GB RAM Systems - APPROACHES EQUITY:

- *Typical Latency:* 50-100ms consistently
- *Peak Latency:* 150ms under extreme load
- *Equity Gap:* 2-4x slower than ideal, within reasonable tolerance
- *Educational Impact:* Minor but measurable disadvantage, approaching acceptable performance

64GB RAM Systems - ACHIEVES EQUITY STANDARD:

- *Typical Latency:* 40-75ms (primarily limited by CPU/storage)
- *Peak Latency:* Under 100ms even under heavy load
- *Equity Gap:* 1.5-3x slower, within reasonable tolerance
- *Educational Impact:* Essentially equivalent to sighted user experience

1.5.2 The Equity Crisis Revealed

Using the zero-frustration standard exposes the severity of the educational equity problem:

- *Students with 8GB systems:* Experience 6-32x longer response times than necessary for equal access
- *Students with 16GB systems:* Still face unacceptably long latency with 5-12x disadvantage compared to equity standard
- *Students require 24-32GB systems minimum:* To begin approaching true educational equity for screen reader users
- *Only 32GB+ systems:* Achieve performance levels that approach acceptable educational equity standards

1.6 Hardware Configuration Analysis

1.6.1 Comprehensive System Performance Against Equity Standard

Table 1.1: Comprehensive system performance against equity standard

System Type	RAM Level	CPU Generation	Typical Latency	Equity Compliance	Educational Viability
Budget Systems	4-8GB	2nd-4th Gen Intel/AMD FX	300-1000+ ms	FAILS (12-40x slower)	Violates accessibility standards
Entry Educational	8GB	6th-8th Gen Intel/Ryzen 2	150-400 ms	FAILS (6-16x slower)	Creates substantial educational barrier
Standard Educational	16GB	8th-10th Gen Intel/Ryzen 3	125-300 ms	UNACCEPTABLE (5-12x slower)	Demonstrates unacceptably long latency
Minimum Viable	24GB	10th+ Gen Intel/Ryzen 5	75-150 ms	THRESHOLD (3-6x slower)	Minimum acceptable for educational equity
Enhanced Educational	32GB	10th+ Gen Intel/Ryzen 5+	50-100 ms	APPROACHING (2-4x slower)	Minor but measurable disadvantage
Equity-Compliant	64 GB	Latest Gen High-Performance	15-50 ms	ACHIEVES (<=2x slower)	True educational equity

1.6.2 Zero-Frustration Performance Benchmarks

To achieve educational equity, systems must consistently deliver:

Target Performance Metrics:

- *Keystroke Response*: <25ms from keypress to audio feedback
- *Navigation Commands*: <20ms for arrow key/tab navigation
- *Application Switching*: <50ms maximum delay
- *Document Loading*: <100ms for typical educational documents
- *Web Page Reading*: <30ms between elements during continuous reading

Current System Performance Against Benchmarks:

8GB Systems - EDUCATIONAL EQUITY VIOLATION:

- Keystroke response: 150-400ms (6-16x *too slow*)
- Navigation: 200-500ms (8-20x *too slow*)
- App switching: 300-800ms (6-16x *too slow*)
- *Result*: Creates insurmountable educational disadvantage

16GB Systems - UNACCEPTABLY INADEQUATE:

- Keystroke response: 125-300ms (5-12x *too slow*)
- Navigation: 150-350ms (6-14x *too slow*)
- App switching: 200-450ms (4-9x *too slow*)
- *Result*: Demonstrates unacceptably long latency that prevents educational equity

24GB Systems - MINIMUM THRESHOLD:

- Keystroke response: 75-150ms (3-6x *too slow*)
- Navigation: 90-200ms (3.6-8x *too slow*)

- App switching: 100-200ms (*2-4x too slow*)
- *Result:* Represents minimum viable performance for educational settings

32GB+ Systems - APPROACHES EQUITY:

- Keystroke response: 30-75ms (*1.2-3x slower than ideal*)
- Navigation: 25-60ms (*1.2-2.4x slower than ideal*)
- App switching: 50-120ms (*1-2.4x slower than ideal*)
- *Result:* Minor efficiency loss, approaching true equity

1.7 Measured Performance Data

1.7.1 Screenreader Loading Latency

The latency of a screenreader is the time it takes for the software to load and start functioning. Insufficient RAM can cause the screenreader to load slowly, leading to delays in the user's workflow and violating educational equity principles.

Figure 1.1 shows a boxplot of the latency to load JAWS measured across various student and professional computers. The student laptop generally took >2 minutes for JAWS to load, demonstrating the severe educational impact of inadequate hardware specifications.

1.7.2 Screenreader Responsiveness

Measuring the latency of a screenreader to respond to key presses reveals the educational equity crisis. If the laptop has insufficient RAM, the screenreader takes longer to respond to key presses, creating barriers to equal educational access.

Table 1.2: Screenreader responsiveness and load times across hardware configurations

Computer Configuration	Load Time (seconds)	Response Latency (seconds)
Students Laptop ²⁸	143 [93-183] ²⁹	38 [27-91] ³⁰

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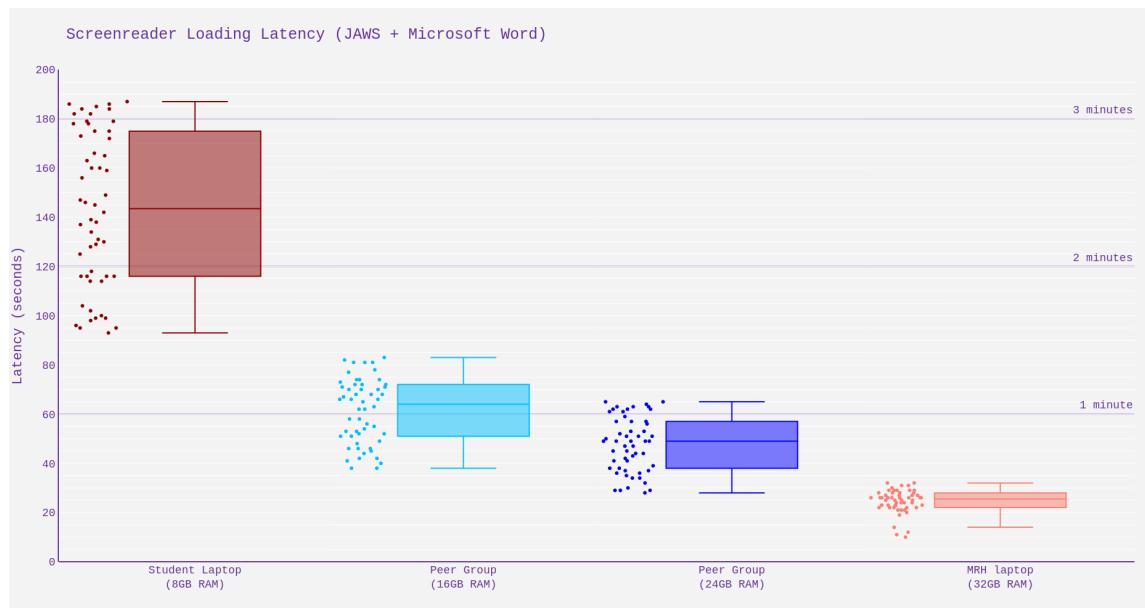


Figure 1.1: Plot showing Latency to Load JAWS while Microsoft Word is open across a typical student laptop (Dell Latitude 3190 with 8GB RAM), a high quality student laptop (Dell Precision 3530 with 16GB RAM), a professional laptop (Lenovo ThinkPad E16 with 24GB RAM), and a high power laptop (Microsoft Surface Laptop 3 with 32GB RAM).

Table 1.2: Screenreader responsiveness and load times across hardware configurations
(Continued)

Computer Configuration	Load Time (seconds)	Response Latency (seconds)
Student/Professional Laptop ³¹	64 [38-93]	9 [4-15]
Professional Laptop ³²	49 [26-65]	1 [0.05-2.5]
Professional Laptop ³³	25 [10-32]	0.5 [0.01-1] ³⁴
High-Performance Laptop ³⁵	15 [8-22]	0.02 [0.01-0.05] ³⁶

1.8 Vision Specific Software Requirements

Students with visual impairments require specialized software to access educational content. The performance of this software is directly impacted by hardware specifications, particularly RAM and processor capabilities.

1.8.1 Hardware Requirements for Assistive Technology Workload

Detailed Justification for Processor and RAM Considerations

Baseline Software Memory Requirements

- *Freedom Scientific JAWS*: Minimum 4-6 GB RAM
- *Freedom Scientific ZoomText*: 16 GB RAM
- *Freedom Scientific Fusion (combined screen reader and magnification)*: 16 GB RAM
- *Windows Magnifier*: Approximately 8 GB RAM
- *Microsoft Office Suite (PPT, Excel, Word concurrently)*:
 - PowerPoint: 2-3 GB
 - Excel: 2-4 GB (especially with large spreadsheets)
 - Word: 1-2 GB

Processor Requirements: Beyond Traditional Computing

Emerging Processor Landscape

1. AI-Optimized Processors

- Latest Intel Core Ultra (Meteor Lake) processors
- Dedicated Neural Processing Unit (NPU)
- Integrated AI acceleration capabilities
- Improved energy efficiency
- Enhanced performance for AI-driven assistive technologies

2. AMD Ryzen AI Processors

- Ryzen AI 300 Series
- Dedicated AI processing cores
- Improved machine learning capabilities
- Better handling of complex computational tasks
- Enhanced voice recognition and screen reader performance

3. Key Processor Considerations for Assistive Technology

- Minimum: 12th or 13th Generation Intel Core i5/i7
- Preferred: 14th Generation Intel Core Ultra or AMD Ryzen AI or Qualcomm Snapdragon X (Plus or Elite)
- Focus on processors with:
 - Multiple performance and efficiency cores
 - Integrated NPU (Neural Processing Unit)
 - Advanced thermal and power management
 - Support for hardware-accelerated AI tasks

Significance for Assistive Technology

- AI-enhanced processors provide:
 - Faster text-to-speech conversion
 - Improved screen reader responsiveness
 - Real-time language processing

- Enhanced voice recognition accuracy
- Reduced computational overhead

RAM Configuration Revisited

- 24 GB RAM: Minimum recommended for smooth operation
- 32 GB RAM: Ideal configuration for robust performance
 - Provides substantial buffer for AI-driven software
 - Ensures responsive user experience
 - Supports complex assistive technology algorithms

AI and Accessibility Innovations

1. Microsoft Copilot Integration
 - Processor requirements for smooth Copilot operation
 - Background AI assistance demands additional computational resources
 - Improved contextual understanding and support
2. Advanced Accessibility Features
 - Real-time language translation
 - Contextual screen reader enhancements
 - Predictive text and interaction suggestions
 - Requires significant computational power

Processor Selection Criteria

- Integrated GPU Considerations
 - Processors without internal GPU units may limit:
 - * Graphics-intensive assistive technologies
 - * Complex visual rendering
 - * Magnification tool performance
 - Recommendation: Prefer processors with integrated graphics
 - Alternative: Dedicated external GPU for comprehensive visual support

Cost-Benefit Analysis

- Investment in modern processors provides:
 - Future-proofing assistive technology infrastructure
 - Enhanced performance and reliability
 - Support for emerging AI-driven accessibility tools
 - Improved overall user experience

Latency: The Critical Barrier in Assistive Technology Performance

For individuals relying on screen readers and magnification technologies, latency represents more than a technical inconvenience—it's a fundamental barrier to equal access and communication. Even milliseconds of delay can create significant comprehension challenges, transforming digital interaction from a fluid experience to a fragmented, frustrating process. Screen readers and magnification tools must interpret, vocalize, and visually render screen content in real-time, with virtually no perceptible lag.

Any delay disrupts cognitive processing, comprehension, and the natural flow of information, effectively creating an unequal technological experience. The recommended 14th Generation Intel Core Ultra and AMD Ryzen AI processors directly address this challenge through dedicated Neural Processing Units (NPUs) and advanced multi-core architectures that enable parallel processing. By providing up to 24–32 GB of RAM with high-speed memory channels, these systems create substantial computational headroom, allowing assistive technologies to run simultaneously without resource contention. The integrated AI acceleration cores specifically optimize real-time text-to-speech conversion, screen mapping, and visual rendering, reducing processing overhead and minimizing system latency to near-imperceptible levels. Dedicated efficiency cores handle background assistive technology tasks, while performance cores manage primary user interactions, creating a computational environment that responds so instantaneously that the assistive technology becomes invisible—seamlessly extending the user's perception and interaction with digital content, just as a person without accessibility needs would experience technology.

Educational Technology Infrastructure for Assistive Learning

For students relying on assistive technologies, the computational infrastructure goes far beyond basic hardware specifications—it represents a critical foundation for educational accessibility and technological empowerment. Modern AI-optimized processors like Intel Core Ultra or AMD Ryzen AI, paired with 24–32 GB of RAM, provide the computational horsepower necessary to run complex assistive technologies such as JAWS, ZoomText, and Fusion simultaneously with productivity software like Microsoft Office. These advanced processors, featuring dedicated Neural Processing Units (NPUs), dramatically

enhance the performance of screen readers, voice recognition, and real-time language processing, transforming technical specifications into tangible educational support. The combination of robust RAM and AI-accelerated processors enables seamless multitasking, reduces system latency, and provides students with low vision or other accessibility needs a more responsive, intuitive computing experience that adapts to their unique learning requirements. By investing in high-performance hardware with AI capabilities, educational institutions can create a more inclusive technological ecosystem that empowers students to navigate digital learning environments with greater independence, efficiency, and confidence.

1.8.2 Student Software Needs

Table 1.3 lists software used by students with visual impairments, along with minimum and preferred RAM requirements. This data reveals the inadequacy of current standard configurations.

Table 1.3: Student software needs and recommended hardware specifications

Program	Type of Program	Cost	Min RAM	Pref RAM	Processor
JAWS	Screenreader	\$225/yr ⁵⁸	8GB	>24GB ⁵⁹	>11th Gen Intel® Core™ i5+
TypeAbility	Typing Instruction ⁶⁰	\$150	8GB	>24GB	>11th Gen Intel® Core™ i5+
Narrator	Screenreader ⁶¹	\$0	4GB	>16GB	>11th Gen Intel® Core™ i5
NVDA	Screenreader ⁶²	\$0	2GB	>16GB	>11th Gen Intel® Core™ i5

Continued on next page

Table 1.3: Student software needs and recommended hardware specifications (Continued)

Program	Type of Program	Cost	Min RAM	Pref RAM	Processor
ZDSR	Screenreader	\$232	2GB	>16GB	>11th Gen Intel® Core™ i7+
Dolphin Screenreader	Screenreader	\$1105/yr	8GB	>32GB	>11th Gen Intel® Core™ i7+
ZoomText	Magnification & Speech ⁶³	\$85/yr	16GB	>32GB	>11th Gen Intel® Core™ i7+
Windows Magnifier	Magnification ⁶⁴	\$0	16GB	>24GB	>11th Gen Intel® Core™ i7+
Dolphin SuperNova	Magnification	\$545/yr	16GB	>32GB	>11th Gen Intel® Core™ i7+
Dolphin SuperNova + Speech	Magnification & Speech	\$825/yr	16GB	>32GB	>11th Gen Intel® Core™ i7+

1.9 Current Educational Technology Inadequacy

Analysis of current student and professional laptop configurations reveals systematic educational equity violations:

Table 1.4: Comparison of student and professional laptop configurations for educational equity

Device	Cost	Keyboard	RAM	Screen Size	Processor
Dell Latitude 3190	\$379	QWERTY	4GB ⁸³	11.6" Touchscreen	Intel® Celeron Silver
Lenovo 500w Gen 3	\$358	QWERTY	4GB ⁸⁴	11.6" Touchscreen	Intel® Pentium Silver
Dell Precision 3530	\$1751	QWERTY	16GB ⁸⁵	16.0"	8th Gen Intel® Core™ i7
Dell Precision 7420	\$1349	QWERTY	16GB ⁸⁶	16.0"	8th Gen Intel® Core™ i7
Microsoft Surface Laptop 3	\$1500	QWERTY	32GB ⁸⁷	15.0" Touchscreen	AMD® Ryzen™ 7
Framework Laptop 16	\$2750	QWERTY	64GB ⁸⁸	16.0"	AMD® Ryzen™ 9

1.10 The Educational Equity Crisis: A Civil Rights Issue

The RAM-latency relationship reveals a fundamental civil rights violation in educational technology:

Current State of "Accommodation":

- Students with 8GB systems: *10-20x slower* than necessary for equal access
- Students with 16GB systems: *6-12x slower* with unacceptably long latency
- Students with 24GB systems: *3-6x slower*, representing minimum threshold for basic equity
- Only students with 32GB+ systems: Approach true educational equity

The False Economy of "Adequate" Systems: Educational institutions providing 8GB or 16GB systems to screen reader users are not providing accommodation—they are creating systematic educational disadvantage that violates principles of equal access. The unacceptably long latency demonstrated by 16GB systems makes them unsuitable for educational equity.

True Cost of Inadequate Systems:

- Extended time requirements don't compensate for efficiency loss
- Increased cognitive load impairs learning outcomes
- Accumulated disadvantage over academic career
- Reduced preparation for technology-dependent careers
- Perpetuation of disability-based educational inequality

1.10.1 The 16GB Inadequacy Crisis

Systems with 16GB RAM, while previously considered adequate, demonstrate unacceptably long latency that violates educational equity principles:

- *Persistent Latency:* 125-300ms response times during typical educational tasks
- *Performance Degradation:* Memory pressure from modern educational software exceeds 16GB capacity
- *Accessibility Violation:* Response times 5-12x slower than equity standard constitute discrimination
- *Educational Impact:* Students experience measurable disadvantage in all computer-based learning activities

The evidence clearly demonstrates that 16GB RAM is insufficient for screen reader users in educational environments, necessitating a minimum recommendation of 24-32GB RAM for basic educational equity.

1.11 Recommendations

1.11.1 Immediate Interventions - Equity-Focused Approach

1. *Equity Audit:* Identify all students using systems that fail to meet <25ms response standard
2. *Emergency Hardware Replacement:* Immediately upgrade systems with <24GB RAM as accessibility violation
3. *16GB System Discontinuation:* Recognize 16GB systems as demonstrating unacceptably long latency for screen reader users
4. *Performance Optimization:* Implement aggressive memory management and audio driver optimization
5. *Interim Accommodations:* Provide alternative assessment methods while hardware is upgraded
6. *Legal Compliance:* Recognize sub-standard systems as potential ADA/Section 504 violations

1.11.2 Long-term Solutions - Civil Rights Compliance

1. *Minimum Hardware Standards:* Establish 24-32GB RAM as minimum for screen reader accessibility compliance, with 32GB as the preferred standard
2. *Equity-Based Budgeting:* Allocate budget based on true cost of educational equity, not minimum functionality
3. *Technology Equity Audits:* Regular assessment of response times to ensure ongoing compliance
4. *Faculty Education:* Train educators on the civil rights implications of inadequate assistive technology
5. *Procurement Standards:* Mandate equity-compliant hardware (24-32GB minimum) in all accessibility technology purchases
6. *Performance Monitoring:* Implement real-time latency monitoring to ensure systems maintain equity standards

1.12 Conclusion

Screen reader response latency caused by inadequate RAM creates a fundamental violation of educational equity principles. The zero-frustration standard—requiring response times under 25ms to match sighted user experiences—reveals that most current educational technology fails to provide true accessibility.

1.12.1 The Equity Crisis:

- Systems with 8GB RAM create 6-32x slower response times than necessary for equal access
- Systems with 16GB RAM demonstrate unacceptably long latency with 5-12x disadvantage compared to equity standard
- Systems require 24-32GB RAM minimum to begin approaching educational equity for screen reader users
- Only systems with 32GB+ RAM achieve performance levels that approach true educational equity

1.12.2 The Civil Rights Imperative:

This is not merely a technology issue but a civil rights matter. Students using screen readers must receive response times equivalent to their sighted peers. Any additional latency constitutes systematic educational discrimination that violates principles of equal access under ADA and Section 504. The unacceptably long latency demonstrated by 16GB systems makes them unsuitable for educational use by screen reader users.

1.12.3 The Path Forward:

Educational institutions must recognize that providing 8GB or 16GB systems to screen reader users is not accommodation—it is the creation of systematic educational disadvantage. The evidence clearly shows that 16GB systems demonstrate unacceptably long latency periods that prevent educational equity. True equity requires systems capable of consistent sub-25ms response times, which currently means 24-32GB+ RAM configurations as the minimum standard.

The cost of inadequate systems extends far beyond hardware—it includes reduced learning outcomes, accumulated academic disadvantage, increased stress and anxiety,

and ultimately, the perpetuation of disability-based educational inequality. Educational equity demands nothing less than response times that enable screen reader users to compete on truly equal footing with their sighted peers, which requires moving beyond the demonstrably inadequate 16GB standard to 24-32GB minimum configurations.

1.13 Recommended Minimum Specifications

Based on the educational equity analysis, the following minimum specifications are required for screen reader accessibility compliance:

Table 1.5: Minimum and preferred RAM specifications for educational technology configurations

Configuration Type	Minimum RAM	Preferred RAM	Educational Viability
Screen Reader Only	24GB	32GB	Minimum threshold for equity
Screen Magnification Only	32GB	64GB	Approaches equity standard
Combined SR + Magnification	32GB	64GB	Required for true accessibility
Future-Proof Educational	64GB	128GB	Ensures long-term equity compliance

1.13.1 Processor Requirements:

- Minimum: 11th Generation Intel® Core™ i7 or AMD® Ryzen™ 7
- Preferred: 13th Generation Intel® Core™ i7+ or AMD® Ryzen™ 7+
- Future-Proof: Latest generation high-performance processors

1.13.2 Additional Requirements:

- SSD storage (minimum 512GB)

- Integrated or dedicated GPU for magnification tasks
- High-quality audio subsystem for screen reader output
- Minimum 15.6" display for magnification users
- Professional-grade build quality for durability

1.13.3 Comprehensive Laptop Display Guidelines for Students with Low Vision

Screen Specification Recommendations

Visual Accessibility Considerations

For students with low vision, display specifications are critically more than technical metrics—they represent enhanced learning accessibility and reduced eye strain.

Detailed Display Specification Analysis

Resolution Optimization

- *Recommended Resolution:* 3840x2160 (4K)
- *Minimum Acceptable:* 2560x1440 (QHD)
- *Key Benefits for Low Vision Students:*
 - Increased pixel density enables larger text scaling
 - Sharper image reduces visual fatigue
 - Supports magnification software without significant quality loss
 - Allows precise text and graphical clarity

Refresh Rate Considerations

- *Optimal Rate:* 90–120 Hz
- *Minimum Acceptable:* 60 Hz
- *Low Vision Specific Advantages:*
 - Reduced screen flickering
 - Smoother text rendering
 - Less eye strain during extended study sessions
 - Improved visual tracking for screen readers

Response Time

- *Ideal:* 4–5 ms
- *Maximum Recommended:* 10 ms
- *Importance for Low Vision:*
 - Minimizes motion blur during screen navigation
 - Reduces visual artifact interference
 - Supports more predictable visual transitions

Contrast Ratio

- *Minimum Recommended:* 3000:1
- *Optimal Range:* 5000:1–10000:1
- *Critical for Low Vision:*
 - Enhanced text legibility
 - Better differentiation between foreground/background
 - Supports high-contrast accessibility modes
 - Reduces eye strain during prolonged use

Brightness Management

- *Recommended Range:* 400–600 nits
- *Low Vision Specific Features:*
 - Adaptable brightness settings
 - Blue light reduction capabilities
 - Automatic brightness adjustment
 - Supports external lighting condition variations

Color Accuracy and Gamut

- *Color Coverage:* 100% sRGB
- *Delta E:* Below 2
- *Low Vision Benefits:*
 - Consistent color representation

- Supports color-based learning materials
- Enhances visual clarity for color-coded information
- Reduces visual confusion

Panel Technology

- *Recommended:* OLED or Advanced IPS
- *Low Vision Specific Advantages:*
 - Wider viewing angles (178 degrees)
 - Superior color consistency
 - Better contrast and detail preservation
 - Reduced glare and reflection

Additional Accessibility Features

- HDR Support: HDR10 or Dolby Vision
- Adaptive Color Modes:
 - Grayscale options
 - High-contrast modes
 - Color temperature adjustments
- Blue Light Filtering
- Integrated Magnification Support

Recommended Screen Sizes

- Laptop: 15–17 inches
- External Monitor: 24–32 inches
- Aspect Ratio: 16:10 preferred for additional vertical space

Connectivity Considerations

- Multiple Port Options:
 - HDMI 2.1
 - USB-C with DisplayPort
 - Thunderbolt support

- Enables external display connections
- Supports adaptive display technologies

Conclusion

For students with low vision, the ideal laptop display combines critical specifications that prioritize visual clarity and comfort: a 4K resolution (3840x2160) with a high contrast ratio of 5000:1 to 10000:1, coupled with a brightness range of 400–600 nits that can be easily adjusted. The screen should feature an OLED or advanced IPS panel with 100% sRGB color coverage, offering wide 178-degree viewing angles and a refresh rate of 90–120 Hz to minimize eye strain. A 15–17 inch laptop screen with a 16:10 aspect ratio is recommended, supporting adaptive color modes, blue light filtering, and integrated magnification capabilities. These specifications ensure optimal visual support, transforming technological limitations into enhanced learning opportunities by providing crisp, clear, and customizable visual information that accommodates the unique needs of students with low vision.

Educational Recommendations

For students with low vision, the ideal laptop display combines critical specifications that prioritize visual clarity and comfort: as high a resolution screen as possible with a high contrast ratio of >5000:1, coupled with a brightness range of >300–600 nits that can be easily adjusted. (Note, 300 nits is adequate for laptop vendors that have favored the use of office-based screen quality—i.e., Lenovo Thinkpad line—over high color representation—i.e., Dell XPS line. For the same screen brightness the Lenovo will be better for school, text-based usage as the screens are optimized for those purposes. I recommend Dell laptops with 400+ nit brightness but Lenovo with 300+ as they perform similarly for Microsoft Office application usage.) The screen should feature an OLED or advanced IPS panel with 100% sRGB color coverage, offering wide 178-degree viewing angles and a refresh rate of 90–120 Hz to minimize eye strain. A 15–17 inch laptop screen with a 16:10 aspect ratio is recommended, supporting adaptive color modes, blue light filtering, and integrated magnification capabilities. These specifications ensure optimal visual support, transforming technological limitations into enhanced learning opportunities by providing crisp, clear, and customizable visual information that accommodates the unique needs of students with low vision.

1.14 Implementation Timeline

1.14.1 Immediate (0-6 months):

- Audit all current systems against equity standards
- Identify students using sub-standard equipment
- Begin emergency hardware replacement for 8GB systems
- Discontinue procurement of 16GB systems for screen reader users

1.14.2 Short-term (6-12 months):

- Replace all 16GB systems with 24-32GB configurations
- Implement performance monitoring systems
- Train staff on equity standards and civil rights implications
- Update procurement policies to reflect equity requirements

1.14.3 Long-term (1-3 years):

- Establish 32GB as minimum standard for all new deployments
- Implement proactive replacement cycles based on performance metrics
- Develop equity compliance monitoring protocols
- Create sustainable funding models for accessibility technology

1.14.4 The Educational Imperative:

The evidence presented in this chapter demonstrates that adequate hardware for screen reader users is not a luxury but a civil rights requirement. Educational institutions must move beyond minimum compliance to true educational equity. The cost of failing to provide adequate technology extends far beyond the hardware investment—it represents a fundamental failure to provide equal educational opportunity.

Students using screen readers deserve technology that enables them to learn, compete, and succeed on equal terms with their sighted peers. This requires response times under

25ms, which current research shows requires 24-32GB RAM as a minimum, with 32GB+ configurations preferred for true educational equity.

The time for incremental improvements has passed. Educational equity demands immediate action to ensure that all students have access to technology that truly enables their success, not systems that create barriers to their educational achievement.

1.14.5 Laptops Meeting Minimal Educational Requirements

Table 1.6: Comprehensive Modern Laptop Specifications for Accessibility and Performance (2025)

Company	Model	Price (USD)	RAM	Processor	Screen	Brightness (nits)	Contrast Ratio
Microsoft	Surface Laptop 7 Copilot+	\$2,000+	32-64GB	Snapdragon X Elite/X Plus (ARM)	13.8"/15" 2496x1664 120Hz Touch	600-650	1500:1
Microsoft	Surface Pro 11 Copilot+	\$2,100+	32-64GB	Snapdragon X Elite/X Plus (ARM)	13" OLED/IPS 120Hz Touch	up to 900	1,000,000:1 (OLED)
Dell	Premium	\$1,500+	32GB	Snapdragon X Plus (ARM)	13.4" FHD+ 120Hz OLED Touch	500-600	1,000,000:1 (OLED)
Dell	16 Premium	\$2,000+	32-64GB	Intel Core Ultra 9 185H	16" up to 4K OLED	400-600	2000:1 (IPS)/1,000,000:1 (OLED)
Dell	14 Plus	\$1,000+	16GB	Snapdragon X Plus (ARM)	14" FHD+ IPS	300	1200:1 (IPS)

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Table 1.6: Comprehensive Modern Laptop Specifications for Accessibility and Performance (2025) (Continued)

Company	Model	Price (USD)	RAM	Processor	Screen	Brightness (nits)	Contrast Ratio
Dell	14 Plus	\$1,200+	16GB	AMD Ryzen AI 5 340	14" FHD+ IPS	300	1200:1 (IPS)
Dell	14 Pro	\$1,700+	up to 32GB	Snapdragon X Elite (ARM)	14" QHD+ Touch IPS	400–500	1500:1 (IPS)
HP	OmniBook Ultra Copilot+ 14	\$1,449+	32GB	Snapdragon X Elite (ARM)	14" 2240x1400 Touch	500	1500:1 (IPS)
HP	OmniBook Ultra Flip 14	\$1,449+	32GB	AMD Ryzen AI 9 HX 375 / Intel Core Ultra Series 2	14" 2880x1800 OLED 120Hz Touch	500–600	1,000,000:1 (OLED)
HP	EliteBook Ultra Copilot+	\$1,800+	up to 32GB	Snapdragon X Elite (ARM)	14" 2240x1400 IPS	400–500	1500:1 (IPS)
Lenovo	Yoga Slim 7x Copilot+	\$1,300+	32GB	Snapdragon X Elite (ARM)	14.5" 2944x1840@1000 OLED	up to 1000	1,000,000:1 (OLED)

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Table 1.6: Comprehensive Modern Laptop Specifications for Accessibility and Performance (2025) (Continued)

Company	Model	Price (USD)	RAM	Processor	Screen	Brightness (nits)	Contrast Ratio
Lenovo	ThinkPad T14s Gen 6 Copilot+	\$1,700+	32GB	Snapdragon X Elite (ARM)	14" 2240x1400 IPS	400–500	1500:1
ASUS	Zenbook S 14 Copilot+	\$1,300+	32GB	Snapdragon X1 Elite (ARM)	14" 2880x1800 OLED	550–600	1,000,000:1
ASUS	Zenbook Duo 14 OLED (2025)	\$2,499+	32GB	Intel Core Ultra 9	Dual 14" 3K OLED Touch	500–600	1,000,000:1
MSI	Prestige A16 AI+	\$2,299+	32GB	AMD Ryzen AI 9-365	16" 3840x2400 OLED	500–600	1,000,000:1
MSI	Pulse 16 AI Gaming	\$2,799+	64GB	Intel Core Ultra 9	16" 2560x1600 QHD 240Hz	350–400	1200:1
Razer	Blade 18 (2025)	\$3,500+	32–64GB	Intel Core Ultra 9 275HX	18" QHD+/miniLED 240/300Hz	up to 1000	1,000,000:1
Acer	Aspire 16	\$1,499+	32GB	Intel Core Ultra 7 155U	16" 3200x2000 OLED	400–500	1,000,000:1

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Table 1.6: Comprehensive Modern Laptop Specifications for Accessibility and Performance (2025) (Continued)

Company	Model	Price (USD)	RAM	Processor	Screen	Brightness (nits)	Contrast Ratio
Framework	Framework 13	\$1,499+	32GB-64GB	Ryzen AI 7	13" 2880x1920 OLED	>500	1,000,000:1 (OLED)
Framework	Framework 16	\$1,499+	32GB-64GB	Ryzen 9	16" 2560x1600 QHD+	>500	1500:1 (IPS)

Chapter 2

Transformative Tablets: Pioneering Success for Visually Impaired Students Through Innovative Apps

In an era where technology shapes the landscape of education, tablets have emerged as transformative tools, providing visually impaired students with unprecedented access to knowledge and fostering independence in their academic journeys.¹ Both iPad and Android devices offer user-friendly interfaces and a diverse array of applications specifically tailored to bridge the accessibility gap. This chapter explores how tablets, in tandem with purpose-built apps, are not just tools but catalysts for success in the educational journey of visually impaired students.

Tablets serve as dynamic portals for visually impaired learners, offering a multi-sensory approach to engagement. Their unique functionalities, combined with a robust ecosystem of accessibility apps, empower students to navigate the digital realm with confidence and independence.

2.1 Tablet Considerations

When selecting a tablet for students with visual impairments, consider the following:

¹ I am omitting iPhone and Android phones from this document as the purchase of student phones is beyond the purview of a school district. However, iOS apps are provided as many of these are available on both Tablets and Phones and training students to use the technology on their personal device is often necessary, particularly within the auspice of Orientation & Mobility instruction

- **Accessibility features:** Ensure compatibility with screen readers and magnification tools (e.g., VoiceOver for iOS, TalkBack for Android).²
- **Tactile features, size, and weight:** Choose a device that accommodates the student's specific needs.
- **Contrast and color settings:** High contrast and customizable color settings, as well as text-to-speech functionalities, enhance readability.
- **Screen size:** Larger screens can help reduce visual fatigue and improve usability, but balance with portability.
- **App compatibility:** Ensure the device supports a variety of educational and accessibility apps.
- **Visual fatigue:** Avoid prioritizing brightness; instead, focus on resolution and screen area. Adjust luminance for students with photophobia.
- **AI Integration:** Modern tablets now offer enhanced AI-powered accessibility features, including improved object recognition and natural language processing.

Contrast ratio is especially important for students with visual impairments. Understanding and prioritizing contrast ratio helps foster an inclusive and enriching educational environment.

2.2 Tablet Options

When choosing an Android Tablet or iPad for a student with visual impairments, several factors must be considered to ensure that the student receives free and appropriate public education. The first factor to consider is the screen contrast ratio. A high contrast ratio is essential for students with visual impairments as it makes it easier for them to read text and view images on the screen. For Android Tablets, the W3C recommends a contrast ratio of at least 4.5:1 for small text and 3.0:1 for large text³. Apple devices continue to excel with their "Increase Contrast" feature and additional accessibility enhancements⁴.

The second factor to consider is the size of the screen. A larger screen is beneficial for students with visual impairments as it allows them to view text and images more clearly.

² Android accessibility features have significantly improved since 2020, with TalkBack now offering comparable functionality to VoiceOver. However, iOS devices still maintain a slight advantage in terms of app compatibility and developer support for accessibility features.

³ Google. (n.d.). Color contrast - Android Accessibility Help. Retrieved December 19, 2023

⁴ iMore. (n.d.). How to increase contrast for visual accessibility on iPhone and iPad. Retrieved December 19, 2023

Tablets usually have larger screens than smartphones, making them a better choice for students with visual impairments⁵. However, it is important to note that larger screens come at the expense of portability. Therefore, it is essential to find a balance between screen size and portability.

The third factor to consider is the availability of accessible apps. Both Android and iOS devices have built-in accessibility features such as screen readers, magnifiers, and high contrast modes^{6,7}. Additionally, there are several apps available that are specifically designed for students with visual impairments. Enhanced AI-powered apps like Be My Eyes now include Be My AI functionality, while SeeingAI continues to evolve with improved object recognition capabilities⁸.

Tables 2.1 through 2.4 describe current tablet computers that are available for students with visual impairments.

2.2.1 AndroidOS 14+ Tablets

Table 2.1: AndroidOS 14+ tablets suitable for students with visual impairments (Updated 2025)

Tablet	Screen Size
Google Pixel Tablet	10.9
Samsung Galaxy Tab A9	8.7
Samsung Galaxy Tab A9+	11.0
Samsung Galaxy Tab S9	11.0
Samsung Galaxy Tab S9 FE	10.9

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⁵ American Foundation for the Blind. (n.d.). Smartphone or Tablet: Which is Best for You? Retrieved December 19, 2023

⁶ American Academy of Ophthalmology. (n.d.). 30 Apps, Devices and Technologies for People With Vision Impairments. Retrieved December 19, 2023

⁷ American Foundation for the Blind. (n.d.). Apple iOS for iPhone and iPad: Considerations for Users with Visual Impairments. Retrieved December 19, 2023

⁸ American Academy of Ophthalmology. (n.d.). Technology Tools for Children with Low Vision. Retrieved December 19, 2023

Table 2.1: AndroidOS 14+ tablets suitable for students with visual impairments (Updated 2025) (Continued)

Tablet	Screen Size
Samsung Galaxy Tab S9 FE+	12.4
Samsung Galaxy Tab S9 Ultra	14.6
Samsung Galaxy Tab S9+	12.4
Samsung Galaxy Tab S10+	12.4
Samsung Galaxy Tab S10 Ultra	14.6
OnePlus Pad	11.6
OnePlus Pad 2	12.1
Lenovo Tab P12	12.7
Lenovo Tab P12 Pro	12.6
Lenovo Tab M10 Plus (4th Gen)	10.6
Lenovo Tab M11	11.0
Xiaomi Pad 6	11.0
Xiaomi Pad 6 Pro	11.0
Xiaomi Pad 6S Pro	12.4
Honor Pad 9	12.1
Realme Pad 2	11.5
Redmi Pad Pro	12.1
Oppo Pad Air 2	11.4
Vivo Pad 3	12.1

Note: Summary: Comprehensive list of Android tablets running OS 14 or higher, showing model name and screen size in inches

2.2.2 iPadOS Tablets

Table 2.2: iPadOS tablets suitable for students with visual impairments (Updated 2025)

Tablet	Cost	Screen Size
Apple iPad 10.9 (10th Gen)	\$349	10.9
Apple iPad Air 11 (M2)	\$599	11.0
Apple iPad Air 13 (M2)	\$799	13.0
Apple iPad Pro 11 (M4)	\$999	11.0
Apple iPad Pro 13 (M4)	\$1299	13.0
Apple iPad mini 7 (A17 Pro)	\$499	8.3

2.2.3 Windows OS Tablets

Table 2.3: Windows OS tablets suitable for students with visual impairments (Updated 2025)

Tablet	Cost	Screen Size
Microsoft Surface Pro 11	\$1199	13.0
Microsoft Surface Pro 10	\$1099	13.0
Microsoft Surface Go 4	\$629	10.5
Microsoft Surface Laptop Studio 2	\$1999	14.4
Dell XPS 13 2-in-1	\$1299	13.0
HP Spectre x360	\$1149	13.5
Lenovo ThinkPad X1 Tablet	\$1449	13.0

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Table 2.3: Windows OS tablets suitable for students with visual impairments (Updated 2025) (Continued)

Tablet	Cost	Screen Size
Asus VivoBook 13 Slate	\$849	13.3

2.2.4 ChromeOS Tablets

Table 2.4: ChromeOS tablets suitable for students with visual impairments (Updated 2025)

Tablet	Cost	Screen Size
Lenovo Chromebook Duet 3	\$349	11.0
Lenovo Chromebook Duet 5	\$449	13.3
HP Chromebook x2 11	\$599	11.0
Asus Chromebook CM3	\$399	10.5
Acer Chromebook Spin 714	\$729	14.0

2.3 Mobile Applications

Mobile apps run on tablets are becoming increasingly important for students with visual impairments to access a free and appropriate public education. These apps can provide students with access to digital content, assistive technology, and other tools that can help them succeed in their studies. High-quality mobile apps can help students with visual impairments access the same educational materials as their sighted peers and participate fully in the curriculum. They can also help improve literacy skills, comprehension, and productivity. In this section, we will explore the importance of high-quality mobile apps for students with visual impairments and discuss some of the best apps available on the market today.

2.3.1 Accessibility Training/Auditory Games

Table 2.5: Mobile apps for accessibility training and auditory games for students with visual impairments (Updated 2025)

App	Cost	Function	OS
CosmoBally in Space	free	Train VoiceOver Gestures	iOS/iPadOS
Ballyland Magic Plus	\$4.99	Train VoiceOver Gestures	iOS/iPadOS
Ballyland Rotor	\$3.99	Train VoiceOver rotor	iOS/iPadOS
Ballyland Stay Still Squeaky!	\$3.99	Train VoiceOver Gestures	iOS/iPadOS
Blindfold Games Launcher	free ¹²	Sonic Games	iOS/iPadOS
Blindfold Tap and Swipe	free	Train VoiceOver Gestures	iOS/iPadOS
ObjectiveEd Games	free ¹²	Sonic Games	iOS/iPadOS
VO Lab	\$5.99	Train VoiceOver Gestures	iOS/iPadOS
Screenreader	free	Train Accessibility Gestures	iOS/iPadOS, Android 14+

2.3.2 Cortical Vision Impairment

Table 2.6: Mobile apps for cortical vision impairment (CVI) training for students with visual impairments (Updated 2025)

App	Cost	Function	OS
Art of Glow	free	CVI-based Vision Training	iOS/iPadOS
Big Band Patterns	\$39.99	CVI-based Vision Training	iOS/iPadOS
Big Bang Pictures	\$39.99	CVI-based Vision Training	iOS/iPadOS
CVI Connect	\$12/mo	CVI-based Vision Training	iOS/iPadOS
CVI Connect Pro	free ¹⁶	CVI-based Vision Training	iOS/iPadOS
CVI Toddler Visual Eye Train	free	CVI-based Vision Training	iOS/iPadOS
CVI Training (Color)	free	CVI-based Vision Training	iOS/iPadOS
CVI Training (Human face)	free	CVI-based Vision Training	iOS/iPadOS
CVI Training (Pattern)	free	CVI-based Vision Training	iOS/iPadOS
CVI Training (Recognition)	free	CVI-based Vision Training	iOS/iPadOS
CVI Training (Visual Tracking)	free	CVI-based Vision Training	iOS/iPadOS

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Table 2.6: Mobile apps for cortical vision impairment (CVI) training for students with visual impairments (Updated 2025) (Continued)

App	Cost	Function	OS
Dexteria VMI	\$6.99	CVI-based Vision Training	iOS/iPadOS
EDA Play	\$5.99	CVI-based Vision Training	iOS/iPadOS
EDA Play ELIS	\$3.99	CVI-based Vision Training	iOS/iPadOS
EDA Play PAULI	\$3.99	CVI-based Vision Training	iOS/iPadOS
EDA Play TOBY	free	CVI-based Vision Training	iOS/iPadOS
EDA Play TOM	free	CVI-based Vision Training	iOS/iPadOS
EyeMove	free	CVI-based Vision Training	iOS/iPadOS
Little Bear Sees	\$5.99	CVI-based Vision Training	iOS/iPadOS
Peekaboo Barn	\$3.99	CVI-based Vision Training	iOS/iPadOS
Sensory Light Box	\$4.99	CVI-based Vision Training	iOS/iPadOS
Tap-n-See Now	\$3.99	CVI-based Vision Training	iOS/iPadOS
Visual Attention Therapy Lite	free	CVI-based Vision Training	iOS/iPadOS

Note: Summary: Specialized apps designed for CVI training and assessment, including current pricing and supported platforms

2.3.3 Audiobook/Reading

Table 2.7: Mobile apps for audiobook, e-book, and DAISY reading for students with visual impairments (Updated 2025)

App	Cost	Function	OS
Audible	free ³⁵	Audiobook	iOS/iPadOS, AndroidOS 14+
BARD Mobile	free ³⁶	e-Book	iOS/iPadOS, AndroidOS 14+
Bookshare Reader	free	DAISY Reader	iOS/iPadOS
Dolphin EasyReader	free	DAISY Reader	iOS/iPadOS, AndroidOS 14+
KNFB Reader (OneStepReader)	\$109.99	OCR/Reading	iOS/iPadOS, AndroidOS 14+
Kindle	free ³⁷	e-Book	iOS/iPadOS, AndroidOS 14+
Libby	free ³⁸	Audiobook	iOS/iPadOS, AndroidOS 14+
Speech Central	free ³⁹	Text-to-Speech	iOS/iPadOS, AndroidOS 14+
VoiceDream Reader	\$19.99 ⁴⁰	DAISY Reader	iOS/iPadOS

2.3.4 Productivity/Schoolwork/Optical Character Recognition

Table 2.8: Mobile apps for productivity, schoolwork, and optical character recognition (OCR) for students with visual impairments (Updated 2025)

App	Cost	Function	OS
Aiko	free	AI Speech to text	iOS/iPadOS
Ballyland Code 1: Say Hello	\$3.99	Auditory Coding	iOS/iPadOS
Ballyland Code 2: Give Rotor	\$3.99	Auditory Coding	iOS/iPadOS
Ballyland Code 3: Pick Up	\$3.99	Auditory Coding	iOS/iPadOS
Clusiv	free ⁵³	Online learning platform	iOS/iPadOS
Code Quest	free	Auditory Coding	iOS/iPadOS
Desmos Graphing Calculator	free	Accessible Graphing	iOS/iPadOS, AndroidOS 14+
Desmos Scientific Calculator	free	Accessible Scientific Calculator	iOS/iPadOS, AndroidOS 14+
Envision AI	free ⁵⁴	AI-powered OCR	iOS/iPadOS, AndroidOS 14+
GoodNotes 5	\$7.99	Scan & Markup Documents	iOS/iPadOS, AndroidOS 14+
Microsoft 365	free ⁵⁵	Office Suite	iOS/iPadOS, AndroidOS 14+
Notability	\$11.99	Scan & Markup Documents	iOS/iPadOS

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Table 2.8: Mobile apps for productivity, schoolwork, and optical character recognition (OCR) for students with visual impairments (Updated 2025) (Continued)

App	Cost	Function	OS
SeeingAI	free	Talking Camera	iOS/iPadOS, AndroidOS 14+
TapTapSee	free	Talking Camera	iOS/iPadOS, AndroidOS 14+
Voice Control for ChatGPT	free ⁵⁶	AI Assistant	iOS/iPadOS, AndroidOS 14+

2.3.5 Orientation & Mobility / Navigation

Table 2.9: Mobile apps for orientation, mobility, and navigation for students with visual impairments (Updated 2025)

App	Cost	Function	OS
Apple Maps	free	Turn by Turn Navigation	iOS/iPadOS
Be My Eyes	free	Visual assistance via volunteers	iOS/iPadOS, AndroidOS 14+
BlindSquare	\$49.99	GPS Navigation	iOS/iPadOS
Clew	free	Indoor navigation	iOS/iPadOS, AndroidOS 14+
GoodMaps Explore	free	Indoor/Outdoor navigation	iOS/iPadOS
Google Maps	free	Turn by Turn Navigation	iOS/iPadOS, AndroidOS 14+

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Table 2.9: Mobile apps for orientation, mobility, and navigation for students with visual impairments (Updated 2025) (Continued)

App	Cost	Function	OS
Lazarillo	free	GPS navigation	iOS/iPadOS, AndroidOS 14+
Moovit	free ⁶⁰	Public Transit	iOS/iPadOS, AndroidOS 14+
Oko	free	Smart traffic detection	iOS/iPadOS, AndroidOS 14+
Soundscape	free	3D audio navigation	iOS/iPadOS, AndroidOS 14+
Waymap	free	Indoor/Outdoor navigation	iOS/iPadOS, AndroidOS 14+

2.3.6 Independent Living Skills

Table 2.10: Mobile apps for independent living skills for students with visual impairments (Updated 2025)

App	Cost	Function	OS
CashReader	free ⁷⁰	Currency identification	iOS/iPadOS, AndroidOS 14+
Lookout	free	AI-powered assistance	AndroidOS 14+
Magnifier	free	Built-in magnification	iOS/iPadOS
Menus4All	free ⁷¹	Restaurant menus	iOS/iPadOS

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Table 2.10: Mobile apps for independent living skills for students with visual impairments (Updated 2025) (Continued)

App	Cost	Function	OS
PenFriend	free	Labeling system app	iOS/iPadOS
Supersense	free ⁷²	AI scene description	iOS/iPadOS, AndroidOS 14+
Voice Assistant	free	Voice control	iOS/iPadOS, AndroidOS 14+

2.4 Conclusion

The landscape of assistive technology for visually impaired students continues to evolve rapidly, with new applications and enhanced features being released regularly. When selecting tablets and applications for educational use, it is essential to consider the specific needs of each student, the available budget, and the compatibility with existing assistive technologies. Regular updates to both hardware and software ensure that students have access to the most current and effective tools for their educational success.

The integration of artificial intelligence and machine learning in accessibility applications has significantly improved the user experience for visually impaired students. From enhanced object recognition to more accurate optical character recognition, these technological advances continue to break down barriers and provide greater independence in educational settings.

Chapter 3

Bridging Literacy: The Crucial Role of Refreshable Braille Displays in Empowering Visually Impaired Students

In the intricate tapestry of education, the pursuit of literacy is a fundamental thread, weaving through the academic journey of every student. For visually impaired learners, the path to literacy takes on a unique character, one in which the tactile elegance of braille becomes a vital conduit to knowledge. Within this narrative, refreshable braille displays emerge as indispensable companions, unlocking the doors to literacy, fostering engagement, and propelling students toward academic success. This chapter explores how refreshable braille displays are not merely tools but keystones in the quest for literacy and educational achievement among visually impaired students.

Refreshable braille displays integrate the tactile richness of braille with the dynamic capabilities of digital communication. These devices are pivotal in ensuring that visually impaired students not only read but actively participate in the discourse of knowledge acquisition.

Refreshable braille displays serve as conduits for accessing textual content, enabling the exploration of literature, textbooks, and diverse educational materials in a format that aligns with the tactile language of braille. They also empower students to actively contribute to the discourse, facilitating note-taking, writing, and engaging in classroom discussions with the same spontaneity and fluency as their sighted peers.

By providing visually impaired students with the means to interact with written

information independently and dynamically, these devices foster a sense of agency and pave the way for academic success.

3.1 Braille Notetakers and Laptops

Braille notetakers such as the BrailleSense6 and BrailleNote Touch Plus are essential tools for students with visual impairments to access their schoolwork and receive a free and accessible public education. These devices are small and portable, allowing students to take notes in class using either braille or standard (QWERTY) keyboard, or both. They can also be used to read books, write class assignments, find directions, record lectures, and listen to podcasts. The notes written on these devices can be transferred to a computer for storage or printed in either braille or print formats. Many note-taking devices have word processors, appointment calendars, calculators or clocks, and can do almost everything a computer can do. Some note-taking devices have a speech program with braille input. Many newer models are Bluetooth accessible which allows them to be used with iPads, iPhones and other Bluetooth devices as well as Wi-Fi access. Braille notetakers are useful not only for note taking in class, but also for composing and printing essays, writing notes, sending e-mails, or browsing the Internet. These devices can give students who are blind or have low vision support in all academic areas as well as in expanded core curriculum. By providing students with visual impairments access to braille notetakers, we can help ensure that they have the tools they need to succeed in their studies and beyond.

Table 3.1: Braille notetakers and laptops: device and operating system

Device Name	Operating System
BrailleNote Touch+	Android 8
BrailleSense 6	Android 12
BTSpeak Pro	Linux
Canute Console	Rasperian 12
ElBraille 40	Windows 10
InsideONE+	Windows 11

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Table 3.1: Braille notetakers and laptops: device and operating system (Continued)

Device Name	Operating System
Nattiq Note	Windows 11
Notey the Notetaker	Windows 11
Orbit Optima	Windows 11
Seika Studio	Windows 10
b.note	Windows 10
b.book	Windows 10

3.2 Braille Notetaker/Laptop Recommendations

The BrailleNote Touch Plus runs on Android 8.1 Oreo, while the BrailleSense 6 now runs on Android 12 following the V2.0 firmware update released by HIMS¹. While the BrailleSense 6 has received this important update, the BrailleNote Touch Plus remains on an outdated operating system. As of July 6, 2025, Android 16 is the current version of the Android operating system².

Using outdated operating systems can pose a security risk, as they no longer receive security updates. This makes it easier for harmful viruses, spyware, and other malicious software to gain access to your device. Hackers often target outdated operating systems because of their vulnerability, allowing them to breach your device and gain personal information. Preventing malicious access to hardware is one major reason why drivers and applications are made back-compatible only to versions of the operating system still receiving security updates.

It is important to keep your operating system up-to-date to ensure that you have access to the latest features and improvements. This can help improve the performance of your device and ensure that it is compatible with the latest software and hardware. Updating your operating system is a simple and effective way to keep your device running smoothly and securely.

¹ HIMS Released the BrailleSense 6 V2.0 update in 2024, upgrading the device from Android 10 to Android 12 Release Notes

² Android 16 was released in stable version on June 10, 2025 for Pixel phones, with broader rollouts following

However, updating an operating system is not always possible, as it depends on the device's hardware and software compatibility. It is also important to note that updating to the latest operating system may not always be the best option, as it may cause compatibility issues with older software and hardware.

Table 3.2 gives the recommendations for currently available braille notetakers. An important note is that I favor Windows-based systems, though the BrailleSense 6 with its Android 12 update represents a significant improvement in security and compatibility compared to devices still running older Android versions.

Table 3.2: Braille notetaker and laptop recommendations with key specifications

Display	Battery	Keyboard	Manufacturer	OS
BrailleSense 6	18h	Perkins	HIMS	Android 12
Orbit Optima	TBD	QWERTY	Orbit Research	Windows 11
Seika Studio	TBD	QWERTY	Nippon Telesoft	Windows 10
b.book	15h	Perkins	Eurobraille	Windows 10

3.3 Refreshable Braille Displays

Refreshable braille displays are essential tools for students with visual impairments to access digital content. The number of braille cells in a display is an important factor to consider when selecting a device. Displays with 32-40 cells are generally better than those with 14-20 cells for several reasons. Firstly, they provide more space for displaying text, which can help reduce the need for scrolling and improve reading speed. Secondly, they allow for more complex formatting, such as tables and graphs, which can be important for STEM subjects. Thirdly, they provide more context for the user, which can help improve comprehension and reduce errors. Fourthly, they are more versatile and can be used for a wider range of tasks, such as taking notes, writing essays, and browsing the internet. Finally, they are more future-proof, as they are more likely to be compatible with new technologies and software updates. While 14-20 cell displays may be more affordable, investing in a 32-40 cell display can provide significant benefits for students with visual impairments in the long run.

3.3.1 14-20 cell Refreshable Braille Displays

There are some situations where 14-20 cell displays may be more appropriate. For example, if the student only needs to read short messages or simple documents, a smaller display may be sufficient. Additionally, smaller displays are more portable and can be easier to carry around. They may also be more affordable, which can be important for students on a tight budget. Finally, smaller displays may be more appropriate for younger students who are just learning braille and may not need as much space for displaying text. While 14-20 cell displays may not be as versatile as larger displays, they can still provide significant benefits for students with visual impairments in certain situations.

Table 3.3: 14-20 cell refreshable braille displays: device and battery life

Device Name	Battery Life
Actilino	16 hours
Basic Braille 20	16 hours
Brailliant BI20x	14 hours
Chameleon 20	14 hours
Focus 14 Blue	18 hours
Orbit Reader 20+	20 hours
Orbit Speak	20 hours
BTSpeak	15 hours
Seika 24	20 hours
Seika Mini Plus	20 hours
VarioUltra 20	12 hours
b.note 20	15 hours

3.3.2 32-40 cell Refreshable Braille Displays

Displays with 32-40 cells provide more space for displaying text, allow for more complex formatting, and are more versatile for a wider range of tasks. While 14-20 cell displays may be more affordable, investing in a 32-40 cell display can provide significant benefits for students with visual impairments in the long run.

Table 3.4: 32-40 cell refreshable braille displays: features and manufacturers

Display	Battery	Keyboard	Manufacturer
Activator	40	Perkins	Help Tech
Active Braille	20	Perkins	Help Tech
Active Star	40	Perkins	Help Tech
Alva 640 Comfort	10	Perkins	Optelec
Alva 640 USB	n/a	none	Optelec
Alva BC 640	10	none	Alva
Basic Braille Plus	12	Perkins	Help Tech
Brailliant BI40x	14	Perkins	Humanware
Focus 40 Blue	18	Perkins	Vispero
Mantis Q40	14	QWERTY	APH
Orbit Reader 40	20	Perkins	Orbit Research
QBraille XL	16	Perkins	HIMS
Seika V5	20	none	Nippon Telesoft
Vario 340	20	none	VisioBraille
Vario 440	20	none	VisioBraille
Vario Ultra 40	12	Perkins	VisioBraille

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Table 3.4: 32-40 cell refreshable braille displays: features and manufacturers (Continued)

Display	Battery	Keyboard	Manufacturer
b.note 40	15	Perkins	Eurobraille

3.4 Multiple Line Braille Displays/Tablets

Multiple line braille displays are better than single line refreshable braille displays for students with visual impairments for several reasons. Firstly, they provide more space for displaying text, which can help reduce the need for scrolling and improve reading speed. Secondly, they allow for more complex formatting, such as tables and graphs, which can be important for STEM subjects. Thirdly, they provide more context for the user, which can help improve comprehension and reduce errors. Fourthly, they are more versatile and can be used for a wider range of tasks, such as taking notes, writing essays, and browsing the internet. Finally, they are more future-proof, as they are more likely to be compatible with new technologies and software updates. While single line refreshable braille displays may be more affordable, investing in a multiple line display can provide significant benefits for students with visual impairments in the long run.

Table 3.5: Multiple line braille displays and tablets: features and manufacturers

Display	Battery	Braille Lines	Keyboard	Manufacturer
APH Monarch	11 hr	10 row x 32 cell + 32 cell line	Perkins	Humanware, APH
Blitab	TBD	14 row x 23 cell	Touch Interface	Blitab
BraillePad	TBD	50 row x 40 cells	none	4Blind
Cadence	TBD	6 row x 8 cells, stack to 24 x 16	Perkins	Tactile Engineering
Canute 360	Req AC	9 row x 40 cell	none	Bristol Braille

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Table 3.5: Multiple line braille displays and tablets: features and manufacturers (Continued)

Display	Battery	Braille Lines	Keyboard	Manufacturer
DotPad	11 hr	10 row x 32 cell + 20 cell line	Touch interface	Dot Inc.
Graphiti	20-22	60 row x 40 cell	Perkins	Orbit Research
Graphiti Plus	20-22	60 row x 40 cell + 40 cell line	Perkins	Orbit Research
Orbit Slate 340	20-22	5 row x 20 cell	Perkins	Orbit Research
Orbit Slate 520	20-22	5 row x 20 cell	Perkins	Orbit Research
TACTIS 100	Req AC	4 row x 25 cell	none	Tactisdisplay
TACTIS Table	Req AC	25 row x 40 cell	none	Tactisdisplay
TACTIS Walk	Req AC	10 row x 25 cell	none	Tactisdisplay
Tactile Pro	TBD	TBD	Perkins	PCT
Tactonom Pro	Req AC	89 row x 119 cell	N/A	Tactonom

3.5 Braille Education Devices

In many cases, students do not learn braille as efficiently as their sighted peers learn print. One potential explanation is that there is limited time that a student has access to a teacher trained in braille. One solution is to provide devices that can be used to reinforce or train a student in braille skills without the need for a braille-fluent adult present. This is analogous to the Lexia, Prodigy, or other academic learning systems that allow for self-paced learning. In the last 5 years, a number of teaching tools have been developed, primarily by groups in India and South Korea to address these needs.

Specialized tools like Taptilo and Polly/Annie are crucial for teaching Braille to students with visual impairment. These tools provide a more interactive and engaging learning experience for students, which can help them learn Braille more effectively. Taptilo is a Braille learning device that uses a modular design to teach Braille in a fun and interactive way. It has a variety of features such as audio feedback, games, and quizzes that can help students learn Braille more effectively³. Polly and Annie are two Braille teaching tools that use a combination of hardware and software to teach Braille to students. They use a variety of interactive games and activities to help students learn Braille more effectively⁴.

In addition to providing a more engaging learning experience, specialized tools like Taptilo and Polly/Annie can also help students learn Braille more quickly. These tools are designed to be intuitive and easy to use, which can help students learn Braille more quickly than traditional methods. Additionally, these tools can provide students with immediate feedback on their progress, which can help them identify areas where they need to improve.

Finally, specialized tools like Taptilo and Polly/Annie can help students with visual impairment become more independent. By learning Braille more effectively and quickly, students can become more independent in their daily lives. They can read books, take notes, and communicate with others more easily, which can help them lead more fulfilling lives.

Table 3.6: Braille education devices and their manufacturers

Equipment	Manufacturer
Braille Doodle	Touchpad Pro Foundation
Braille Teach	Braille Teach
BrailleBlox	BrailleBot
BrailleBuzz	APH
BrailleCoach	Logan Tech
Feelfi Creator	Feelfi Technology
Feelfi Pro	Feelfi Technology

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³ Taptilo. (n.d.). Taptilo. Retrieved December 19, 2023 <https://www.taptilo.com/>

⁴ Thinkerbell Labs. (n.d.). Polly. Retrieved December 19, 2023 <https://www.thinkerbelllabs.com/>

Table 3.6: Braille education devices and their manufacturers (Continued)

Equipment	Manufacturer
Mountbatten Braille Tutor	Harpo
Polly ⁸	APH / Thinkerbell Labs
Read Read	EdVar Tech
SMART Brailler	Perkins
Taptilo	HIMS / OHFA Tech

Chapter 4

Empowering Minds: The Crucial Role of High-Quality Braille Embossers in Unlocking STEM Literacy for Visually Impaired Students

In the ever-evolving realms of Science, Technology, Engineering, and Mathematics (STEM), the pursuit of literacy takes on a particularly intricate form. For visually impaired students, the challenges are multifaceted, but with the advent of high-quality braille embossers, a transformative bridge has been constructed. This chapter explores the indispensable role that high-quality braille embossers play in shaping the educational narrative of visually impaired students, especially in the critical domains of Math and STEM. These devices, with their ability to translate complex symbols and notations into tangible braille and tactile graphics, foster literacy, comprehension, and success in STEM fields.

The crux of this exploration lies in recognizing the nuanced requirements of visually impaired students pursuing education in Math and STEM disciplines. Traditional print materials, laden with intricate diagrams, mathematical symbols, and graphs, pose formidable challenges for learners with visual impairments. High-quality braille embossers bridge this gap, converting abstract mathematical concepts and scientific data into tangible formats, empowering students to actively engage with and comprehend the intricacies of STEM subjects.

Embossed tactile graphics break down the barriers to understanding complex mathematical equations, graphical representations, and scientific concepts, ultimately fostering a sense of autonomy and empowerment among visually impaired students. By providing access to the visual nuances inherent in STEM fields, these devices pave the way for literacy, comprehension, and active participation, ensuring that visually impaired students can unlock the full spectrum of opportunities in Math and STEM disciplines.

4.1 Braille Embossers

Having access to a high-quality braille embosser is essential for students with visual impairments to receive a free and appropriate public education. Braille embossers are printers that produce braille text and tactile graphics on paper. They are used to create braille copies of textbooks, worksheets, and other educational materials. High-quality embossers produce sharp, clear braille that is easy to read and tactile graphics that are easy to interpret. This is important because it allows students with visual impairments to access the same educational materials as their sighted peers. Braille embossers also allow students to create their own braille notes and written work, which can help improve their literacy skills and independence. By providing students with visual impairments access to high-quality braille embossers, we can help ensure that they have the tools they need to succeed in their studies and beyond. *Table 4.1 lists current available embossers¹.*

Table 4.1: Braille embosser comparison: machine, capability, and company (Updated 2024-2025)

Machine	Capability	Company
APH PageBlaster (Index-D V4)	Simple Graphics, Interpoint Braille	APH, Index Braille
Basic-D V5	Simple Graphics, Interpoint Braille, 16.7 lbs portable	Index Braille
Braille Box V5	Production Braille, Advanced Technology	Index Braille

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¹ I am only focusing on 11x11.5" braille paper size as US Letter size is impractical for braille

Table 4.1: Braille embosser comparison: machine, capability, and company (Updated 2024-2025) (Continued)

Machine	Capability	Company
BrailleTrac 120	Simple Graphics, Interpoint Braille	Irie-AT
Juliet 120	Simple Graphics, Interpoint Braille	ETS, Humanware
ViewPlus Columbia	Complex Graphics, Interpoint Braille	ViewPlus
ViewPlus Max (formerly Rogue)	Complex Graphics, Interpoint Braille, 8 dot heights	ViewPlus
ViewPlus Premier	Complex Graphics, High-speed (100 CPS), Production	ViewPlus
ViewPlus Delta 2	Complex Graphics, Power-Dot Braille, 120 CPS	ViewPlus
Marathon Brailler	High-speed single-sided, 200 CPS	HumanWare
Mountbatten Brailler	Electronic braille embosser	HumanWare

4.2 High Resolution Tactile Graphics

There are some historical challenges that have befallen blind students that rely on tactile graphics and braille.

- Historically, by the time students with visual impairments enter school, they have not received enough instruction in the development and use of their tactile skills or had enough opportunities to touch and explore their world.²

² Adkins, A., Sewell, D., & Cleveland, J. (2016). The Development of Tactile Skills. *TX SenseAbilities, Fall/Winter*.

- Tactile Graphicacy requires the ability to access, comprehend, and produce tactile graphics or raised line drawings. This requires:
 - Fine motor sensitivity and dexterity
 - Efficient use of carefully constructed knowledge
 - Variety of tactile-cognitive strategies
- Students have to develop a perception that there are different kinds of symbolic information on a page with different kinds of meaning
- Students have to develop an ability to discriminate between different tactile surfaces and to draw meaning from them
- These are *not* inherent or natural for braille readers as they require:
 - Explicit attention
 - Education
 - Careful, systematic building of tactile exploratory and interpretive skills

Recent advances in tactile graphics technology have introduced AI-generated tactile graphics systems that can automatically convert visual information into tactile formats while adhering to Braille Authority of North America (BANA) guidelines. These developments promise to address the traditional labor-intensive production methods that have limited scalability of tactile graphics creation.

There are a number of benefits to having access to accessible tactile graphics in the classroom. These include:

- Provides a focus for attention and perception
- Builds pathways to retain and memorize information
- Natural destination for conversation and social interaction
- Pictures invite and motivate a learner's curiosity and engagement
- Modern embossers with multiple dot heights (up to 8 different levels) allow for more sophisticated tactile representations

Table 4.2 lists current available embossers and other devices for creation of high resolution tactile graphics.

Table 4.2: High resolution tactile graphics embossers: machine and company (Updated 2024-2025).

Machine	Company	Special Features
APH PixBlaster (ViewPlus Columbia)	APH, ViewPlus	High-resolution tactile graphics
Basic-D V5	Index Braille	Portable, simple graphics
Braille Box V5	Index Braille	Production-level, advanced technology
EZ-Form Brailon Duplicator	American Thermoform	Thermoform duplication
PIAF tactile embosser	Humanware	Capsule paper technology
Swell Form Machine	American Thermoform	Swell touch paper
ViewPlus Columbia	ViewPlus	Complex graphics, desktop model
ViewPlus Delta 2	ViewPlus	Power-Dot Braille, 120 CPS
ViewPlus Elite	ViewPlus	High-end production model
ViewPlus Max	ViewPlus	8 dot heights, desktop tactile graphics
ViewPlus Premier	ViewPlus	100 CPS, production strength

Specialized embossers for high-resolution tactile graphics production, listing available models with enhanced capabilities and specifications.

4.3 Tactile Graphic Supplies

The advancement in tactile graphics technology has also led to improvements in specialized media and supplies. Modern production environments benefit from enhanced paper feeding systems, with tractor-feed technology providing the most reliable sheet handling for continuous production. *Table 4.3* lists materials needed to use with the

graphics devices shown in *Table 4.2*.

Table 4.3: Paper supplies for Tactile Graphics Generation (Updated 2024-2025)

Paper / Medium	Company	Compatible Devices
Brailon Thermoform Paper	American Thermoform	EZ-Form Duplicator
Swell Touch Paper	American Thermoform	Swell Form Machine
Tangible Magic Capsule Paper	Humanware	PIAF tactile embosser
Tractor-Feed Braille Paper	APH	Production embossers
High-Resolution Tactile Paper	ViewPlus	ViewPlus embosser series
11x17 Tactile Graphics Paper	Various	Large format tactile graphics

4.4 Market Trends and Future Developments

The braille embosser market has experienced significant growth, with major players including A11yTech, Tobii Dynavox, Perkins Solutions, Freedom Scientific, and HumanWare. Recent market analysis indicates sustained demand for both educational and institutional applications, with government institutions representing a significant market segment.

Current technological developments focus on improving production speeds, with some industrial models capable of output rates exceeding 200 characters per second. The integration of advanced software suites, such as the TIGER software suite included with ViewPlus systems, has streamlined the process of creating tactile graphics from standard documents.

The emergence of AI-powered tactile graphics generation represents a paradigm shift in the field, potentially addressing the scalability challenges that have historically limited access to tactile materials. These systems can automatically convert visual content while maintaining adherence to established accessibility standards, promising to democratize access to tactile graphics across educational institutions.

Educational institutions continue to recognize the critical importance of these

technologies in providing equitable access to STEM education. The combination of high-speed braille production capabilities with sophisticated tactile graphics generation ensures that visually impaired students can engage with complex mathematical and scientific concepts at the same pace as their sighted peers.

Chapter 5

Shaping Knowledge: The Imperative Role of 3D Printed Materials in Fostering Hands-On Literacy for Visually Impaired Students

In the realm of education, the power of hands-on experience is unparalleled. For visually impaired students, the journey toward literacy and comprehension takes on a unique dimension—one that is enriched and transformed through the tactile exploration of 3D printed materials. This chapter explores the indispensable role that 3D printed materials play in providing a tangible, tactile bridge to knowledge. These innovative creations facilitate hands-on engagement with concepts and serve as catalysts for literacy, fostering success for visually impaired students across a diverse spectrum of subjects.

The need for tangible exploration is paramount, especially when conceptualizing abstract ideas or interacting with physical entities is integral to the learning process. Traditional educational materials often rely on visual cues that pose challenges for students with visual impairments. 3D printed materials transcend the limitations of traditional teaching tools and enhance literacy by providing a multisensory gateway to understanding.

From historical artifacts to mathematical models, 3D printed materials transform abstract concepts into tangible, touchable entities. These creations allow visually impaired students to feel, explore, and internalize knowledge in a manner that aligns with their unique learning styles.

Hands-on learning with 3D printed materials fosters comprehension, empowerment, and curiosity. These tools democratize access to knowledge and enhance the educational

journey for visually impaired students.

5.1 3D Printers

When selecting a 3D printer for students with visual impairments, it is important to consider the following features:

- *Tactile printing:* The printer should produce 3D models that are tactile and easily understood by students with visual impairments.
- *High resolution:* The printer should produce high-resolution models with fine details.
- *Ease of use:* The printer should be easy to use, set up, and maintain.
- *Compatibility:* The printer should be compatible with a wide range of software and file formats.
- *Cost:* The printer should be affordable and within the school or institution's budget.
- *Safety features:* Enclosed designs and automatic bed leveling for safer operation in educational environments.
- *Reliability:* Consistent performance with minimal maintenance requirements.

3D printing can help visually impaired students learn a variety of disciplines such as engineering, manufacturing, food, art, and health.¹ 3D printed models can benefit both blind and sighted students, allowing for multisensory learning and independence.²

Table 5.1 lists current available 3D printers with updated pricing.

Table 5.1: Comparison of 3D printers: model, cost, print bed size, filament size, and manufacturer

Model	Cost	Print Bed Size	Filament Size	Manufacturer
Bambu A1 Mini	\$249	180x180x180mm	1.75mm	Bambu Lab

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¹ Karbowski, C. F. (2020). See3D: 3D Printing for People Who Are Blind. *Journal of Science Education for Students with Disabilities*, 23(1), n1.

² MatterHackers. (2017). 3D printed educational models for the visually impaired. MatterHackers

Table 5.1: Comparison of 3D printers: model, cost, print bed size, filament size, and manufacturer (Continued)

Model	Cost	Print Bed Size	Filament Size	Manufacturer
Elegoo Neptune 3 Pro	\$170	225x225x280mm	1.75mm	Elegoo
Creality Ender-3 V3 KE	\$269	220x220x250mm	1.75mm	Creality
Ender 3 Max Neo	\$389	300x300x320mm	1.75mm	Creality
Ender 5 Plus	\$629	350x350x400mm	1.75mm	Creality
Creality K1	\$649	220x220x256mm	1.75mm	Creality
Anycubic Kobra Max	\$619	450x400x400mm	1.75mm	Anycubic
Anycubic Kobra Plus	\$549	300x300x350mm	1.75mm	Anycubic
AnkerMake M5C	\$429	220x220x250mm	1.75mm	AnkerMake
Prusa Mini+	\$499	180x180x180mm	1.75mm	Prusa
Elegoo Neptune 3 Max	\$520	420x420x500mm	1.75mm	Elegoo
Elegoo Neptune 4 Pro	\$380	225x225x265mm	1.75mm	Elegoo
Anycubic Kobra S1 Combo	\$829	220x220x270mm	1.75mm	Anycubic
Artillery Sidewinder X2	\$449	300x300x396mm	1.75mm	Artillery

Table 5.2: Premium 3D printers: model, cost, print bed size, filament size, and manufacturer.

Model	Cost	Print Bed Size	Filament Size	Manufacturer
Bambu P1P	\$749	256×256×256mm1.75mm		Bambu Lab
Bambu P1S (Combo)	\$699	256×256×256mm1.75mm		Bambu Lab
Bambu X1C Carbon (Combo)	\$1,299	256×256×256mm1.75mm		Bambu Lab
Bambu A1	\$599	256×256×256mm1.75mm		Bambu Lab
Prusa MK4	\$829	250×210×220mm1.75mm		Prusa
Prusa MK4 Kit	\$749	250×210×220mm1.75mm		Prusa
Prusa Core ONE	\$1,299	250×220×270mm1.75mm		Prusa
Creality K2 Plus	\$1,299	350×350×400mm1.75mm		Creality
Creality K2 Plus (with CFS)	\$1,499	350×350×400mm1.75mm		Creality

5.2 Web Resources for 3D Print Files and Accessibility

Designed For VI Specifically

- BTactile, Benetech ImageShare, Median Augenbit, Tactiles, See3D, Accessible3D

Math Curricula

- Nonscriptum Calculus, Geometry, Trigonometry, Tactile Math Models

Astronomy/Physics

- 3D Opal, Astrokit, NASA, Roving Bits Constellations, Tactile Universe, ESA 3D Models

Biology

- 3D Biology, NIH 3D Print Collections/Models, Tactile Anatomy Models

General User-Uploaded 3D Print File Collections

- Printables, Thingiverse, My Mini Factory, Cults 3D, Thangs, MakerWorld, GrabCad, Instructables, Pinshape, Sketchfab, 3D Warehouse, Traceparts, Turbo Squid, YouMagine

3D File Search Aggregators

- Thangs3D, Yeggi, 3D Find It, 3D Print Shelf, 3DSourced, STL Finder, STLBase, MakerOnline, Mito3D, Open 3D Model, SeekSTL, Creazilla, Free3d

AI 3D Model Generation

- Meshy.ai, Luma AI Genie, Sloyd, Kaedim, Spline AI, Masterpiece Studio, 3D AI Studio

Professional Groups

- AT Makers, Makers Making Change, Enabling the Future, Thingiverse Assistive Technology

Visually Impaired Education and Accessibility Resources

- See3D, Accessible3D, MatterHackers Education, Braille Institute, American Foundation for the Blind, Paths to Literacy, 3D Print Accessibility Community

5.3 3D Printer Materials

3D printing creates three-dimensional objects from computer-aided design (CAD) files. The process involves depositing materials layer by layer to build a shape.³ To use a 3D printer in an educational environment, you need:

- *3D printer*: Available in various sizes, from benchtop to large-format, including models with enclosures/environmental control for improved reliability.
- *Filament*: The material used to create the 3D object (e.g., PLA, TPU, ABS, PETG, etc.).⁴
- *Computer*: Required to create the 3D model using CAD software.

³ Dassault Systèmes. (n.d.). 3D printing in education. Retrieved December 19, 2023

⁴ Tech & Learning. (2023). Best 3D printers for schools. Retrieved December 19, 2023

- *CAD software*: Used to create the 3D model.
- *Slicing software*: Converts the 3D model into a format the printer can understand and generates the G-code for printing.⁵

3D Printer Filament (PLA) and Color Resources

FilamentColors is a color checking program for popular PLA vendors, providing Hex codes for reproducible color accuracy. Not all vendors are available, but the list is growing.

Prices are for 1kg/2.2lb basic PLA, default with spool unless noted. Refills require a spool. Current pricing reflects market conditions as of July 2025, including tariff impacts on non-US suppliers.

International Suppliers (prices affected by tariffs):

- Bambu Labs: \$28 (\$23 with 4+ rolls) with spool; \$25 (\$20 with 4+ kg) for refills
- Creality: \$22 Sole Yin Ultra PLA; \$25 Ender Fast PLA
- ELEGOO: \$18
- eSun: \$24
- Sunlu: \$25
- Polymaker: \$26
- OVERTURE: \$22

Manufactured in the USA (minimal tariff impact): Most US PLA is sourced from Natureworks LLC (Ingeo Line).

- Polar Filament: \$19 (Basic PLA), \$22 (Premium colors)
- 3D Fuel: \$27
- American Filament: \$27 (\$14 500g refill)
- Atomic Filament: \$32
- Hatchbox: \$24
- MatterHackers: \$20+
- Overture 3D: \$25
- Polymaker: \$22
- ProtoPasta: \$21

⁵ TeachThought. (2021). 10 ways 3D printing can be used in education. Retrieved December 19, 2023

- Push Plastic: \$26
- Printed Solid: \$26
- Filastruder: \$11 PLA, \$13 PLA Pro
- Splice 3D: \$17/spool (bulk: \$14 w/4+, \$12 w/8+, \$11 w/24+)
- ZYLTech: \$19
- Gizmo Dorks: \$25
- IC3D: \$31
- Keene Village Plastics: \$32
- Numakers: \$22
- Paramount 3D: \$24 (\$21/8pack)
- VoxelPLA: \$18
- Toner Plastics: \$24

Table 5.3 lists materials needed to use the 3D printers shown in Table 5.1.

Table 5.3: 3D Printer Materials

Item	Cost	Vendor
1.75mm filament (see above)	\$18–\$45/kg	Multiple (Bambu, Elegoo, Polar, 3D Fuel, etc.)
3D Print Tool Kit	\$65.00	HJIRH, Amazon
Assorted Sandpaper (48 pcs)	\$9.00	Vicien, Amazon
Glue Sticks (30 pack)	\$12.00	Amazon Basics
Painter's Tape (2" width 12 Pack)	\$48.00	Amazon
Build Surface Cleaner	\$8.00	Various
Nozzle Cleaning Kit	\$15.00	Various

5.4 3D Printer Software

3D printing software allows users to create, edit, and slice 3D models. These programs enable users to design models, slice them into layers, and generate G-code for the printer.

Resources for Programs to Create 3D Models

Free:

- Tinkercad: Browser-based, beginner-friendly, block-building interface.
- Fusion 360: Free for personal/educational use, professional features.
- FreeCAD: Open-source parametric modeler, improving rapidly.
- Blender: Open-source, steep learning curve, excellent for complex models.
- SketchUp Free: Web-based, good balance of usability and functionality.
- OpenSCAD: Script-based modeling, ideal for programmers.
- BRL-CAD: Advanced solid modeling, used by U.S. military.
- Wings3D: Open-source polygon modeler.
- 3D Slash: Fun, voxel-based interface.

Education Plans:

- Fusion 360: Free for students/educators, \$60/month otherwise.
- SolidWorks: Educational licenses available, \$99/year for students.
- Inventor: Educational pricing available.
- Shapr3D: Educational discounts available.

Professional:

- SolidWorks: \$1,395/yr or \$4,195 perpetual.
- Inventor: \$2,085/yr.
- Rhino3D: \$1,095, \$195 student.
- 3DS Max: \$1,645/yr.
- Maya: \$1,645/yr.
- Cinema 4D: \$770/yr or \$4,195 perpetual.
- Modo: \$639/yr or \$1,909 perpetual.

3D Print Slicing Programs

- Bambu Studio: Default for Bambu Lab printers, advanced features.
- PrusaSlicer: Free, excellent for most FDM printers.
- Ultimaker Cura: Free, widely compatible.
- OrcaSlicer: Free, community-developed with advanced features.
- Simplify3D: \$149, commercial slicer with support.
- IdeaMaker: Free, by Raise3D.
- Repetier-Host: Free, includes slicing and printer control.
- KISSlicer: Free version available.
- 3DPrinterOS: Cloud-based slicing and management.

Table 5.4 lists software and their functions with updated pricing.

Table 5.4: 3D Printer Software and Functions

Program	Cost	Function
Tinkercad	Free	Generate 3D file
Fusion 360	Free (Education)/\$60/month	Generate 3D file
FreeCAD	Free	Generate 3D file
SolidWorks	\$1,395/yr/\$99 student	Generate 3D file
SketchUp Free	Free	Generate 3D file
Blender	Free	Generate 3D file
Rhino 7	\$1,095/\$195 student	Generate 3D file
Bambu Studio	Free	Slice & Print 3D Model
PrusaSlicer	Free	Slice & Print 3D Model
Ultimaker Cura	Free	Slice & Print 3D Model

Continued on next page

Table 5.4: 3D Printer Software and Functions (Continued)

Program	Cost	Function
OrcaSlicer	Free	Slice & Print 3D Model
Simplify3D	\$149	Slice & Print 3D Model
Meshmixer	Free	Fix & Modify 3D Print Files
Meshlab	Free	Fix & Modify 3D Print Files
Netfabb	Free (Basic)	Fix & Modify 3D Print Files

5.5 Recent Developments in 3D Printing for Accessibility

The field of 3D printing for visually impaired education continues to evolve rapidly. Recent developments include improved tactile design guidelines, better integration with assistive technologies, and enhanced software accessibility features. Educational institutions are increasingly recognizing the transformative potential of 3D printing technology for creating inclusive learning environments.

Key trends include:

- Integration of AI tools for automatic generation of tactile models
- Development of specialized software with screen reader compatibility
- Increased collaboration between accessibility organizations and 3D printing communities
- Growing libraries of pre-designed accessible educational models
- Enhanced safety features in educational 3D printers

The market growth in 3D printing technology continues to drive down costs while improving accessibility, making these tools more available to educational institutions serving visually impaired students.

Chapter 6

Amplifying Vision: The Vital Role of Video Magnification Products in Fostering Literacy and Success for Visually Impaired Students

In the realm of visual impairment, the quest for literacy and academic success is a journey characterized by innovation and adaptability. For visually impaired students, the challenge of accessing printed materials, charts, and visual content is met with a powerful solution—video magnification products. The indispensable role that video magnification plays in providing enhanced visual access, breaking down barriers to literacy, and empowering students to navigate the educational landscape with confidence cannot be overstated.

The significance of video magnification products lies in their ability to transform the visual experience for students with visual impairments. As we navigate this chapter, we will unravel the sophisticated functionalities of these devices, showcasing how they go beyond traditional magnification methods to provide an immersive and dynamic visual experience. Whether exploring the pages of a textbook, deciphering intricate diagrams, or engaging with digital content, video magnification stands as a technological ally, ensuring that every student can access and interpret visual information with ease.

The video magnification market has experienced substantial growth, with the assistive technologies for visual impairment market valued at USD 125.84 million in 2023 and projected to reach USD 134.21 million in 2024, eventually growing to USD 224.58 million by 2032. This growth is driven by technological advancements including artificial

intelligence integration, augmented reality capabilities, and enhanced portability features that make these devices increasingly accessible to students.

In the pursuit of literacy, the role of video magnification becomes increasingly pivotal, particularly in subjects where visual content is integral to comprehension. This chapter will delve into how these products facilitate not only enhanced readability but also active participation in classroom discussions, visual learning activities, and the overall educational experience. Modern video magnification devices now incorporate AI-powered features such as JAWS Picture Smart AI, which provides detailed image descriptions, revolutionizing accessibility for visually impaired students.

By providing visually impaired students with a clear and magnified view of the visual world, video magnification products serve as gateways to knowledge, fostering a sense of inclusion and leveling the playing field in academic settings. It is evident that these tools are not mere aids; they are essential components in the arsenal of resources necessary for the success of visually impaired students. Video magnification imperatively contributes to shaping a learning environment where visual content is accessible to all, ensuring that literacy and success are attainable goals for every student, regardless of their visual abilities.

6.1 Video Magnification Devices

When purchasing electronic portable magnifiers for students with visual impairments, it is important to consider the following factors to ensure that they can access a free and appropriate public education¹:

- *Magnification power:* The magnification power of the magnifier should be appropriate for the student's needs. Some magnifiers have a fixed magnification, while others have adjustable magnification. Modern systems can magnify content from 2x to 85x times its original size while maintaining perfect focus.
- *Portability:* Portable magnifiers are ideal for students who need to move around the classroom or school. They should be lightweight and easy to carry. Battery life is an important consideration for portable magnifiers. The battery should last long enough to get through a school day without needing to be recharged.
- *Ease of use:* The magnifier should be easy to use and adjust. It should have large buttons and controls that are easy to locate and operate. Compatibility with other

¹ cf., Perkins School for the Blind. (n.d.). Choosing an appropriate video magnifier. Retrieved December 19, 2023

assistive technology devices, such as screen readers and braille displays, is also important.

- *AI and Advanced Features:* Latest trends in low vision magnifiers for 2024 include AI integration, augmented reality, wearable devices, and enhanced connectivity features, which can significantly enhance the learning experience for students.
- *Cost:* The cost of the magnifier should be reasonable and within the school's budget. The American Recovery Plan Act provides funds to libraries and schools to address student learning loss and assist with distance learning through assistive technology. AI-powered devices like MyEye Pro use voice-activated, intuitive AI to audibly describe what's in a room, respond to open-ended queries for specific information, and help users recognize faces.
- *Wearable Technology:* Smart glasses and head-mounted displays are becoming increasingly sophisticated, offering hands-free magnification and real-time text-to-speech capabilities.
- *Enhanced Connectivity:* Modern devices feature improved wireless connectivity, allowing seamless integration with classroom technology and remote learning platforms.
- *Augmented Reality:* AR capabilities are being integrated into magnification devices to provide contextual information and enhanced visual overlays.

Table 6.1: Comparison of video magnification devices: model, deployment, and company (2025 Update)

Model	Deployment	Company
AceSight VR	VR Headset	Zoomax
Acesight	E-Glasses	Zoomax
Acesight 8	E-Glasses	Zoomax
Acuity 22	Desktop	Irie AT
Acuity 22 Speech	Desktop	Irie AT
Amigo	Portable	Enhanced Vision
Clearview+ HD 22"	Desktop	Enhanced Vision

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Table 6.1: Comparison of video magnification devices: model, deployment, and company (2025 Update) (Continued)

Model	Deployment	Company
Cloverbook Plus	Mobile	Irie-AT
Cloverbook Pro	Mobile	Irie-AT
Connect 12	Desktop, Mobile	Humanware
explorē 12	Portable	Humanware
JAWS Picture Smart AI	Software/AI Enhancement	Freedom Scientific
Luna HD 24 Pro	Desktop (24" widescreen)	Zoomax
MyEye Pro	Wearable/AI-Powered	OrCam
OrCam Read 3	Portable/AI Reading	OrCam
Reveal 16i	Desktop	Humanware
ZoomText 2025	Software Magnifier	Freedom Scientific

Table 6.2: Comprehensive video magnification devices and screen magnifiers for visually impaired students (2025 Update)

Model	Deployment/Screen	Company
AceSight VR	VR Headset	Zoomax
Acesight	E-Glasses	Zoomax
Acesight 8	E-Glasses	Zoomax
Clearview+ HD 22"	Desktop (22" HD)	Enhanced Vision
Connect 12 (10x)	Desktop, Mobile	Humanware

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Table 6.2: Comprehensive video magnification devices and screen magnifiers for visually impaired students (2025 Update) (Continued)

Model	Deployment/Screen	Company
Connect 12 (25x)	Desktop, Mobile	Humanware
Distance Camera	Hand-Held	Zoomax
explorē 5	Hand-Held (5" screen)	Humanware
explorē 8	Hand-Held (8" screen)	Humanware
explorē 12	Hand-Held (12" screen)	Humanware
I-See 22"	Desktop	Irie AT
JAWS Picture Smart AI	Software/AI Enhancement	Freedom Scientific
Juno	Hand-Held (7" screen)	APH
Jupiter Portable Magnifier	Desktop, Mobile (heavy)	APH
Luna 6	Hand-Held (6" screen)	Zoomax
Luna 8	Hand-Held (8" screen)	Zoomax
Luna Eye	Hand-Held	Zoomax
Luna HD 24 Pro	Desktop (24" widescreen)	Zoomax
Luna HD Pro	Desktop	Zoomax
Luna S	Hand-Held (4.3" screen)	Zoomax
MAGNA 3	Hand-Held (3.5" screen)	Orbit Research
MAGNA 4	Hand-Held (4.3" screen)	Orbit Research
MAGNA 5	Hand-Held (5" screen)	Orbit Research
MATT Connect v2	Desktop, Mobile (heavy)	APH

Continued on next page

Table 6.2: Comprehensive video magnification devices and screen magnifiers for visually impaired students (2025 Update) (Continued)

Model	Deployment/Screen	Company
Magnibot	Desktop, Mobile	Trysight
MagniLink Air	Desktop	Low Vision International
MagniLink Tab	Desktop	Low Vision International
MagniLink One	Desktop	Low Vision International
MagniLink S Premium	Mobile	Low Vision International
MagniLink Vision	Desktop	Low Vision International
MagniLink WiFiCam	Mobile	Low Vision International
MagniLink Zip	Desktop	Low Vision International
Merlin Mini	Mobile	Enhanced Vision
MyEye Pro	Wearable/AI-Powered	OrCam
ONYX Desk set HD	Desktop	Freedom Scientific
ONYX OCR	Desktop	Freedom Scientific
OrCam Read 3	Portable/AI Reading	OrCam
Panda HD	Desktop	Zoomax
Pebble HD	Handheld	Enhanced Vision
RUBY	Hand-Held (4.3" screen)	Freedom Scientific
RUBY 10	Hand-Held (10" Screen)	Freedom Scientific
RUBY 7 HD	Hand-Held (7" Screen)	Freedom Scientific
RUBY HD	Hand-Held (4.3" screen)	Freedom Scientific

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Table 6.2: Comprehensive video magnification devices and screen magnifiers for visually impaired students (2025 Update) (Continued)

Model	Deployment/Screen	Company
RUBY XL HD	Hand-Held (5" screen)	Freedom Scientific
Reveal 16	Desktop	Humanware
Reveal 16 (XY table)	Desktop	Humanware
Reveal 16i	Desktop	Humanware
Reveal 16i (XY table)	Desktop	Humanware
Snow 12	Desktop, Mobile	Zoomax
Snow Pad	Hand-Held	Zoomax
TOPAZ EZ HD	Desktop	Freedom Scientific
TOPAZ OCR	Desktop	Freedom Scientific
TOPAZ XL HD	Desktop	Freedom Scientific
Tactonum Pro	Desktop (Not Readily Mobile)	Tactonum
Tactonum Reader	Desktop (Not Readily Mobile)	Tactonum
Transformer HD	Mobile	Enhanced Vision
Traveller HD	Mobile	Optelec
ZoomText 2025	Software Magnifier/Reader	Freedom Scientific

6.1.1 Market Growth and Educational Impact

The assistive technology market for visually impaired students continues to expand rapidly. The global assistive technologies for visually impaired market size is expected to reach \$12.31 billion by 2029 at 15% growth rate, segmented by educational devices and

software, braille notetakers, screen readers, and accessible learning software. This growth reflects the increasing recognition of the importance of these technologies in educational settings and their proven effectiveness in supporting student success.

Educational institutions are increasingly investing in video magnification technology, supported by federal funding initiatives. The American Recovery Plan Act provides funds to libraries and schools to address student learning loss, close achievement gaps, and assist with distance learning through assistive technology, making these essential tools more accessible to students who need them.

The integration of artificial intelligence and machine learning capabilities in video magnification devices represents a significant advancement in accessibility technology.

These features enable more intuitive interaction, automatic text recognition, and enhanced image processing, making the devices more effective tools for learning and independent living.

6.1.2 Considerations for Educational Settings

When selecting video magnification devices for educational environments, several additional factors should be considered:

- *Classroom Integration:* Devices should seamlessly integrate with existing classroom technology, including interactive whiteboards, projectors, and learning management systems.
- *Durability and Maintenance:* Educational settings require robust devices that can withstand frequent use by multiple students and require minimal maintenance.
- *Training and Support:* Comprehensive training programs for educators and ongoing technical support are essential for successful implementation.
- *Accessibility Standards:* Devices should comply with current accessibility standards and regulations, including Section 508 and WCAG guidelines.
- *Future-Proofing:* Given the rapid pace of technological advancement, devices should be updatable and compatible with emerging technologies.

The future of video magnification technology in education looks promising, with continued innovation in AI, augmented reality, and wearable technology promising to further enhance accessibility and learning outcomes for visually impaired students. As these technologies continue to evolve, they will play an increasingly vital role in ensuring that all students have equal access to educational opportunities and can achieve their full potential.

Chapter 7

Beyond Boundaries: Text-to-Speech and DAISY as Catalysts for Literacy and Success in Visual Impairment Education

The National Instructional Materials Accessibility Standard (NIMAS) and Digital Accessible Information System (DAISY) are two important tools for the education of students with visual impairments. NIMAS is a technical standard used by publishers to prepare electronic files that are used to convert instructional materials into accessible formats. The purpose of NIMAS is to help increase the availability and timely delivery of instructional materials in accessible formats for qualifying students in elementary and secondary schools, with the National Instructional Materials Access Center (NIMAC) serving as a federally funded, online file repository of more than 83,000 K-12 NIMAS files¹. DAISY is a digital format for audio books that is designed to be more accessible to people with visual impairments, with files that can be used to produce formats like braille, EPUB, DAISY, and large print².

Under IDEA, students must be receiving special education services under IDEA and meet the qualification criteria of the National Library Service for the Blind and Print Disabled (NLS) statute to be eligible for NIMAS-derived materials through the NIMAC³.

¹ NIMAC. (2025). National Instructional Materials Access Center. Retrieved July 4, 2025

² DAISY Consortium. (2024). What is DAISY? Retrieved July 4, 2025

³ Connecticut State Department of Education. (2025). Accessible Educational Materials. Retrieved July 4, 2025

NIMAS and DAISY are important because they help make educational materials more accessible to students with visual impairments. By providing instructional materials in accessible formats, students with visual impairments can participate more fully in the general education curriculum. This can help improve their academic performance and increase their chances of success in school.

Finally, NIMAS and DAISY can help students with visual impairments become more independent. By providing instructional materials in accessible formats, students can read books, take notes, and communicate with others more easily. This can help them lead more fulfilling lives and become more active members of their communities.

In the evolving landscape of education, the pursuit of literacy is a journey marked by innovation and inclusivity. For visually impaired students, the traditional pathways to literacy take on a distinctive form, guided by the transformative power of audiobook and DAISY readers. This chapter explores the indispensable role that these tools play in breaking down barriers to literacy, ensuring access to knowledge, and propelling visually impaired students towards academic success.

7.1 DAISY Readers

Assistive technology is a crucial tool for students with visual impairments or blindness to receive a free and appropriate public education. DAISY (Digital Accessible Information System) is a technical standard for digital audiobooks, periodicals, and computerized text that is designed to be a complete audio substitute for print material and is specifically designed for use by people with print disabilities, including blindness, impaired vision, and dyslexia⁴.

Based on the MP3 and XML formats, the DAISY format has advanced features in addition to those of a traditional audiobook. Users can search, place bookmarks, precisely navigate line by line, and regulate the speaking speed without distortion⁵. DAISY also provides aurally accessible tables, references and additional information. As a result, DAISY allows visually impaired listeners to navigate something as complex as an encyclopedia or textbook, otherwise impossible using conventional audio recordings⁶.

DAISY books provide full accessibility for the reader and allow the reader to play the book on a variety of hardware and software players depending on the DAISY file type (e.g., CD players, mobile phones, computers, iPods & iPads, tablets, etc.)⁷.

⁴ Wikipedia. (2024). Digital Accessible Information System. Retrieved July 4, 2025

⁵ Ibid.

⁶ Encyclopedia MDPI. (2022). DAISY Digital Talking Book. Retrieved July 4, 2025

⁷ California Department of Education. (2025). Digital Talking Books. Retrieved July 4, 2025

Table 7.1: DAISY readers and digital audio players: models, function, and company (Updated 2025)

Model	Function	Company
Milestone 212 Ace Book Reader	DAISY Reader, Digital Audio Player	Bones
PlexTalk PTN2	DAISY Reader, CD Player	PlexTalk
PlexTalk Pocket	DAISY Reader, Digital Audio Player	PlexTalk
Reizen DAISY Digital Recorder	DAISY Reader, Digital Audio Player	Reizen
Victor Reader Stratus	DAISY Reader, Digital Audio Player (Desktop)	Humanware
Victor Reader Stream	Digital Audio Player	Humanware
Victor Reader Trek	GPS, Digital Audio Player	Humanware
Victor Reader Stratus 12	Advanced DAISY Reader, Digital Audio Player	Humanware

7.2 Text-to-Speech

The use of assistive technology, including Text-to-Speech, is required for all students with disabilities that show a need under the Individuals with Disabilities Education Act (IDEA), with eligibility criteria including those with visual impairments, perceptual disabilities, or those otherwise unable through physical disability to hold or manipulate a book or to focus or move the eyes to the extent that would be normally acceptable for reading⁸.

With the push of a single button, text to speech devices photograph your reading material and within seconds, begin reading it aloud. These easy-to-use devices are ideal for blind users of all ages and abilities. Some devices offer the option of smart reading features that enable you to simply ask for the text that interests you and some even offer facial and

⁸ National Center on Accessible Digital Educational Materials. (2024). Addressing Accessible Educational Materials in the 2024 Assistive Technology Guidance. Retrieved July 4, 2025

product recognition⁹.

Table 7.2: Text-to-speech devices: model, function, and company (Updated 2025)

Model	Function	Company
C-Pen Reader	Pen Scanner, Text-to-Speech Reader	C-Pen
OrCam MyEye Pro	AI-powered Smart Glasses, Text-to-Speech, Object Recognition	OrCam
OrCam Read 3	Hand-held Text-to-Speech Reader	OrCam
Scanmarker Air	Hand-held Text-to-Speech Scanner	Scanmarker
Enhanced Vision Smart Reader HD	Portable Text-to-Speech Reader	Enhanced Vision
Voice Dream Reader	Software-based Text-to-Speech (iOS/Android)	Voice Dream
KNFB Reader	Mobile App Text-to-Speech	KNFB
Speechify	AI-powered Text-to-Speech Software	Speechify

7.3 Emerging Technologies and Future Directions

The landscape of assistive technology for visual impairment education continues to evolve rapidly. Assistive technology for people with disabilities has come a long way, with 2025 bringing new tools that are improving their lives¹⁰.

Advanced text-to-speech tools and voice cloning technology are bringing new levels of

⁹ VisionAid. (2025). Text-to-speech. Retrieved July 4, 2025

¹⁰ Speechify. (2025). 10 assistive technology tools to help people with disabilities in 2025 and beyond. Retrieved July 4, 2025

inclusivity to visually impaired people and individuals with speech disorders¹¹.

Modern text-to-speech technology has advanced significantly, offering more natural-sounding voices, better pronunciation of technical terms, and improved navigation features. These advancements make educational materials more accessible and engaging for students with visual impairments.

7.4 Implementation and Best Practices

Educational institutions must ensure proper implementation of these technologies to maximize their effectiveness. The Department of Education provides guidance to states, state educational agencies (SEAs), local educational agencies, and other interested parties with information to facilitate implementation of the National Instructional Materials Accessibility Standard and coordination with the National Instructional Materials Access Center¹².

Key considerations for implementation include:

- Early identification and assessment of students who would benefit from these technologies
- Proper training for educators and support staff on the use of DAISY and text-to-speech devices
- Regular evaluation and updating of assistive technology resources
- Collaboration between special education professionals, general education teachers, and technology specialists
- Ensuring compatibility between different systems and formats

7.5 Conclusion

The integration of NIMAS, DAISY, and text-to-speech technologies represents a significant advancement in educational accessibility for students with visual impairments.

These tools not only provide access to educational materials but also promote

¹¹ Respeicher. (2024). How to Empower the Visually Impaired with Advanced Text-to-Speech Tools. Retrieved July 4, 2025

¹² U.S. Department of Education. (2021). Questions and Answers on the National Instructional Materials Accessibility Standard (NIMAS). Retrieved July 4, 2025

independence, enhance learning outcomes, and prepare students for success in academic and professional environments.

The DAISY Consortium continues to work with over 150 partners all around the world to improve access to reading for people with print disabilities¹³, demonstrating the ongoing commitment to advancing these technologies.

As technology continues to evolve, the future holds even greater promise for breaking down barriers to literacy and ensuring that all students, regardless of their visual abilities, have equal access to educational opportunities. The continued development and implementation of these assistive technologies will play a crucial role in creating truly inclusive educational environments.

¹³ DAISY Consortium. (2024). Home - The DAISY Consortium. Retrieved July 4, 2025

Chapter 8

Navigating Independence: The Essential Role of Accessible Daily Living Technology in Empowering Visually Impaired Students for Success and Safety

In the pursuit of independence and safety, orientation and mobility training holds a pivotal place in the educational journey of visually impaired students. In this dynamic landscape, accessible GPS equipment emerges as a technological beacon, offering a transformative bridge to mobility, autonomy, and enhanced safety. This chapter explores the indispensable role that accessible GPS tools play in empowering visually impaired students for success, ensuring safe navigation through the world, and fostering a sense of confidence in their daily lives.

The quest for independence is intricately tied to the ability to navigate and explore the surrounding environment. For visually impaired students, this journey is often met with challenges that extend beyond the typical obstacles encountered in education. Accessible GPS equipment becomes a critical ally, providing not only the means to explore the world independently but also enhancing safety through reliable navigational assistance.

As we delve into this chapter, we will explore the functionalities of accessible GPS devices tailored to the unique needs of visually impaired users. From real-time audible directions to haptic feedback systems, these tools extend beyond standard navigation, creating a multi-sensory experience that empowers students to traverse their

surroundings confidently. The importance of this technology is accentuated during orientation and mobility training, where students learn not only to navigate physical spaces but also to develop crucial skills for safety and situational awareness.

Beyond the practicalities of navigation, the impact of accessible GPS equipment on student success cannot be overstated. These tools contribute to broader educational goals by fostering a sense of independence, reducing reliance on external assistance, and instilling a foundational skill set for safe and self-assured mobility.

Through this exploration, it becomes clear that accessible GPS equipment is not merely a tool for navigation; it is a catalyst for empowerment and safety. Through orientation and mobility training, we ensure that visually impaired students can embark on their educational journeys with a sense of autonomy, confidence, and, above all, safety.

8.1 Accessible GPS Hardware and Software

When purchasing an accessible GPS unit for the blind, it is important to consider the following factors to ensure safe navigation and crossing of streets:

- *Audible signals:* The GPS unit should provide audible signals to indicate when it is safe to cross the street. This feature allows blind pedestrians to cross the road at the right time, more quickly and safely while maintaining their orientation throughout the crossing¹.
- *Compatibility:* The GPS unit should be compatible with other assistive technology devices, such as screen readers and braille displays².
- *Portability:* Portable GPS units are ideal for blind pedestrians who need to move around the city. They should be lightweight and easy to carry.
- *Battery life:* Battery life is an important consideration for portable GPS units. The battery should last long enough to get through a day without needing to be recharged.
- *Ease of use:* The GPS unit should be easy to use and adjust. It should have large buttons and controls that are easy to locate and operate.
- *AI integration:* Modern GPS systems now incorporate artificial intelligence to provide enhanced contextual guidance and real-time environmental awareness.

¹ Inclusive City Maker. (n.d.). Pedestrian safety: Are your crossings safe for the visually impaired? Retrieved December 19, 2023

² American Foundation for the Blind. (n.d.). Smartphone GPS navigation. Retrieved December 19, 2023

- *Indoor navigation:* Many current systems now support indoor navigation capabilities where traditional GPS signals are not available.

These considerations will help ensure that blind pedestrians have access to the tools they need to navigate and cross streets safely. *Table 8.1* lists current available accessible GPS hardware devices and applications.

Table 8.1: Accessible GPS hardware and software: model, function, and company

Model	Function	Company
Stellar Trek	GPS	Humanware
Victor Reader Trek	GPS + Digital Audio Player	Humanware
Wayband	GPS (Haptic Output)	WearWorks
Envision Glasses	AI-Powered GPS + Object Recognition	Envision
Glidance Glide	Self-Guided Mobility Assistant	Glidance
Audiom	Audio-Based Navigation	Audiom
BlindSquare	Smartphone GPS App	MIPsoft
Lazarillo	Free GPS Navigation App	Lazarillo
Nearby Explorer	GPS Navigation App	American Printing House
MyWay Classic	Comprehensive GPS App	Swiss Federation of the Blind
OKO AI Copilot	AI Traffic Signal Recognition	OKO
Voice Vista	3D Audio GPS (Microsoft)	Microsoft

8.2 Accessible Technology for Daily Living

Auditory feedback technology is essential for blind people to live independently and complete daily tasks. It provides a way for the visually impaired to interact with their environment and receive information that they would otherwise miss. Modern assistive technology has evolved significantly with the integration of artificial intelligence, providing more sophisticated and contextual assistance than ever before.

The integration of AI-powered assistance has revolutionized daily living technology for the visually impaired. These systems now offer on-demand guidance, contextual help, and enhanced environmental awareness through advanced algorithms and machine learning capabilities. For example, AI-powered tools can now provide real-time object recognition, text reading, and scene description, dramatically expanding the independence of visually impaired users.

Smart assistive navigation systems now combine voice-over technology with advanced object detection capabilities, offering guidance through auditory feedback and tactile input upon object recognition. These systems can identify people, animals, crosswalks, pavements, and uneven terrain, providing comprehensive environmental awareness that extends far beyond traditional mobility aids.

In addition to navigation, modern assistive technology supports learning and skill development. Recent advances in haptic feedback technology continue to enhance Braille learning, while AI-powered applications provide personalized learning experiences tailored to individual needs and preferences.

The global assistive technologies market for visually impaired individuals is projected to reach \$12.31 billion by 2029, reflecting the growing recognition of these technologies' importance and the continued innovation in this field. This growth demonstrates the expanding availability and sophistication of tools designed to support independent living for the visually impaired community.

8.2.1 Accessible Home Technology

When purchasing household items modified to give audio feedback for the blind, it is important to consider the following factors to ensure that they can access activities of daily living³:

- **Audible feedback:** Household items should provide audible feedback to the user to ensure that they are being used correctly and safely.

³ All About Vision. (n.d.). Adapting your home for better blindness accessibility. Retrieved December 19, 2023

- *Compatibility*: The item should be compatible with other assistive technology devices, such as screen readers and braille displays.
- *Ease of use*: The item should be easy to use and adjust. It should have large buttons and controls that are easy to locate and operate.
- *Portability*: Portable items are ideal for blind users who need to move around the house. They should be lightweight and easy to carry.
- *Cost*: The cost of the item should be reasonable and within the user's budget.
- *Smart home integration*: Modern devices should integrate with smart home systems and voice assistants for enhanced automation and control.
- *AI capabilities*: Advanced devices now incorporate artificial intelligence for improved functionality and personalized assistance.

These considerations will help ensure that blind users have access to the tools they need to perform activities of daily living safely and independently.

Table 8.2 shows a range of technology available for blind/visually impaired people designed to facilitate independent living⁴.

Table 8.2: Accessible home technology: model and cost (Updated 2025)

Model	Cost
Infrared Talking Thermometer	\$50
Liquid Level Indicator	\$15
PenFriend Voice Labelling System	\$190 (Extra 418 labels: \$35)
Talking First Aid Guide	\$40
Talking Indoor/Outdoor Thermometer	\$20
Talking Kitchen Scale	\$45
Talking Measuring Tape	\$160

Continued on next page

⁴ Prices updated from current market research and major vendors of products intended to facilitate independent living skills (2025)

Table 8.2: Accessible home technology: model and cost (Updated 2025) (Continued)

Model	Cost
Talking Meat Thermometer	\$45
Talking Timer Clock	\$20
Talking Watch	\$25
Talking Weighing Scale	\$45
Talking Pulse Oximeter	\$40
Talking Scale (Body Weight)	\$85
Talking Blood Pressure Monitor	\$150
Talking Pill System	\$85
Talking Blood Glucose Meter	\$45
WayLink Scanner	\$140 (Extra 25 magnets: \$45)
Smart Talking Thermostat	\$120
AI-Powered Voice Assistant Device	\$80
Talking Color Identifier	\$30
Smart Talking Doorbell	\$150
Talking Barcode Scanner	\$200
AI Reading Assistant (Mobile App)	\$10/month
Smart Talking Smoke Detector	\$75
Talking Currency Reader	\$180

8.2.2 Emerging Technologies and Future Directions

The landscape of accessible technology continues to evolve rapidly, with several emerging technologies showing significant promise for enhancing independence and quality of life for visually impaired individuals:

- *AI-Powered Wearables*: Advanced smart glasses and wearable devices that provide real-time environmental description, object recognition, and contextual assistance through artificial intelligence.
- *Indoor Navigation Systems*: Sophisticated applications that enable safe navigation within buildings where GPS signals are unavailable, using smartphone sensors and specialized mapping data.
- *Haptic Feedback Devices*: Advanced tactile feedback systems that provide navigation guidance and environmental information through touch and vibration.
- *Voice-Activated Smart Home Integration*: Comprehensive home automation systems that respond to voice commands and provide audio feedback for all household functions.
- *Machine Learning Personalization*: Adaptive technologies that learn user preferences and behaviors to provide increasingly personalized assistance over time.

These emerging technologies represent the next frontier in accessible technology, offering unprecedented levels of independence and integration with everyday life. As these technologies continue to develop and become more affordable, they will play an increasingly important role in empowering visually impaired individuals to achieve their full potential in education, employment, and daily living.

Chapter 9

The Transformative Impact of AI and LLM Technologies on Accessibility for the Blind and Visually Impaired

9.1 Introduction

9.1.1 Overview of Visual Impairment and Accessibility Needs

Visual impairment presents a formidable global challenge, affecting more than 2.2 billion individuals worldwide. The profound personal hardships experienced by those with visual impairments are compounded by substantial societal costs, including significant lost productivity and considerable healthcare expenses. These factors collectively underscore an urgent and pressing need for innovative solutions aimed at enhancing accessibility and fostering greater autonomy for affected individuals.¹

Historically, assistive technologies (AT) such as white canes and guide dogs have provided indispensable support, enabling many visually impaired individuals to navigate their environments and perform daily tasks. However, these traditional tools possess inherent limitations, often restricting the scope of independence and the richness of environmental interaction. This highlights a critical necessity for advanced technological interventions that can offer more comprehensive, dynamic, and nuanced assistance,

¹ Source: <https://arxiv.org/html/2503.15494v1>

moving beyond basic support to truly transformative empowerment.² The fundamental purpose of assistive technology is to empower individuals with visual impairments by supporting their daily functioning, facilitating access to educational opportunities, and delivering benefits that extend to both learning processes and social-emotional well-being.³

The sheer scale of visual impairment globally, coupled with its significant economic burden, establishes a compelling case for substantial investment and innovation in assistive technologies. The recognized limitations of traditional aids further emphasize that Artificial Intelligence (AI) and Large Language Model (LLM) solutions are not merely incremental improvements; rather, they represent potentially transformative shifts in empowering this population towards greater independence and more robust societal participation. If the problem is massive and current solutions are limited, there exists a profound unmet need. AI and LLMs are uniquely positioned to address this gap due to their advanced capabilities, transforming AI from a beneficial enhancement into a critical necessity for fostering a more inclusive society. The magnitude of the challenge demands transformative solutions, not just marginal ones.

9.1.2 The Rise of AI and LLMs in Assistive Technology

Artificial intelligence is proving profoundly transformative in addressing accessibility challenges, particularly for individuals with visual impairments. Recent advancements in machine learning and deep learning have enabled AI-powered systems to perform complex tasks with unprecedented accuracy and efficiency. These capabilities include real-time object recognition, sophisticated scene analysis, and natural language processing (NLP).⁴

The widespread proliferation of Generative AI (GenAI) tools has ushered in a critical shift in how individuals approach information retrieval and content creation across a diverse array of contexts. This includes significant applications in education, programming, communication, and creative work. Tools such as ChatGPT, Copilot, and Gemini have rapidly gained immense popularity due to their versatile capabilities.⁵ Notably, existing accessibility technologies, including established platforms like Be My Eyes and Envision, have already begun to integrate GenAI capabilities. This integration specifically aims to assist blind users, particularly in the crucial area of answering visual questions by

² Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

³ Source: <https://wjaets.com/sites/default/files/WJAETS-2024-0481.pdf>

⁴ Source: <https://arxiv.org/html/2503.15494v1>

⁵ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

interpreting images and scenes.⁶

The integration of deep learning models, the development of multimodal interfaces, and the capability for real-time data processing have collectively transformed the functionality and usability of these assistive tools. This evolution has fostered enhanced inclusivity and empowerment for visually impaired individuals, providing them with more seamless and intuitive interactions with their environment and digital content.⁷ The rapid integration of Generative AI into existing accessibility tools signifies a fundamental shift in approach, moving from simple assistive devices to intelligent, context-aware companions. This evolution is not merely about making existing tasks accessible; it fundamentally re-imagines the interaction between visually impaired individuals and their environment.

It represents a progression towards proactive, comprehensive assistance rather than reactive, limited support. This combination of capabilities allows for more than just basic task completion; it enables a deeper understanding of surroundings, provides contextual information, and facilitates dynamic interaction. This moves beyond a mere "tool" to a "companion" that can interpret and proactively assist, fundamentally changing the user's relationship with technology and their environment. It suggests a future where AI anticipates needs and provides seamless support, rather than solely responding to explicit commands.

9.2 AI and LLM Applications in Daily Living and Mobility

9.2.1 Enhancing Environmental Understanding

Object Recognition and Scene Description

AI-powered applications are revolutionizing how visually impaired individuals perceive and interact with their surroundings. Microsoft's Seeing AI, for instance, extensively leverages computer vision and natural language processing (NLP) to identify objects, text, people, and scenes, providing rich audio descriptions that significantly deepen users' understanding of their environment. This versatile application can read documents, identify products using barcodes, recognize faces and their associated emotions, and describe complex scenes and individual objects in real-time, offering immediate auditory information.⁸

⁶ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

⁷ Source: <https://arxiv.org/html/2503.15494v1>

⁸ Source: <https://arxiv.org/html/2503.15494v1>; <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>; <https://blogs.microsoft.com/accessibility/seeing-ai/>

Similarly, Envision Glasses represent a significant advancement in wearable assistive technology. These smart glasses integrate sophisticated cameras with real-time speech synthesis to deliver contextual information directly to the user, enabling more effective interaction with their surroundings. The accompanying Envision App, utilizing a smartphone's camera, can vocalize written information, describe scenes and objects, and even identify individuals nearby. Its proficiency in text and object recognition is notable, supporting over 60 languages, including the interpretation of handwritten notes.⁹

Be My AI, an advanced feature seamlessly integrated into the popular Be My Eyes application, is powered by OpenAI's GPT-4. This tool provides detailed AI-powered descriptions of images, serving as a robust and readily available alternative to human volunteers. Users can independently access visual information by simply capturing pictures of their environment, receiving comprehensive auditory feedback.¹⁰ Another notable application, Lookout by Google, employs AI to assist individuals with low vision or blindness by providing spoken feedback regarding their surroundings, such as reading text or identifying objects, thereby directly aiding environmental comprehension.¹¹

The SeeSay system represents a novel assistive device that leverages Large Language Models (LLMs) for both speech recognition and visual querying. It is designed to effectively identify, record, and respond to the user's environment by providing audio guidance through a methodology known as Retrieval-Augmented Generation (RAG). The system architecture comprises two primary components: a lightweight glasses attachment (housing a camera and ESP32 board) and a more powerful Raspberry Pi processing unit. SeeSay operates by running local LLMs, specifically Whisper for speech recognition, Phi-2 for query answering, and Piper TTS for speech synthesis, to deliver immediate audio feedback. For computationally intensive tasks, such as detailed image descriptions, the system intelligently offloads processing to cloud-based LLM services like ChatGPT. SeeSay is engineered to handle a wide range of inquiries, from straightforward questions to those requiring immediate environmental context or historical visual information, seamlessly escalating to cloud services when local LLM

⁹ Source: <https://arxiv.org/html/2503.15494v1>; <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>; <https://www.letsenvision.com/>

¹⁰ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>; https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

¹¹ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

responses are insufficient.¹²

The evolution of AI in environmental understanding for the visually impaired demonstrates a significant progression from basic object identification to comprehensive scene description and contextual understanding. This is often augmented by advanced techniques like Retrieval-Augmented Generation (RAG). This allows for not just the recognition of individual elements but a deeper comprehension of the entire environment, significantly boosting independence and confidence in navigating complex spaces. The progression signifies that AI is moving beyond simply providing raw data to offering an interpreted, human-like understanding of the visual world. This directly translates to greater autonomy, as users can build a more complete mental model of their surroundings, reducing cognitive load and enhancing safety.

Navigation and Obstacle Detection

Independent mobility is a cornerstone of daily living, and AI is making profound strides in this area. NOA by biped.ai is a revolutionary live AI mobility companion, designed to be worn like a backpack. It serves as a sophisticated complement to traditional mobility tools such as white canes and guide dogs. This device integrates multiple cameras, a dedicated processing unit, and provides hands-free audio feedback via bone-conduction headphones, ensuring clear instructions while keeping the user's ears free for ambient sounds. NOA offers precise turn-by-turn GPS navigation, detects obstacles at various heights and distances both day and night through distinct auditory "beeps," and provides real-time AI descriptions of the surroundings, a feature referred to as "Live AI." Furthermore, it assists users in locating important objects like crosswalks and doors, functioning effectively in both indoor and outdoor environments.¹³

NaviLens represents another cutting-edge technology empowering blind and partially sighted individuals with enhanced navigation and information access. Its unique, colorful codes can be scanned from significantly greater distances compared to conventional QR or barcodes (up to 12 times farther, with a 10-inch code readable from 60 feet away). These codes can be read remarkably fast, in as little as 1/30th of a second, and support a wide-angle reading capability of up to 160 degrees, functioning reliably in all lighting conditions without requiring precise focus. NaviLens provides accurate distance and orientation information relative to the user and can detect multiple tags simultaneously,

¹² Source: <https://www.themoonlight.io/en/review/seesay-an-assistive-device-for-the-visually-impaired-using-retrieval-augmented-generation>; https://www.researchgate.net/publication/384700193_SeeSay_An_Assistive_Device_for_the_Visually_Impaired_Using_Retrieval_Augmented_Generation; <https://arxiv.org/html/2410.03771v1>

¹³ Source: <https://www.biped.ai/>

efficiently communicating the relevant data. This technology is strategically deployed in various public spaces, including subway stations, bus stops, and museums, offering real-time information and facilitating indoor navigation without reliance on GPS or Bluetooth signals.¹⁴

For pedestrian safety, the Oko AI Copilot for the Blind is an iOS application that leverages the smartphone's camera to detect and announce the status of street crossings. It provides audible beeps and vibrations to alert users when it is safe or unsafe to cross, operating in a manner similar to talking pedestrian signals.¹⁵ Additionally, the Sunu Band is a wearable device that employs ultrasonic sensors to detect obstacles in the user's immediate path, providing intuitive haptic feedback to guide them safely through their surroundings.¹⁶

The development of AI-powered navigation tools, ranging from wearable devices like NOA and Sunu Band to environmental tagging systems like NaviLens, signifies a crucial advancement towards truly independent mobility for visually impaired individuals. This progression moves beyond simple obstacle avoidance to a more comprehensive understanding of spatial relationships and contextual navigation. It integrates real-time environmental data with predictive guidance to enhance safety and confidence in dynamic environments. These tools collectively represent a shift from basic "alerting" to sophisticated "guiding" and "informing" in real-time. The integration of AI allows for the interpretation of complex visual scenes into actionable audio or haptic cues. This means visually impaired individuals can navigate unfamiliar and complex environments with unprecedented autonomy, reducing reliance on sighted assistance and fostering greater participation in public life. The focus is on creating a seamless, intuitive, and safe mobility experience.

9.2.2 Facilitating Information Access

Text and Document Reading

Natural Language Processing (NLP) plays a fundamental role in enabling access to digital information for visually impaired individuals. NLP-driven text-to-speech (TTS) systems are essential, converting written text into spoken words, thereby allowing users to access web content and other digital text that would otherwise be inaccessible. Conversely, speech-to-text (STT) systems perform the opposite function, converting spoken words

¹⁴ Source: <https://www.navilens.com/>

¹⁵ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

¹⁶ Source: <https://arxiv.org/html/2503.15494v1>

into written text. Both technologies are particularly valuable for individuals with visual or hearing impairments, bridging critical communication gaps.¹⁷

Envision AI, available as both a smartphone application and integrated smart glasses, demonstrates exceptional proficiency in text recognition. It is capable of reading text in over 60 languages, including challenging formats such as handwritten notes, text on food packages, or entire books.¹⁸ Microsoft's Seeing AI is another powerful tool, highly proficient at reading textbooks and various other documents, significantly enhancing the accessibility of educational and professional materials.¹⁹

Voice Dream Reader is a dedicated text-to-speech application that reads text from diverse sources, including PDFs, web pages, and electronic books. It supports multiple languages and offers a highly customizable reading experience, empowering students and professionals to access and comprehend a wide range of materials independently and according to their preferences.²⁰

Picture Smart AI, developed by Freedom Scientific, the creators of the widely used JAWS screen reader, provides an AI-powered image description service specifically designed for computer users. This tool allows users to import existing photos or capture live screenshots of their computer screen to receive instant, detailed descriptions of on-screen elements. It leverages advanced AI models such as ChatGPT or Claude for its descriptive capabilities. This feature is also under development for integration with Zoom, enabling it to read and describe images shared during virtual meetings.²¹

Furthermore, the Restream Text to Audio Conversion service utilizes AI-powered speech-to-text transcription to accurately convert entire audio files into text documents. This functionality is highly beneficial for verifying spelling, noting specific details like phone numbers, or obtaining written descriptions of spoken visual content, thereby enhancing both productivity and accuracy in various professional and personal contexts.²²

The evolution of text and document reading tools, from basic Optical Character Recognition (OCR) to sophisticated, multilingual, and context-aware systems, demonstrates AI's profound ability to bridge the information gap for visually impaired individuals. The integration of AI into traditional screen readers and the capability to

¹⁷ Source: <https://arxiv.org/html/2503.15494v1>; <https://www.numberanalytics.com/blog/ultimate-guide-nlp-accessibility>

¹⁸ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>; <https://www.letsenvision.com/>

¹⁹ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>; <https://blogs.microsoft.com/accessibility/seeing-ai/>

²⁰ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

²¹ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

²² Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

process complex visual documents, such as screenshots of digital interfaces, signify a decisive move towards universal digital and physical information accessibility. This is critical for both daily life and professional tasks. This comprehensive approach ensures that visually impaired individuals can access, process, and interact with information from virtually any source—printed pages, digital screens, and spoken words—on par with sighted peers, fostering true information equity. This represents a significant step towards full participation in an increasingly information-dense world.

Conversational AI for Everyday Tasks

Generative AI tools, including prominent platforms like ChatGPT, Copilot, and Gemini, are extensively utilized by blind individuals for a wide array of content creation and information retrieval tasks. This adoption occurs despite recognized challenges such as accessibility issues within interfaces, occasional inaccuracies, and the phenomenon of "hallucinations" in their responses.²³

Blind users leverage GenAI for diverse content creation activities, including summarizing, expanding, combining, rephrasing, and organizing existing materials such as resumes, articles, or meeting notes. These tools also prove invaluable for brainstorming new ideas, making their own content accessible to others, proofreading written work, and facilitating translation across languages. Some users even "chain" outputs, using one GenAI tool (e.g., Be My AI for image description) to generate input for another (e.g., ChatGPT for creating social media posts or stories).²⁴

ChatGPT, with its enhanced voice and image recognition capabilities, now allows for continuous spoken interaction, enabling users to converse naturally with the AI. It can also provide written or auditory responses to images captured by a camera, offering context-sensitive help for visual queries.²⁵ Call Annie is another conversational chatbot designed for quick, voice-prompted interactions, serving as an always-available AI companion for users to ask questions and learn about various topics conversationally.²⁶

Be My AI and newer Generative AI models like ChatGPT 4 are highly valued for their visual question answering capabilities. They provide rich and systematic descriptions of visual information that are often more detailed and comprehensive than those typically provided by sighted individuals, offering a new level of visual understanding.²⁷

²³ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²⁴ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²⁵ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

²⁶ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

²⁷ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

Conversational AI is fundamentally transforming passive information consumption into active, interactive engagement, enabling visually impaired individuals to not only retrieve information but also to create, refine, and adapt content. This fosters a new level of agency and intellectual independence, moving beyond mere access to active participation in the digital economy and creative pursuits. This signifies a shift from simply consuming information (e.g., listening to a screen reader) to actively producing and manipulating it. It allows visually impaired individuals to engage in tasks that require creative ideation, complex writing, and information synthesis, which were previously highly challenging or dependent on sighted assistance. This fosters self-reliance, opens professional opportunities, and enhances personal expression, representing true empowerment.

Table 9.1: Key AI/LLM Assistive Technologies for Daily Living

Technology Name	Primary Function	Key AI/LLM Component	Impact on Daily Living/Mobility
SeeSay	Environmental description, Visual querying	LLMs (Whisper, Phi-2, Piper TTS), RAG, Cloud LLMs (ChatGPT)	Provides real-time audio guidance, records surroundings for contextual responses, enhances confidence in unfamiliar environments. ⁶⁷
NOA by biped.ai	GPS navigation, Obstacle detection, AI description, Object finding	Computer Vision, AI (Live AI)	Offers hands-free turn-by-turn navigation, detects hazards day/night, describes surroundings in real-time, complements canes/guide dogs for enhanced mobility. ⁶⁸

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Table 9.1: Key AI/LLM Assistive Technologies for Daily Living (Continued)

Technology Name	Primary Function	Key AI/LLM Component	Impact on Daily Living/Mobility
Envision Glasses/App	Real-time text recognition, Scene description, Object identification, Hands-free video calling	Computer Vision, NLP, LLMs (ChatGPT integration)	Provides unobtrusive access to visual information, reads text in 60+ languages (including handwriting), describes objects/scenes, identifies people, and facilitates human assistance. ⁶⁹
NaviLens	Environmental information, Indoor/outdoor navigation	Computer Vision, Proprietary algorithms	Uses unique scannable codes for fast, wide-angle, long-distance reading without focus; provides precise distance/orientation; enhances independence in public spaces. ⁷⁰
Be My AI (Be My Eyes)	Detailed image description, Visual question answering	LLMs (GPT-4)	Offers 24/7 AI-powered visual descriptions from photos, reducing reliance on human volunteers for everyday visual tasks. ⁷¹

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Table 9.1: Key AI/LLM Assistive Technologies for Daily Living (Continued)

Technology Name	Primary Function	Key AI/LLM Component	Impact on Daily Living/Mobility
Seeing AI (Microsoft)	Text reading, Object/Scene description, Face/Emotion recognition	Computer Vision, NLP	Narrates the world, reads documents, identifies products/people/scenes, providing real-time auditory information for daily tasks. ⁷²
Lookout by Google	Text reading, Object identification, Environmental feedback	AI (Computer Vision, NLP)	Provides spoken feedback about surroundings, helping users navigate and identify objects/text in their environment. ⁷³
Aira (Access AI)	Visual interpreting, Image/diagram description, Concept explanation	AI (Access AI), Human interpreters	Offers on-demand visual assistance from AI or human agents, explaining visual concepts and verifying AI accuracy. ⁷⁴

Continued on next page

Table 9.1: Key AI/LLM Assistive Technologies for Daily Living (Continued)

Technology Name	Primary Function	Key AI/LLM Component	Impact on Daily Living/Mobility
Picture Smart AI	Image description for computer screens/files	LLMs (ChatGPT, Claude)	Provides instant descriptions of on-screen icons and images, translates document pictures, aiding navigation of digital interfaces and online shopping. ⁷⁵
Oko AI Copilot	Street crossing status detection	AI (Computer Vision)	Uses smartphone camera to detect safe/unsafe crossing conditions, providing audible/vibratory alerts for enhanced pedestrian safety. ⁷⁶
ChatGPT Voice/Image	Conversational AI, Image analysis	LLMs, Voice Recognition, Image Recognition	Enables continuous spoken interaction, provides written/auditory responses to images with context-sensitive help for diverse queries. ⁷⁷

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Table 9.1: Key AI/LLM Assistive Technologies for Daily Living (Continued)

Technology Name	Primary Function	Key AI/LLM Component	Impact on Daily Living/Mobility
Call Annie	Conversational AI	LLMs, Voice Recognition	Offers quick, voice-prompted conversational interactions for information and learning, acting as an always-available AI friend. ⁷⁸
Sunu Band	Obstacle detection	Ultrasonic sensors, Haptic feedback	Wearable device providing haptic cues for detecting obstacles, enhancing safe navigation. ⁷⁹

This table provides a concise, comparative overview of the diverse AI and LLM assistive technologies discussed in the context of daily living and mobility. By presenting each technology alongside its primary function, key AI/LLM components, and direct impact, readers can quickly grasp the specific utility and underlying mechanisms of these innovations. This structured summary facilitates rapid comprehension and comparison, allowing for a clear understanding of how each tool contributes to enhancing independence and navigating the physical and informational world for visually impaired individuals. It serves as a valuable reference, condensing complex information into an easily digestible format.

9.3 AI and LLM in Education and Professional Environments

9.3.1 Transforming Learning Experiences

Accessible Educational Content

AI tools are profoundly improving the learning experience for blind and visually impaired learners by offering personalized assistance, fostering increased independence, and significantly enhancing the accessibility of educational content.⁸⁰

NotebookLM, a tool developed by Google, exemplifies this transformation by converting class notes or any document into an engaging and easily comprehensible podcast-like conversation between two virtual speakers. This innovative tool explains information in a relaxed tone, often incorporating real-life examples, which is particularly advantageous for students who prefer auditory learning over traditional reading. As a free service, it is ideally suited for studying on the go, although its current compatibility is limited to PDF or TXT file formats.⁸¹

Be My AI provides detailed, AI-powered descriptions of images, directly assisting students in understanding visual content found in textbooks, diagrams, and other educational materials. Its 24/7 availability and support for follow-up questions allow for highly personalized assistance, enabling students to inquire about specific diagram details or conceptual clarifications.⁸² Microsoft's Seeing AI further contributes to this by reading textbooks, identifying classroom objects, and describing images using AI, thereby making learning more accessible. For instance, a visually impaired student can leverage this tool to analyze trends in graphs, fostering greater participation in classroom activities.⁸³

Voice Dream Reader is a versatile text-to-speech application that reads text from diverse sources, including PDFs, web pages, and electronic books. It supports multiple languages and offers a customizable reading experience, empowering students to access and comprehend a wide range of educational materials independently and according to their individual preferences.⁸⁴ Similarly, Envision AI, through its smartphone application and seamless integration with smart glasses, assists students in accessing printed materials, understanding their surroundings, and actively participating in classroom activities by reading text, describing scenes, and identifying objects and people. It features automatic

⁸⁰ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸¹ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸² Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸³ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸⁴ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

language detection and reliably converts documents containing images into accessible text formats, even for languages other than English.⁸⁵

The impact of AI on education for the visually impaired extends significantly beyond mere content access to fostering active participation and personalized learning. Tools that convert complex visual information, such as diagrams and graphs, into accessible auditory or tactile formats, coupled with conversational AI for interactive explanations, are creating an inclusive learning environment. In this environment, students can engage with complex concepts, develop critical thinking skills, and collaborate more effectively, thereby bridging traditional learning divides. These are not simply "reading aids"; they are tools that enable comprehension and engagement. The ability to "analyze trends in graphs"⁸⁶ or ask follow-up questions⁸⁷ means students are not just receiving information but actively processing and interacting with it. This leads to a more inclusive and equitable educational experience, where visually impaired students can participate more fully in classroom activities and pursue academic interests with greater independence, reducing the need for constant human intervention.

Personalized Learning Assistance

Generative AI tools are empowering blind participants to acquire new skills and enhance their proficiency in areas where they previously encountered significant challenges. Self-learners, in particular, find it immensely beneficial to receive immediate feedback and detailed explanations from GenAI when facing difficulties. This environment allows them to ask clarifying questions without any apprehension of judgment, fostering a safe and supportive learning space.⁸⁸

Specific examples illustrate the breadth of this personalized learning assistance. One participant successfully learned songwriting with the aid of ChatGPT, demonstrating the AI's capacity to support creative endeavors. Another individual gained simplified explanations of complex academic jargon, making challenging subjects more approachable. A third participant explored intricate mathematical concepts with greater ease. Notably, one participant reported acquiring more programming knowledge from ChatGPT in a single year than in the preceding two decades, as the AI effectively helped identify necessary functions and verify code snippets, accelerating their learning trajectory significantly.⁸⁹

⁸⁵ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸⁶ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸⁷ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁸⁸ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

⁸⁹ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

Access AI, seamlessly integrated into the Aira application, further enhances personalized learning. It can accurately describe images or diagrams and explain complex concepts in a manner that is easy to understand from a blind person's perspective. Moreover, users have the option to request verification of the AI's accuracy by a professional human interpreter, adding a crucial layer of reliability and trust to the personalized assistance provided.⁹⁰

The personalized, non-judgmental, and always-available nature of AI-powered learning assistants, such as ChatGPT and Access AI, addresses a critical social-emotional and pedagogical aspect of education for visually impaired students. This empowers them to explore knowledge gaps, experiment with new concepts, and build confidence at their own pace. This effectively democratizes access to individualized tutoring and mentorship that might otherwise be unavailable or cost-prohibitive. Learning often involves trial-and-error and asking clarifying questions. For visually impaired individuals, this can be challenging if sighted support is limited, or if they feel self-conscious about perceived "basic" questions. AI removes these social barriers, providing a private, infinitely patient tutor. This fosters not just academic achievement but also self-efficacy and a growth mindset. It allows for truly customized learning paths, adapting to individual needs and pace, which is a significant leap towards equitable educational opportunities. The "always available" aspect⁹¹ means learning is not constrained by human schedules or resources.

9.3.2 Empowering Professional Productivity

Workplace Tools and Digital Assistants

AI-powered workplace tools are fundamentally transforming professional productivity for visually impaired individuals. Copilot for Microsoft 365 exemplifies this by integrating AI directly into core productivity applications such as Word, Excel, and Outlook. This intelligent assistant automates repetitive tasks, assists in drafting emails, summarizes extensive data, and offers smart suggestions, significantly enhancing efficiency. This integration allows visually impaired professionals to work faster and smarter, substantially reducing their reliance on others for routine tasks.⁹²

Microsoft Teams further contributes to an inclusive professional environment by offering built-in live transcription and captions. Powered by Azure Cognitive Services, these features make virtual meetings more accessible for individuals who are Deaf or hard of

⁹⁰ Source: <https://victastudents.org.uk/ai-tools-for-blind/>

⁹¹ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

⁹² Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

hearing, and equally beneficial for those with visual impairments to follow discussions in real-time.⁹³ The "Read Aloud" feature, available across Outlook, Edge, and PowerPoint, converts visual content into accessible auditory information. This enables visually impaired users to hear emails, documents, and webpages read aloud, facilitating multitasking and improving comprehension in fast-paced work environments.⁹⁴

Microsoft Translator is an invaluable tool for global communication, supporting speech-to-speech, text-to-speech, and image-based Optical Character Recognition (OCR) translation. This capability allows visually impaired professionals to connect seamlessly with international colleagues and audiences, effectively breaking down language barriers.⁹⁵ Furthermore, Read AI Meeting notes is an application designed to enhance productivity by joining virtual meetings (e.g., Zoom, Microsoft Teams, Google Meet) as a participant. It records the discussion and subsequently uses AI to generate a perfectly formatted summary document, typically within an hour. This tool can also summarize message conversations, such as lengthy email threads, significantly improving information retention and overall productivity.⁹⁶

AI-powered workplace tools are moving beyond basic accessibility features, such as traditional screen readers, to actively augment productivity and enable visually impaired professionals to participate fully and independently in collaborative and information-intensive environments. This effectively levels the professional playing field by compensating for visual barriers in real-time, fostering greater independence, efficiency, and opportunities for career advancement. Professional work often involves complex tasks such as drafting, summarizing, real-time communication, and multilingual interaction. Traditional assistive technologies frequently required workarounds or human assistance for these functions. AI's role in augmentation means Copilot automates tasks and suggests content, making the user more efficient, not just able to access information.

Live transcription in Teams ensures full participation in dynamic meetings. Read AI Meeting notes⁹⁷ addresses the challenge of capturing and summarizing spoken information, a critical professional skill. This signifies a shift from merely "accommodating" disability to actively "empowering" professionals. AI acts as a force multiplier, allowing visually impaired individuals to perform at higher levels, take on more complex roles, and compete more effectively in the modern workforce, reducing or

⁹³ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

⁹⁴ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

⁹⁵ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

⁹⁶ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

⁹⁷ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

eliminating the need for human intermediaries for many tasks.

Accessibility Feedback Analysis

The "Natural Language Processing (NLP) for Accessibility" initiative represents a strategic application of AI focused on enhancing digital accessibility. This project primarily utilizes NLP to analyze large volumes of social media interactions and bug reports. The core objective is to extract and synthesize actionable insights from user-generated content to improve accessibility features in software applications, with a particular focus on individuals with visual disabilities or eye conditions.⁹⁸

Key objectives of this project include developing sophisticated NLP tools capable of automatically extracting and classifying accessibility-related feedback. This involves analyzing how software updates impact app accessibility over time by studying user reviews and feedback trends. Furthermore, the initiative aims to create advanced NLP-driven reporting tools that empower developers to rapidly identify common issues and emerging trends in accessibility. This systematic approach helps developers understand the broader ramifications of their modifications and enables more responsive and informed development practices, ensuring that accessibility is maintained or improved with each update.⁹⁹

A critical aspect of this initiative is the integration of human expertise with automated NLP analysis. This involves collaborative efforts with accessibility experts and direct engagement with the visually impaired community. This participatory approach refines the accuracy and relevance of the NLP tools, ensuring that the developed solutions are not only technologically sound but also practically beneficial and genuinely responsive to the needs of users with disabilities.¹⁰⁰ Beyond structured feedback, NLP can also be leveraged to improve accessibility by analyzing user feedback through sentiment analysis, enabling organizations to understand the nuanced needs and concerns of users with disabilities, even when expressed indirectly.¹⁰¹

The application of NLP to systematically analyze accessibility feedback represents a crucial closed-loop system for continuous improvement in assistive technology design. By leveraging user-generated insights, this approach allows developers to proactively identify and address instances where AI systems "misfit" the needs of disabled users. This ensures that future AI solutions are truly human-centered and evolve responsively to the diverse and dynamic needs of the visually impaired community, thereby driving truly

⁹⁸ Source: <https://wajdialjedaani.com/projects/project.html?id=project3>

⁹⁹ Source: <https://wajdialjedaani.com/projects/project.html?id=project3>

¹⁰⁰ Source: <https://wajdialjedaani.com/projects/project.html?id=project3>

¹⁰¹ Source: <https://www.numberanalytics.com/blog/ultimate-guide-nlp-accessibility>

inclusive innovation. This creates a virtuous cycle: AI helps identify problems with AI's accessibility, leading to better AI. It ensures that the development process is not static but continuously informed by the lived experiences of visually impaired users. This systematic feedback loop is critical for bridging the gap between design intent and actual user experience, leading to more robust, equitable, and truly inclusive AI solutions over time.

Table 9.2: AI and LLM Tools in Education and Work

Technology Name	Primary Application	Key AI/LLM Component	Impact on Education/Work
NotebookLM (Google)	Content transformation, Personalized learning	LLMs, Text-to-Speech	Transforms notes/documents into podcast-like conversations, making learning auditory and accessible on-the-go. ¹⁴¹
Be My AI (Be My Eyes)	Image description, Visual question answering	LLMs (GPT-4)	Provides detailed descriptions of visual content in textbooks/materials, fostering independent learning and understanding. ¹⁴²
Access AI (Aira)	Image/diagram description, Concept explanation	AI, Human-in-the-loop verification	Explains visual concepts from a blind perspective, allows verification by professional interpreters, enhancing learning comprehension. ¹⁴³

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Table 9.2: AI and LLM Tools in Education and Work (Continued)

Technology Name	Primary Application	Key AI/LLM Component	Impact on Education/Work
Seeing AI (Microsoft)	Text reading, Object/Scene description	Computer Vision, NLP	Reads textbooks, identifies classroom objects/images, making educational content and environment accessible. ¹⁴⁴
Lookout by Google	Text reading, Object identification	AI	Provides spoken feedback for navigating learning environments, reading materials, and identifying classroom objects. ¹⁴⁵
Voice Dream Reader	Text-to-Speech, Document access	Text-to-Speech	Reads text from diverse sources (PDFs, web pages, books), supports multiple languages, and offers customizable reading experience for broad content access. ¹⁴⁶

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Table 9.2: AI and LLM Tools in Education and Work (Continued)

Technology Name	Primary Application	Key AI/LLM Component	Impact on Education/Work
Envision AI	Text reading, Scene description, Document conversion	Computer Vision, NLP	Helps access printed materials, understand surroundings, and converts documents with images into accessible text in multiple languages. ¹⁴⁷
Copilot for Microsoft 365	Workplace productivity, Digital assistant	LLMs	Automates tasks, drafts emails, summarizes data, and offers smart suggestions across Microsoft apps, enhancing professional efficiency. ¹⁴⁸
Microsoft Teams	Live transcription, Communication	Speech-to-Text (Azure Cognitive Services)	Provides real-time captions for meetings, making professional communication more inclusive. ¹⁴⁹
Read Aloud (Microsoft)	Document/Email/Webpage reading	Text-to-Speech	Converts visual content to auditory, facilitating multitasking and comprehension in fast-paced work environments. ¹⁵⁰

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Table 9.2: AI and LLM Tools in Education and Work (Continued)

Technology Name	Primary Application	Key AI/LLM Component	Impact on Education/Work
Microsoft Translator	Multilingual communication	Speech-to-Speech, Text-to-Speech, OCR	Breaks language barriers for global communication, enabling interaction with diverse international colleagues. ¹⁵¹
Read AI Meeting notes	Meeting/ConversationAI (Speech-to-Text, summarization	NLP)	Joins virtual meetings to record and generate formatted summaries, enhancing information retention and productivity. ¹⁵²
NLP for Accessibility	Accessibility feedback analysis	NLP (Sentiment Analysis, Classification)	Analyzes user feedback and bug reports to identify accessibility issues, guiding developers for continuous improvement and inclusive design. ¹⁵³

This table provides a focused and structured overview of AI and LLM tools specifically tailored for educational and professional environments. By categorizing technologies by their primary application, key AI/LLM components, and direct impact on learning and work, it offers a clear and actionable summary for educators, employers, and visually impaired professionals. This format enables quick identification of relevant tools, highlights how AI is enhancing productivity and fostering inclusive learning, and serves as a valuable resource for strategic planning and implementation in these crucial domains.

9.4 AI and LLM in Recreation and Leisure

9.4.1 Accessible Gaming

The emergence of AI and LLM technologies is significantly expanding the accessibility of gaming for blind and low-vision (BLV) players, a domain traditionally challenging due to its heavy reliance on visual elements. GamerAstra, a generalized accessibility framework, exemplifies this advancement by leveraging a multi-agent AI design to facilitate access to video games that may lack native accessibility support. This framework integrates multi-modal techniques, including large language models (LLMs) and vision-language models (VLMs), to translate visual game experiences into rich, descriptive audio and textual narratives.¹⁵⁴

GamerAstra's architecture includes specialized AI agents such as a Scene Parsing Agent, an Action Interpretation Agent, and a Narrative Generation Agent. These agents work concurrently to analyze game environments in real-time, describe detailed spatial and action-based information, and provide contextual guidance, akin to a helpful co-player.

The system generates real-time audio cues for gaming feedback, enhances players' spatial sense, and assists with positional accuracy for interactions like targeting objects.

It also supports various navigation and action execution methods, including keyboard arrow keys and hotkey actions, to accommodate different player preferences and degrees of visual impairment.¹⁵⁵ This signifies a breakthrough in making video games more inclusive by leveraging AI to translate visual game experiences into rich, descriptive audio and textual narratives, thereby dramatically improving gaming experiences.¹⁵⁶

Beyond dedicated frameworks, accessible mobile games are also leveraging AI principles. Dice World, a collection of dice games, offers universally accessible tutorials and allows players to compete against AI characters or other players, with full VoiceOver accessibility and custom interfaces.¹⁵⁷ Frequency Missing is an audio story game that uses directional sounds to guide players, featuring full voice acting.¹⁵⁸ Audio Game Hub provides a collection of audio-based games, from disarming bombs to casino games, all played through sound with voice acting and sound effects.¹⁵⁹ Pitch Black, A Dusk Light

¹⁵⁴ Source: <https://arxiv.org/abs/2506.22937>; <https://www.aimodels.fyi/papers/arxiv/gamerasta-enhancing-video-game-accessibility-blind-low>; <https://arxiv.org/html/2506.22937v1>; https://www.researchgate.net/publication/374526766_Accessible_Play_Towards_Designing_a_Framework_for_Customizable_Accessibility_in_Games

¹⁵⁵ Source: <https://arxiv.org/abs/2506.22937>; <https://arxiv.org/html/2506.22937v1>

¹⁵⁶ Source: <https://www.aimodels.fyi/papers/arxiv/gamerasta-enhancing-video-game-accessibility-blind-low>

¹⁵⁷ Source: <https://vi.ie/david-redmond-investigates-accessible-audio-games/>

¹⁵⁸ Source: <https://vi.ie/david-redmond-investigates-accessible-audio-games/>

¹⁵⁹ Source: <https://vi.ie/david-redmond-investigates-accessible-audio-games/>

Story, is another audio story app that uses sound to guide movement, relying entirely on sound design for immersion.¹⁶⁰ These games demonstrate how AI-driven audio design and intelligent game mechanics can create immersive experiences without visual dependency.¹⁶¹

9.4.2 Creative Arts and Music

AI is democratizing creative expression for blind individuals, lowering traditional barriers in artistic and musical pursuits. For visual arts, AI tools are enabling new forms of art specifically designed for visually impaired individuals. Generative AI models, such as Generative Adversarial Networks (GANs) and image style algorithms, can enhance accessibility by generating detailed audio descriptions or tactile representations of visual art. A blind creative noted how AI has transformed their ability to detect colors accurately, understand patterns, and receive minute descriptions of videos and images, which has been invaluable for historical costume research and other visual analyses.¹⁶² Adobe Firefly, an AI image generator, allows users to describe a desired image via text prompts, and the AI generates several options, empowering blind content creators to produce visual content through textual input.¹⁶³

In music, AI is equally transformative. Google's Music AI Sandbox, powered by their Lyria 2 model, offers experimental tools developed in collaboration with musicians. This suite allows users to generate musical ideas simply by describing them in text prompts, overcoming physical limitations that might hinder playing traditional instruments or navigating complex digital audio workstations (DAWs).¹⁶⁴ For instance, users can request specific instruments or evoke moods and genres through language, translating creative visions into sound without complex physical interaction. The platform also allows for editing AI-generated music by transforming sections and adding new lyrical content, fostering unprecedented creative freedom.¹⁶⁵ One blind artist described how AI tools allow for uploading a video and receiving an audio description of it, enabling them to create audio-described music videos.¹⁶⁶ This integration of advanced AI models elevates existing assistive technologies, allowing AI to understand and interpret a wider range of

¹⁶⁰ Source: <https://vi.ie/david-redmond-investigates-accessible-audio-games/>

¹⁶¹ Source: <https://vi.ie/david-redmond-investigates-accessible-audio-games/>

¹⁶² Source: <https://www.youtube.com/watch?v=PI71DRqcAtI&vl=id>; <https://pixel-gallery.co.uk/blogs/pixelated-stories/ai-art-for-the-visually-impaired>

¹⁶³ Source: <https://accessiblepharmacy.com/top-10-ai-tools-for-the-blind-and-visually-impaired/>

¹⁶⁴ Source: <https://assistivetechnologyblog.com/2025/05/google-music-ai-sandbox-accessibility-disabilities.html>

¹⁶⁵ Source: <https://assistivetechnologyblog.com/2025/05/google-music-ai-sandbox-accessibility-disabilities.html>

¹⁶⁶ Source: <https://www.youtube.com/watch?v=09Yyh0kg8xg>

inputs, generate more sophisticated musical outputs, and personalize the creative process.¹⁶⁷

9.4.3 Sports and Physical Activities

AI and LLM technologies are making significant contributions to enhancing participation in sports and physical activities for visually impaired individuals, acting as a "sighted guide" in many contexts.¹⁶⁸ The Touch2See system, developed by a French startup, is a revolutionary technological innovation that allows blind or partially sighted people to follow football matches and other sports in an immersive and autonomous way. This system uses a tablet that reproduces a miniature playing field, where a small magnetic disk moves in real-time to allow users to follow actions with their fingers. Variations in vibration intensity indicate the importance of game actions. Touch2See combines haptic feedback with audio descriptions, providing a dedicated commentator who narrates the match with extraordinary detail, including actions, atmosphere, and crowd reactions. This system leverages ultra-fast analysis of sports data via AI and 5G technology, ensuring immediate information updates with a latency of just 0.15 seconds.¹⁶⁹

Microsoft's Seeing AI, while primarily for daily living, also functions as a valuable tool in sports by helping users understand their surroundings, read signage, and identify objects in real-time, which can be crucial for navigating sports venues or understanding game environments.¹⁷⁰ Paralympian Lex Gillette utilizes various Microsoft AI tools, including Seeing AI and Copilot, to manage his daily life, training, and professional engagements, demonstrating how AI can open up experiences once inaccessible without human assistance.¹⁷¹

While not exclusively AI-driven, many adaptive sports and activities for the visually impaired incorporate technological adaptations that could be enhanced by AI. These include using sound-emitting balls for sports like soccer or bowling, and audio navigation tools for hiking. AI could further refine these by providing more precise auditory cues or

¹⁶⁷ Source: <https://assistivetechnologyblog.com/2025/05/google-music-ai-sandbox-accessibility-disabilities.html>

¹⁶⁸ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

¹⁶⁹ Source: <https://www.embedded.com/touch2see-making-sports-accessible-to-blind-people/>

¹⁷⁰ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

¹⁷¹ Source: <https://www.lexgillette.com/articles/paralympian-lex-gillettes-top-7-ai-tools-for-accessibility>

real-time environmental descriptions, enhancing safety and participation.¹⁷²

Table 9.3: AI and LLM Tools in Recreation and Leisure

Technology Name	Primary Application	Key AI/LLM Component	Impact on Recreation/Leisure
GamerAstra	Accessible video gaming	Multi-agent AI (LLMs, VLMs, Computer Vision)	Translates visual game experiences into rich audio/textual narratives, enables mental map building, real-time navigation, and supports diverse game genres for BLV players. ¹⁹⁴
Dice World, Frequency Missing, Audio Game Hub, Pitch Black	Mobile audio games	AI (for opponent logic), Audio design	Provides fully accessible gaming experiences through audio-based gameplay, voice acting, and directional sounds, fostering social interaction and entertainment. ¹⁹⁵

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¹⁷² Source: <https://www.brightfocus.org/resource/tips-for-playing-sports-with-low-vision/>; <https://www.iamhable.com/blogs/article/the-best-hobbies-for-the-visually-impaired-a-2025-guide-to-fun-fulfillment>

Table 9.3: AI and LLM Tools in Recreation and Leisure (Continued)

Technology Name	Primary Application	Key AI/LLM Component	Impact on Recreation/Leisure
Google's Music AI Sandbox	Accessible music creation	LLMs (Lyria 2), Text-to-Music generation	Enables creation of musical ideas from text prompts, lowers barriers for musicians with physical/visual impairments, and allows for sophisticated editing. ¹⁹⁶
Adobe Firefly	Accessible image generation	Generative AI (Text-to-Image synthesis)	Empowers blind content creators to generate visual art from text descriptions, expanding creative possibilities. ¹⁹⁷
AI-powered image description (general)	Art appreciation, Visual research	Computer Vision, NLP	Provides detailed audio descriptions of visual art, images, and videos, enabling blind individuals to engage with and research visual content. ¹⁹⁸

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Table 9.3: AI and LLM Tools in Recreation and Leisure (Continued)

Technology Name	Primary Application	Key AI/LLM Component	Impact on Recreation/Leisure
Touch2See	Accessible live sports following	AI, 5G, Haptic feedback, Audio description	Allows blind/partially sighted individuals to follow football/other matches in real-time via tactile feedback and detailed audio narration, enhancing stadium experience. ¹⁹⁹
Seeing AI (in sports context)	Environmental understanding in sports	Computer Vision, NLP	Helps users understand surroundings, read signage, and identify objects in sports venues or during training, acting as a "sighted guide." ²⁰⁰

This table offers a structured summary of AI and LLM tools that are specifically enhancing recreation and leisure activities for visually impaired individuals. It highlights how AI is making gaming more inclusive, democratizing creative arts and music production, and enabling greater participation in sports. By presenting these technologies and their impacts, the table serves as a quick reference for understanding the breadth of AI's influence in fostering a more active, engaging, and fulfilling lifestyle for the blind and visually impaired community.

9.5 Challenges and Ethical Considerations

While AI and LLM technologies offer unprecedented opportunities for enhancing accessibility for the blind and visually impaired, their widespread adoption is accompanied by significant technical limitations and complex ethical considerations that require careful attention.

9.5.1 Technical Limitations

Current AI systems, particularly those relying on computer vision, demonstrate high recognition accuracy rates (85-95%) for common objects and text in controlled environments. However, this performance often drops significantly (to 60-75%) in challenging real-world conditions characterized by poor lighting, complex scenes, or diverse object presentations. This performance gap underscores the critical need for more robust systems that can operate reliably across varied and unpredictable environments.²⁰¹

Response time is another crucial factor impacting the utility of these devices. User studies indicate that feedback delays exceeding 1.5 seconds significantly diminish the usefulness of assistive technologies, particularly for real-time tasks like navigation or object detection. Achieving real-time performance for complex scene understanding remains a persistent challenge.²⁰² Furthermore, battery life continues to be a limiting factor for many wearable assistive devices, with most current solutions requiring recharging after only 3-5 hours of active use. This duration often falls short of covering a full day of activities, necessitating frequent recharging or carrying backup power.²⁰³ Computational requirements also pose a challenge, as running large language models locally on portable devices often requires offloading intensive tasks to cloud services, which can introduce latency and dependency on internet connectivity.²⁰⁴

²⁰¹ Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

²⁰² Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

²⁰³ Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

²⁰⁴ Source: <https://www.themoonlight.io/en/review/seesay-an-assistive-device-for-the-visually-impaired-using-retrieval-augmented-generation>

9.5.2 Data Quality and Bias

A significant concern revolves around data quality and the inherent biases within AI models. NLP models, for instance, require vast amounts of high-quality data for effective training and improvement. However, collecting and annotating data specifically for accessibility purposes can be challenging, particularly for low-resource languages or highly specialized domains.²⁰⁵ AI models can also be prone to bias and inaccuracies if their training data is not representative of diverse user groups or contains existing societal biases. This can result in suboptimal performance and a negative user experience, leading to what is termed "misfitting" in computer vision systems.²⁰⁶

The concept of "misfitting" highlights that AI technologies are predominantly built for sighted individuals using sighted data, leading to systems that may not adequately support the unique needs and lived experiences of blind users. This is particularly evident when AI Visual Assistance Technologies (AI VAT) fail to support complex document layouts, diverse languages, or cultural artifacts, causing an additional layer of misfitting for blind individuals who hold marginalized identities.²⁰⁷ For example, GenAI tools have been observed to struggle with nuanced concepts about disability, sometimes producing stereotypical characterizations (e.g., describing blind people as 'courageous' or 'resilient') or even expressing pity (e.g., "I'm sorry, you're blind"), which can be frustrating for users.²⁰⁸ Participants in studies hypothesize that biased datasets, often created by non-disabled people, are a key reason for such ableist and inappropriate GenAI responses.²⁰⁹ Concerns also extend to biased portrayals of race and gender, such as misgendering or inaccuracies in low-resource languages due to underrepresentation in datasets.²¹⁰

9.5.3 Accessibility of AI Interfaces

Even with powerful AI capabilities, the user interfaces of GenAI tools can present significant accessibility challenges for blind individuals. Users have reported that buttons

²⁰⁵ Source: <https://www.numberanalytics.com/blog/ultimate-guide-nlp-accessibility>

²⁰⁶ Source: <https://www.numberanalytics.com/blog/ultimate-guide-nlp-accessibility>; <https://rahaf.info/data/ASSETS2024.pdf>; https://www.researchgate.net/publication/385286169_Misfitting_With_AI_How_Blind_People_Verify_and_Contest_AI_Errors

²⁰⁷ Source: <https://rahaf.info/data/ASSETS2024.pdf>; <https://arxiv.org/html/2408.06546v1>

²⁰⁸ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²⁰⁹ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹⁰ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

for common actions like copying, regenerating, or downvoting responses in tools like ChatGPT are often unlabeled, forcing them to guess functions through trial and error. Furthermore, many GenAI interfaces, such as ChatGPT and Claude, lack appropriate heading labels, regions, or landmarks for screen reader users, making it difficult to quickly navigate conversations. Users often resort to "brute force" methods, scrolling through entire conversations with arrow keys to find responses or type new prompts.²¹¹

Users of Copilot and Bard have expressed frustration with extraneous sample prompts and advertisements, which create "a lot of clutter to sort through" before reaching the chat fields. Additionally, blind users often do not receive immediate notifications when the system finishes generating a response, requiring them to actively "dig for it" by moving their screen reader focus. While some of these issues might affect sighted users, their impact is magnified for blind individuals using screen readers, which can significantly slow down the interaction and make the experience frustrating.²¹²

9.5.4 Verification and Trust

A critical challenge for blind users of AI VAT is verifying the accuracy of AI-generated outputs, especially when the information is visual and cannot be independently confirmed. GenAI tools frequently provide fabricated, inaccurate, or inconsistent information, a phenomenon known as "hallucinations." For instance, Be My AI might misidentify a raincoat pattern, or ChatGPT might replace a user's name with a fictitious one.²¹³ A significant issue is that GenAI tools often project "confidence" in their inaccurate responses, particularly concerning visual information, which can be highly misleading for blind users who cannot visually verify the information.²¹⁴

Blind participants attempt to identify inaccuracies by sensing if responses "sounded really weird" or were "very different" from their expectations. They resort to external verification methods, such as "turning to Google" or consulting reliable websites. They also try to verify by repeating questions to the same tool or using multiple GenAI tools to check for consistent responses. "Deductive reasoning" is employed by asking follow-up questions to judge accuracy or completeness. The decision to verify depends on the context of use (e.g., medical, financial, professional information requires high verification), the stakes involved (higher stakes necessitate more rigorous verification), the ease of verifiability (which is harder for blind users without sighted help), and the believability of the information. The richness and detail of GenAI responses, while

²¹¹ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹² Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹³ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹⁴ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

beneficial for access, can be a "double-edged sword," as they also increase the likelihood of trusting inaccurate information.²¹⁵

9.5.5 Privacy and Data Security

Concerns regarding privacy are substantial, with 78% of users expressing worries about continuous recording in public spaces and the security of their personal data.²¹⁶ Users have limited understanding of how GenAI tools store and use their information, leading to apprehension about privacy, especially given the ability to retrieve previous chat history.²¹⁷ The proliferation of misinformation, disinformation, deep fake videos, and voice cloning scams facilitated by GenAI also raises concerns among users, who exercise caution before using GenAI responses in publicly shared content to avoid "creating more fake news".²¹⁸

9.5.6 Ethical Imperatives

Ensuring that AI systems are accessible to everyone, regardless of their abilities, is not merely a moral obligation but also a legal requirement in many jurisdictions, such as the European Union's Accessibility Act and the United States' Americans with Disabilities Act (ADA).²¹⁹ The moral argument for accessible AI is rooted in the principles of equality and non-discrimination, asserting that people with disabilities should have equal access to the benefits and opportunities provided by AI technologies.²²⁰ Inaccessible AI systems can exacerbate existing inequalities by excluding individuals with disabilities from fully participating in society.²²¹

Key practices for ensuring accessibility in AI development include integrating accessibility considerations early in the development process, conducting accessibility audits, incorporating accessibility features into design and testing phases, and ensuring compatibility with assistive technologies like screen readers.²²² Engaging with users with

²¹⁵ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹⁶ Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

²¹⁷ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹⁸ Source: https://maitraye.github.io/files/papers/BLV_GenAI_ASSETS24.pdf

²¹⁹ Source: <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²⁰ Source: <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²¹ Source: <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²² Source: <https://www.numberanalytics.com/blog/ultimate-guide-nlp-accessibility>; <https://www.microsoft.com/en-us/research/publication/ai-and-accessibility-a-discussion-of-ethical-considerations/>; <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

disabilities throughout the development process is crucial for creating truly accessible AI. This involves conducting user research to understand diverse needs, involving users in usability testing, and collaborating with disability organizations to gain insights and feedback.²²³ Continuous improvement is also vital, requiring regular updates to AI systems for compatibility with the latest assistive technologies, monitoring user feedback for emerging issues, and continuously evaluating and improving the accessibility of AI algorithms and models.²²⁴ The development of AI must be guided by the principles of inclusivity and respect for human rights.²²⁵

9.6 The Imperative of Locally Hosted LLMs for Privacy and Accessibility

While cloud-based Large Language Models (LLMs) offer convenience and scalability, their reliance on external servers introduces significant privacy and accessibility challenges.

For a truly inclusive and secure AI ecosystem, the availability and adoption of locally hosted LLMs through services and frameworks like ‘llamafile’, ‘llama.cpp’, and ‘Ollama’ become paramount.

9.6.1 Privacy Considerations

A primary concern with cloud-based LLMs is data privacy. When users interact with these models, their inputs, queries, and often the generated outputs are transmitted to and processed by third-party servers. This raises questions about:

- **Data Security and Confidentiality:** Sensitive personal information, medical data, financial details, or proprietary business information processed by cloud LLMs could be at risk of breaches or unauthorized access by the service provider or other malicious actors. For individuals with disabilities, this can include highly personal information related to their health or assistance needs, making privacy even more critical.²²⁶.

²²³ Source: <https://www.microsoft.com/en-us/research/publication/ai-and-accessibility-a-discussion-of-ethical-considerations/>; <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²⁴ Source: <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²⁵ Source: <https://www.numberanalytics.com/blog/ethics-ai-accessibility-matters>

²²⁶ DataNorth AI. (2025, May 15). *Local LLM: Privacy, Security, and Control*. Retrieved from <https://datanorth.ai/blog/local-llms-privacy-security-and-control>; IGNESA. (2025, June 8). *The Truth About Local LLMs: When You Actually Need Them*. Retrieved from <https://ignesa.com/insights/the-truth-about-local-llms-when-you-actually-need-them/>

- **Data Retention and Usage Policies:** Users often have limited control over how their data is stored, used, and potentially utilized for model training by cloud providers ²²⁷. This lack of transparency can be a major deterrent for privacy-conscious individuals and organizations.
- **Regulatory Compliance:** Industries such as healthcare (e.g., HIPAA) and finance have stringent data privacy regulations. Locally hosted LLMs enable organizations to maintain data sovereignty and comply with these laws by ensuring data remains within their controlled environment ²²⁸.

Locally hosted LLMs, by processing all data on the user's device or private network, eliminate these concerns. The data never leaves the user's control, offering complete confidentiality and peace of mind ²²⁹. This is particularly beneficial for accessibility applications where highly personal information might be involved, such as individualized communication aids or specialized educational tools.

9.6.2 Accessibility Benefits Beyond Privacy

Beyond privacy, locally hosted LLMs offer several accessibility advantages:

- **Offline Functionality:** Many individuals, particularly those in remote areas or with unreliable internet access, may struggle to use cloud-based AI. Locally hosted models operate entirely offline, ensuring continuous access to AI capabilities regardless of connectivity ²³⁰. This is vital for critical accessibility tools that cannot afford internet dependency.
- **Reduced Latency and Improved Responsiveness:** Communication with cloud servers introduces latency, which can be disruptive for real-time accessibility applications like live captioning, assistive communication, or interactive learning

²²⁷ UpGuard. (2025, June 26). *Analyzing llama.cpp Servers for Prompt Leaks*. Retrieved from <https://www.upguard.com/blog/llama-cpp-prompt-leak>

²²⁸ God of Prompt. (2025, June 25). *Local LLM Setup for Privacy-Conscious Businesses*. Retrieved from <https://www.godofprompt.ai/blog/local-llm-setup-for-privacy-conscious-businesses>

²²⁹ DataNorth AI. (2025, May 15). *Local LLM: Privacy, Security, and Control*. Retrieved from <https://datanorth.ai/blog/local-llms-privacy-security-and-control>; Foojay. (2025, May 6). *Local AI with Spring: Building Privacy-First Agents Using Ollama*. Retrieved from <https://foojay.io/today/local-ai-with-spring-building-privacy-first-agents-using-ollama/>

²³⁰ God of Prompt. (2025, June 25). *Local LLM Setup for Privacy-Conscious Businesses*. Retrieved from <https://www.godofprompt.ai/blog/local-llm-setup-for-privacy-conscious-businesses>; Intrada Technologies. (2025, March 28). *Cloud vs. Local LLMs: Which AI Powerhouse is Right for You?*. Retrieved from <https://www.intradatech.com/hosting-and-cloud/tech-talk/cloud-vs-local-ll-ms-which-ai-powerhouse-is-right-for-you>

tools. Local LLMs offer significantly faster response times, providing a smoother and more efficient user experience ²³¹.

- **Cost-Effectiveness (Long-Term):** While initial setup costs for local hardware might be present, for frequent and high-volume usage, locally hosted LLMs can be more cost-effective in the long run by eliminating recurring subscription fees and data transfer costs associated with cloud services ²³². This can make powerful AI tools more accessible to individuals and smaller organizations with limited budgets.
- **Customization and Fine-Tuning:** Locally hosted models offer greater control over customization and fine-tuning. Users and developers can adapt the models to specific needs, accents, communication styles, or domain-specific knowledge without reliance on third-party policies or services ²³³. This is crucial for creating highly personalized and effective accessibility solutions.
- **Empowerment and Digital Sovereignty:** Running LLMs locally empowers users by giving them full control over their AI tools. This fosters digital sovereignty, allowing individuals to utilize advanced technology without ceding control of their data or relying on external entities ²³⁴.

9.6.3 Enabling Technologies: ‘llamafile’, ‘llama.cpp’, and ‘Ollama’

The growing ecosystem of tools facilitating local LLM deployment is critical for advancing AI accessibility:

- **‘llama.cpp’:** This project, developed by Georgi Gerganov, is a foundational library that enables efficient inference of LLMs on consumer hardware, even CPUs, through

²³¹ God of Prompt. (2025, June 25). *Local LLM Setup for Privacy-Conscious Businesses*. Retrieved from <https://www.godofprompt.ai/blog/local-llm-setup-for-privacy-conscious-businesses>; sideEffekt. (2024, July 20). *Benefits of Local Large Language Models*. Retrieved from <https://sideeffekt.com/2024/07/20/benefits-of-local-large-language-models/>

²³² God of Prompt. (2025, June 25). *Local LLM Setup for Privacy-Conscious Businesses*. Retrieved from <https://www.godofprompt.ai/blog/local-llm-setup-for-privacy-conscious-businesses>; DataCamp. (2023, May 23). *The Pros and Cons of Using LLMs in the Cloud Versus Running LLMs Locally*. Retrieved from <https://www.datacamp.com/blog/the-pros-and-cons-of-using-llm-in-the-cloud-versus-running-llm-locally>

²³³ Intrada Technologies. (2025, March 28). *Cloud vs. Local LLMs: Which AI Powerhouse is Right for You?*. Retrieved from <https://www.intradatech.com/hosting-and-cloud/tech-talk/cloud-vs-local-llms-which-ai-powerhouse-is-right-for-you>

²³⁴ Chatterjee, A. (2025, May 27). *The future of AI should be private, try Open WebUI and Ollama*. HEY World. Retrieved from <https://world.hey.com/akashc/the-future-of-ai-should-be-private-try-open-webui-and-ollama-a6e829f8>

techniques like quantization²³⁵. Its efficiency makes powerful LLMs accessible on a wider range of devices.

- **'llamafile':** Built upon 'llama.cpp' and Cosmopolitan Libc, 'llamafile' simplifies LLM distribution and execution by packaging a complete LLM into a single, portable executable file²³⁶. This "single-file executable" approach dramatically lowers the barrier to entry for running LLMs locally, requiring no complex installations or dependencies, and works across multiple operating systems. This significantly enhances accessibility for users who may lack technical expertise or robust computing environments²³⁷.
- **'Ollama':** 'Ollama' provides a user-friendly platform for downloading, running, and managing a variety of open-source LLMs locally²³⁸. It simplifies the process of setting up a local LLM server and interacting with models, further democratizing access to powerful AI capabilities for a broad audience. While 'Ollama' enhances ease of use, it's important for users to be aware of security best practices, as some configurations could expose data if not properly managed²³⁹.

By promoting and supporting these and similar locally-focused technologies, we can ensure that the benefits of advanced AI are accessible to everyone, fostering innovation and independence without compromising privacy or reliance on external infrastructure.

9.6.4 Other Promising Ecosystems and Considerations for Local LLMs

Beyond 'llama.cpp' and 'Ollama', several other projects and frameworks are contributing to the local LLM ecosystem, some with explicit or implicit benefits for accessibility,

²³⁵ Codecademy. (n.d.). *How to Use llama.cpp to Run LLaMA Models Locally*. Retrieved from <https://www.codecademy.com/article/llama-cpp>; KDnuggets. (2025, June 24). *Building AI Agents with llama.cpp*. Retrieved from <https://www.kdnuggets.com/building-ai-agent-with-llama-cpp>

²³⁶ Analytics Vidhya. (2024, January 24). *Using Llamafies to Simplify LLM Execution*. Retrieved from <https://www.analyticsvidhya.com/blog/2024/01/using-llamafies-to-simplify-lm-execution/>; Mozilla-Ocho. (n.d.). *llamafile: Distribute and run LLMs with a single file.* GitHub. Retrieved from <https://github.com/Mozilla-Ocho/llamafile>

²³⁷ BytePlus. (n.d.). *Llamafile: Bringing LLMs to the People, and to Your Own Computer*. Retrieved from <https://www.byteplus.com/en/topic/464464>

²³⁸ DEV Community. (2025, January 29). *Unlocking AI's Potential: Ollama's Local Revolution in AI Development*. Retrieved from <https://dev.to/sina14/unlocking-ais-potential-ollamas-local-revolution-in-ai-development-1945>; Foojay. (2025, May 6). *Local AI with Spring: Building Privacy-First Agents Using Ollama*. Retrieved from <https://foojay.io/today/local-ai-with-spring-building-privacy-first-agents-using-ollama/>

²³⁹ Ridge Security. (2025, March 20). *Securing Your AI: Critical Vulnerabilities Found in Popular Ollama Framework*. Retrieved from <https://ridgesecurity.ai/blog/securing-your-ai-critical-vulnerabilities-found-in-popular-ollama-framework/>

especially when integrated into user-facing applications.

User-Friendly Frontends and Desktop Applications

For screen reader users, the graphical user interface (GUI) or command-line interface (CLI) of the *application* interacting with the local LLM is paramount. Some notable efforts in this space include:

- **LM Studio:** This provides a desktop application with a graphical user interface for discovering, downloading, and running various LLMs locally (often leveraging ‘llama.cpp’ under the hood)²⁴⁰. Its user-friendly interface could potentially be more accessible than command-line tools for some users, depending on the implementation of its UI elements for screen readers.
- **Jan:** Positioned as an open-source, lightweight alternative offering both frontend and backend features for running local LLMs, Jan aims for a clean and elegant UI²⁴¹. Its focus on user experience suggests a higher likelihood of screen reader compatibility compared to raw command-line tools.
- **GPT4All:** This is an ”all-in-one” application that mirrors a ChatGPT-like interface and is designed for quickly running local LLMs for common tasks²⁴². Its end-user focus can mean more attention is paid to the overall usability, including potential screen reader support.
- **Oobabooga Text Generation Web UI:** This is a highly popular and feature-rich web-based interface for running and interacting with local language models, supporting many backend loaders including ‘llama.cpp’²⁴³. As a web UI, its accessibility largely depends on adherence to web accessibility standards (WCAG), which is a key consideration for screen reader users.

²⁴⁰ GetStream.io. (n.d.). *The 6 Best LLM Tools To Run Models Locally*. Retrieved from <https://getstream.io/blog/best-local-llm-tools/>

²⁴¹ Lam, V. (2024, March 12). *50+ Open-Source Options for Running LLMs Locally*. The Deep Hub. Retrieved from <https://medium.com/thedeephub/50-open-source-options-for-running-llms-locally-db1ec6f5a54f>

²⁴² Lam, V. (2024, March 12). *50+ Open-Source Options for Running LLMs Locally*. The Deep Hub. Retrieved from <https://medium.com/thedeephub/50-open-source-options-for-running-llms-locally-db1ec6f5a54f>

²⁴³ Lam, V. (2024, March 12). *50+ Open-Source Options for Running LLMs Locally*. The Deep Hub. Retrieved from <https://medium.com/thedeephub/50-open-source-options-for-running-llms-locally-db1ec6f5a54f>

Frameworks for Building LLM Applications

While not direct LLM inference engines themselves, these frameworks are crucial for building accessible applications that *leverage* local LLMs:

- **LangChain and LlamaIndex:** These are popular open-source frameworks designed to streamline the development of applications powered by LLMs. They simplify building workflows that combine LLMs with external data sources (like Retrieval Augmented Generation, RAG), APIs, or computational logic²⁴⁴. The accessibility of applications built with these frameworks will depend on the developers' implementation choices for the user interface, but their existence makes it easier to create sophisticated, locally-powered AI tools.
- **Hugging Face Transformers:** This is a widely used library offering a comprehensive collection of pre-trained models and tools for various NLP tasks, including inference. While often associated with cloud services, it can also be used for local inference and is a cornerstone for many open-source LLM projects²⁴⁵. Its robustness and community support can indirectly aid in the development of accessible applications.

Specialized Accessibility-Focused LLM Applications/Research

It's also important to acknowledge emerging research and specific projects that directly address accessibility challenges using LLMs, which may or may not heavily rely on a single backend like 'llama.cpp' or 'Ollama':

- **MATE (LLM-Powered Multi-Agent Translation Environment for Accessibility Applications):** This is a multi-agent system designed for modality adaptation tasks, such as converting images to audio descriptions for visually impaired users²⁴⁶. While a research project, it highlights the potential for localized LLMs to directly provide accessibility solutions through various modality conversions, which would inherently need to be screen reader compatible in their output.
- **DexAssist:** A voice-enabled dual-LLM framework designed for accessible web

²⁴⁴ Zilliz blog. (2025, January 2). *10 Open-Source LLM Frameworks Developers Can't Ignore in 2025*. Retrieved from <https://zilliz.com/blog/10-open-source-lm-frameworks-developers-cannot-ignore-in-2025>

²⁴⁵ BytePlus. (n.d.). *Best Alternatives for llama.cpp*. Retrieved from <https://www.byteplus.com/en/topic/497811>

²⁴⁶ arxiv.org. (2025, June 24). *MATE: LLM-Powered Multi-Agent Translation Environment for Accessibility Applications*. Retrieved from <https://arxiv.org/html/2506.19502v1>

navigation, aiming to assist individuals with fine motor impairments²⁴⁷. Such systems demonstrate the direct application of LLMs (potentially local) to improve digital accessibility, where screen reader compatibility would be a core requirement for user interaction and feedback.

When discussing screen reader accessibility for local LLM ecosystems, it's crucial to emphasize that the underlying inference engine (like 'llama.cpp') often doesn't have a direct user interface to interact with. Instead, the accessibility largely depends on the *applications* built on top of these engines. Therefore, promoting frameworks and tools that prioritize user-friendly GUIs and adherence to accessibility standards (like WCAG for web UIs) is key for ensuring these powerful local AI capabilities are truly accessible to all, including screen reader users.

9.6.5 Affordability and Equitable Access

The cost of advanced AI assistive systems remains a significant barrier for many potential users. High-end systems are often priced between \$2,000 and \$5,000, creating substantial accessibility barriers for those who could benefit most from these technologies.²⁴⁸ Ensuring affordability and equitable access is crucial for widespread adoption and to prevent exacerbating existing inequalities.

9.7 Conclusion

The recent emergence of AI and LLM-based technologies marks a pivotal moment in enhancing accessibility for blind and visually impaired individuals. These advancements are profoundly transforming daily living, educational pursuits, professional productivity, and recreational activities, fostering unprecedented levels of independence and participation.

In daily living and mobility, AI-powered tools have evolved from basic object identification to comprehensive environmental understanding, providing contextual comprehension and predictive guidance. Devices like SeeSay, NOA, Envision Glasses, and NaviLens offer real-time scene descriptions, intelligent navigation, and seamless information access, significantly improving safety and autonomy in navigating complex environments. The ability of conversational AI to bridge digital and physical information

²⁴⁷ arXiv. (2024, November 5). *DexAssist: A Voice-Enabled Dual-LLM Framework for Accessible Web Navigation*. Retrieved from <https://arxiv.org/html/2411.12214v1>

²⁴⁸ Source: <https://www.aimodels.fyi/papers/arxiv/ai-powered-assistive-technologies-visual-impairment>

gaps further empowers individuals to interact with their surroundings and manage everyday tasks with greater ease.

Within educational and professional settings, AI and LLMs are democratizing access to information and fostering personalized learning experiences. Tools like NotebookLM, Be My AI, and Access AI convert traditional learning materials into accessible formats and provide individualized tutoring, allowing students to engage with complex concepts and develop skills without judgment. In the workplace, AI-powered digital assistants such as Copilot, Microsoft Teams, and Read AI Meeting notes are augmenting productivity, automating tasks, and facilitating inclusive communication, enabling visually impaired professionals to participate fully and independently in the modern workforce. The application of NLP to analyze accessibility feedback represents a crucial closed-loop system for continuous improvement, ensuring that future AI solutions are human-centered and responsive to user needs.

In the realm of recreation and leisure, AI is opening new avenues for engagement. Accessible gaming frameworks like GamerAstra are translating visual game experiences into rich auditory narratives, while AI tools are democratizing creative arts and music production, allowing blind individuals to generate visual art from text or compose music through voice commands. In sports, technologies like Touch2See are providing immersive real-time experiences through haptic feedback and audio descriptions, fostering greater participation and enjoyment.

Despite these transformative advancements, significant challenges persist. Technical limitations related to accuracy in complex environments, latency, and battery life require ongoing research and development. Ethical considerations surrounding data quality, algorithmic bias, and the "misfitting" of AI systems designed primarily for sighted users are paramount. These issues can lead to inaccuracies, ableist content, and a diminished user experience. Furthermore, the accessibility of AI interfaces themselves often falls short, with unlabeled elements and poor navigation hindering usability for screen reader users. Concerns about privacy, data security, and the high cost of advanced systems also present considerable barriers to equitable access.

Addressing these challenges necessitates a commitment to human-centered design, active engagement with the visually impaired community throughout the development lifecycle, and continuous iteration based on user feedback. Prioritizing accessibility is not merely a technical or legal requirement but a fundamental ethical imperative to ensure that AI's transformative potential is realized inclusively for everyone. The continued evolution of AI and LLM technologies holds immense promise for creating a more accessible, equitable, and empowering world for blind and visually impaired students and adults, enabling them to succeed comprehensively in all facets of life.

Chapter 10

Conclusion

Technology as the Cornerstone of Educational Equity

This document has demonstrated that technology is not merely an accommodation for students with visual impairments—it is the cornerstone of educational equity. Achieving true equity requires more than compliance with legal mandates; it demands a proactive, evidence-based approach to selecting, implementing, and supporting technology that enables visually impaired students to access, participate in, and excel within the educational environment.¹

Key Findings and Imperatives

- **Hardware and Performance:** The responsiveness of assistive technologies such as screen readers is fundamentally dependent on robust hardware. Underpowered devices create unacceptable barriers to learning, while high-performance systems empower students to engage with digital content on equal footing with their sighted peers.²
- **Accessible Devices and Materials:** The integration of tablets, braille notetakers, refreshable braille displays, video magnifiers, and high-quality embossers expands access to literacy, STEM, and the broader curriculum. Tactile graphics and 3D printed models transform abstract concepts into tangible learning experiences.³
- **Digital Literacy and Independence:** Tools such as text-to-speech engines, DAISY readers, accessible GPS, and daily living technologies foster not only academic achievement but also independence, self-advocacy, and community participation.⁴

¹ See Introduction and Chapter 1.

² See Chapter 1: Impact of Hardware Limitations on Screen Reader Response Latency.

³ See Chapters 2–5.

⁴ See Chapters 6–8.

- **Assessment and Individualization:** There is no one-size-fits-all solution. Individualized assessment frameworks, such as the SETT model, and ongoing collaboration among students, families, and educators are essential to matching technology to each learner’s unique needs.⁵
- **Instructional Programs and Support:** Effective technology use is sustained by high-quality training, troubleshooting resources, and a commitment to continuous improvement. The appendices provide practical guidance for educators and families to ensure ongoing success.⁶
- **Accessible Design:** Attention to accessible fonts, formatting, and instructional materials ensures that all students—regardless of their degree of vision—can engage with content in a way that maximizes comprehension and comfort.⁷

A Call to Action

Educational equity for students with visual impairments is not achieved by chance, but by design. It is the result of intentional decisions to prioritize accessibility, invest in appropriate technology, and foster a culture of inclusion and high expectations. As technology continues to evolve, so too must our commitment to leveraging it as a force for justice and opportunity.

By embracing technology as a driver of equity, we empower visually impaired students to pursue academic excellence, independence, and full participation in school and society.

The tools, strategies, and frameworks presented in this document are not merely recommendations—they are a roadmap for transforming educational outcomes and realizing the promise of equity for all learners.

Let us move forward with resolve, ensuring that every student—regardless of vision—has the technology, support, and opportunity to thrive.

⁵ See Appendix 3.

⁶ See Appendices 1–4.

⁷ See Appendix 5.

Part II

Part III

Implementation Guides

Appendix A

Troubleshooting Screenreader & Magnifier Performance

A.1 Clearing System Cache

One thing that it often recommended to users of screenreaders is that they maintain a habit of clearing the browser and system cache(s) in order to optimize performance of their laptop. Clearing the computer and browser cache is a common practice to free up space on the hard drive and improve the performance of the computer. However, this practice does not speed up the response of a computer if it has a Solid State Drive (SSD) rather than a spinning hard drive. This is because SSDs work differently than spinning hard drives. When data is written to an SSD, it is written to a block of memory called a page. When the page is full, the data is moved to another block of memory called a block. The block must be erased before new data can be written to it. This process is called garbage collection and it happens automatically in the background. Clearing the cache does not speed up the garbage collection process.

In addition, SSDs have a limited number of write cycles. Every time data is written to an SSD, it uses up one of these write cycles. Clearing the cache causes more data to be written to the SSD, which can reduce the lifespan of the drive. This is because when the cache is cleared, the computer must download the data again, which requires writing the data to the SSD. This can cause unnecessary wear and tear on the drive and reduce its lifespan.

Finally, clearing the cache can actually slow down the response of a computer with an SSD. This is because the cache stores frequently accessed data, such as images and scripts, so that they can be loaded quickly. When the cache is cleared, the computer must

download this data again, which can slow down the response time. In contrast, spinning hard drives are slower than SSDs and can benefit from clearing the cache. This is because spinning hard drives have to physically move a read/write head to access data, which can take longer than reading data from an SSD.

A.2 Slow Responsiveness

When a screen reader like JAWS or NVDA is not responding to input or is taking a long time to report changes on the screen, there are several things you can try to resolve the issue. First, try restarting the screen reader and the computer. This can help clear any temporary issues that may be causing the problem. If this does not work, try updating the screen reader to the latest version. Screen readers are updated regularly to fix bugs and improve performance. As of 2025, both JAWS and NVDA continue to receive regular updates with enhanced features and performance improvements.

JAWS 2025 includes new features like FS Companion, an AI assistant that helps users learn the software more effectively, and enhanced language detection capabilities. NVDA has introduced AI-powered image descriptions and automatic add-on updates in recent versions, which can help reduce barriers for users worldwide. These updates often include performance optimizations that may resolve responsiveness issues.

If the problem persists, try adjusting the settings of the screen reader. Some screen readers have settings that can be adjusted to improve performance. For example, you can adjust the verbosity level to reduce the amount of information that is read out loud. You can also adjust the speed of the screen reader to make it faster or slower. For JAWS, use Insert + J to access settings, and for NVDA, use Insert + N to open the settings dialog. It's best not to make other changes unless you are absolutely sure about what they do.

Memory usage can also affect screen reader performance. Close unnecessary applications and browser tabs to free up system resources. Additionally, ensure that your computer meets the minimum system requirements for your screen reader. NVDA requires Windows 8.1 or later, while JAWS has similar requirements for optimal performance.

Finally, if none of these steps work, you may need to contact the manufacturer of the screen reader for further assistance. They may be able to provide additional troubleshooting steps or help you diagnose the problem. It's important to remember that screen readers are complex pieces of software and may require specialized knowledge to troubleshoot. By following these steps, you can help ensure that your screen reader is working properly and providing you with the accessibility you need.

A.3 Browser Compatibility Issues

Screen readers work differently across various web browsers, and compatibility issues can sometimes cause performance problems. Chrome and Firefox generally offer the best compatibility with modern screen readers, while Edge has improved significantly in recent years. Some websites may work better with specific browser and screen reader combinations.

If you're experiencing issues with a particular website, try switching to a different browser. Clear your browser cache and cookies, and ensure that JavaScript is enabled, as many accessibility features depend on it. Some screen readers also offer browser-specific settings that can be adjusted for optimal performance.

Regular browser updates are important for maintaining compatibility with screen readers. However, sometimes new browser versions can introduce temporary compatibility issues. If you notice problems after a browser update, check the screen reader manufacturer's website for known issues and workarounds.

A.4 AI and Machine Learning Enhancements

Modern screen readers are increasingly incorporating AI and machine learning technologies to improve user experience. NVDA's AI-powered image descriptions can automatically describe images on web pages, reducing the need for manual alt-text. JAWS 2025 includes FS Companion, which uses AI to help users learn the software more effectively and troubleshoot common issues.

These AI features may require internet connectivity to function properly. If you're experiencing issues with AI-powered features, check your internet connection and ensure that your screen reader has permission to access online services. Some organizations may have firewall restrictions that prevent these features from working properly.

A.5 Official Support Contact

- **JAWS/Fusion:** You can submit a technical support request online, call 800-444-4443 or 727-803-8000 weekdays during business hours, or visit Freedom Scientific Support. For sales inquiries, contact info@vispero.com.
- **Dolphin Products:** You can contact Dolphin's technical support team by emailing Dolphin Support.

- NVDA: You can submit a bug report or request support by visiting NV Access or emailing NVDA Support Desk. NVDA can be downloaded free of charge, and the organization relies on donations to continue development.
- Windows: You can contact Microsoft's technical support team by visiting Microsoft Support.
- VoiceOver (Apple): Contact Apple Support through their website or the Apple Support app for assistance with VoiceOver on Mac, iOS, and iPadOS devices.

A.6 Community Support via Groups and Forums

Online communities and discussion groups can often provide faster responses than official customer support. These communities consist of experienced users, developers, and accessibility professionals who can share practical solutions and workarounds. Members of these communities are often experts in their field and can provide quick and accurate answers to questions.

Here are links to relevant online communities for visual impairment accessibility needs:

- JAWS / Fusion
 - The JAWS for Windows Support List
 - JFW Users List
 - JAWS Discussion
 - JAWS Lite
 - JAWS Scripting
- NVDA
 - NVDA Group
 - NVDA Addons Group
 - Chat Subgroup of the NVDA Group
 - NVDA Development
 - NVDA Discussion
 - NVDA Help

- Windows / General Accessibility
 - Windows Access with Screen Readers
- General Technology (Screen Readers Discussed Frequently)
 - Blind Tech Discuss
 - Tech For Blind
 - BlindADTech
 - Blind Techies
- Social Media and Modern Platforms
 - Reddit: r/Blind and r/accessibility communities
 - Discord servers for accessibility and assistive technology
 - Facebook groups for specific screen reader users

A.7 Professional Testing and Development Resources

For developers and accessibility professionals, there are specialized resources and tools available for testing screen reader compatibility. Services like AssistivLabs provide cloud-based access to real screen readers, magnifiers, and other assistive technologies for testing purposes. This allows developers to test their applications with actual screen readers rather than relying on simulations.

Organizations like TPGi (The Paciello Group) maintain technical resources and knowledge bases for accessibility professionals. Their ARC Platform includes KnowledgeBase, which provides up-to-date information on screen reader compatibility and testing techniques.

A.8 Staying Current with Updates

Screen reader technology evolves rapidly, with new features and compatibility improvements released regularly. Both JAWS and NVDA release annual major updates, while smaller updates and patches are distributed throughout the year. It's important to stay informed about these updates through official channels, community discussions, and accessibility news sources.

Consider subscribing to newsletters from screen reader manufacturers and accessibility organizations to stay informed about new features, known issues, and best practices. The WebAIM Screen Reader User Survey, conducted periodically, provides valuable insights into current usage patterns and preferences in the screen reader community.

Remember that while community support can be invaluable, it's important to verify information from unofficial sources. Official documentation and support channels should be your primary reference for critical issues or when making important decisions about screen reader configuration and usage.

Appendix B

Troubleshooting Braille Notetakers and Displays

B.1 Braille Notetakers

If your Braille notetaker is not responding to user input, there are several modern troubleshooting steps you can try. First, ensure that the device is properly charged and turned on. Many current devices now support USB-C charging, which provides faster and more reliable power delivery. If the device is still not working, try performing a soft reset by holding down the power button for 10-15 seconds, or check if your device has a dedicated reset button.

For connectivity issues, ensure that Bluetooth is properly paired if using wireless connections, as most modern Braille notetakers now support Bluetooth connectivity for enhanced mobility. Check that your device is compatible with your current screen reader software, as compatibility requirements have evolved significantly with recent updates to NVDA, JAWS, and other screen readers.

If you are using a BrailleNote Touch Plus (now available in 32-cell configurations), you can reset the device through the Android settings menu, as these devices now run on Android Oreo platform for enhanced functionality¹. This Android-based system provides access to Google Play Store apps and enhanced web browsing capabilities.

For BrailleSense 6 users, the device now supports advanced features including improved wireless connectivity and enhanced battery life. You can update the firmware through the device's built-in update system or by connecting to Wi-Fi and downloading updates

¹ Humanware. BrailleNote Touch Plus 32. Retrieved July 2025

directly². Factory reset options are available through the device's settings menu under System Recovery.

Modern Braille notetakers also feature improved troubleshooting diagnostics. Many devices now include self-diagnostic tools that can identify hardware issues, connectivity problems, or software conflicts. Access these through the device's utilities menu or settings panel.

B.2 Braille Displays

Current refreshable Braille displays offer enhanced connectivity options and improved troubleshooting capabilities. If your display is not responding to your computer's screen reader, start by checking both USB and Bluetooth connections, as most modern displays support dual connectivity modes.

For USB connections, ensure you're using a high-quality USB cable, preferably USB-C where supported, as older micro-USB cables may cause intermittent connection issues. Many displays now feature USB-C ports for more reliable data transfer and power delivery.

Modern Braille displays often include automatic driver installation, but manual driver updates may be necessary. Check Windows Device Manager or your operating system's accessibility settings to verify proper driver installation. Recent Windows 11 updates have improved native Braille display support significantly.

The latest Braille displays, such as the Brailliant BI 20X, now include built-in text-to-speech functionality, providing a hybrid experience³. This can help with troubleshooting by providing audio feedback during setup and configuration.

For wireless connectivity issues, ensure your display is within range (typically 30 feet) and that no other Bluetooth devices are interfering. Modern displays support Bluetooth 5.0 for improved range and stability.

If problems persist, many current displays feature firmware update capabilities through Wi-Fi or USB connections. Regular firmware updates address compatibility issues and improve performance with evolving screen reader software.

² HIMS International. BrailleSense 6. Retrieved July 2025

³ Humanware. Ultra-portable Braille Display Devices. Retrieved July 2025

B.3 Official Support Contact

- HIMS/Selvas: Technical support is available at 888-308-0059 extension 2, weekdays 8:30 AM - 5:30 PM CT. You can also email HIMS Technical Support or visit their updated support resources online.
- Humanware: Contact technical support at 1-800-722-3393, weekdays 8:30 AM - 7:00 PM ET. Submit requests through their Customer Support Portal with enhanced ticket tracking capabilities.
- Orbit Research: Reach technical support at 1-888-606-7248, 9:00 AM - 5:00 PM ET, or email Orbit Research Technical Support. They now offer remote diagnostic services for compatible devices.
- Freedom Scientific: Technical support available at 727-803-8600, weekdays 8:30 AM - 7:00 PM ET. Their updated online support portal includes AI-powered troubleshooting assistance.
- APH (American Printing House): Customer service at 800-223-1839, weekdays 8:00 AM - 8:00 PM ET, or email APH Customer Service. They now offer virtual training sessions for new device users.
- Eurobraille: International support at +33 1 55 26 91 00 (France), with multilingual support in French, Spanish, and English. Email Eurobraille Support for technical assistance.
- Help Tech: Submit support requests through their enhanced Help Tech Service Portal with real-time chat support options.
- Irie-AT: Specialized support for b.note devices and other innovative Braille technologies. Contact through their website or email for technical assistance with next-generation refreshable displays.

B.4 Community Support Resources

Online communities continue to provide valuable peer support and often faster responses than official channels. These platforms have evolved to include video tutorials, real-time chat, and enhanced search capabilities for finding solutions to common issues.

B.4.1 Braille-Specific Communities

- Braille Display Users - Active community with daily discussions about troubleshooting and device comparisons
- Brailliant BI-X Users - Dedicated support for Humanware Brailliant series devices
- BrailleNote Users - Comprehensive support for BrailleNote devices with Android-specific discussions
- HIMS Notetakers Chat - Real-time support for BrailleSense and other HIMS devices
- Orbit Reader Discussion - Community support for Orbit Research products

B.4.2 General Assistive Technology Communities

- Blind Tech Discuss - Broad technology discussions with frequent Braille device coverage
- Tech For Blind - Product reviews and troubleshooting assistance
- BlindADTech - Professional-focused discussions about assistive technology
- Blind Techies - Technical discussions and advanced troubleshooting

B.4.3 Modern Support Platforms

- Reddit communities: r/Blind and r/VisuallyImpaired offer active discussions about Braille technology
- Discord servers: Real-time chat support available through various accessibility-focused Discord communities
- YouTube channels: Many creators now offer video tutorials for Braille device setup and troubleshooting
- Manufacturer-specific forums: Most companies now maintain dedicated user forums with searchable knowledge bases

B.5 Emerging Technologies and Future Considerations

The Braille technology landscape continues to evolve rapidly. Current market trends indicate significant growth, with the global Braille notetaker market expected to reach \$200.2 million by 2033⁴. Key developments include:

- Enhanced wireless connectivity with 5G support for faster data synchronization
- Integration with cloud services for seamless document access across devices
- Improved battery life with fast-charging capabilities
- Advanced tactile feedback systems for better user experience
- AI-powered text processing and predictive input features

When troubleshooting, consider that newer devices may have features that older troubleshooting guides don't address. Always check for firmware updates and consult online communities for the latest solutions to emerging issues.

⁴ Market research indicates 6.2% CAGR from 2026-2033 for Braille notetaker technologies

Appendix C

Assistive Technology Considerations

Assistive technology is an essential component of ensuring that students with visual impairments receive a free and appropriate public education. However, it is important to use a valid assistive technology assessment before providing assistive technology to a student. A valid assessment can help identify the specific needs of the student and determine the most appropriate assistive technology solutions. This can help ensure that the student receives the right tools to succeed in their studies¹. Additionally, a valid assessment can help ensure that the student receives the appropriate accommodations and modifications to their educational program².

It is also essential to use all the data available to guide decision making when providing assistive technology to a student. This includes data from the student, their family, and their educators. By using all the data available, educators can make informed decisions about the most appropriate assistive technology solutions for each student. This can help ensure that the student receives the right tools to succeed in their studies³. It is important to note that convenience should not be a factor when making decisions about assistive technology. The focus should always be on what is best for the student.

The landscape of assistive technology continues to evolve rapidly, with emerging technologies such as AI-powered devices showing significant promise. Recent developments include advanced wearable devices that combine artificial intelligence with real-time environmental feedback, offering unprecedented levels of independence for students with visual impairments. However, the fundamental principles of proper

¹ AEM Center. (n.d.). NIMAS & NIMAC. Retrieved December 19, 2023

² DAISY Consortium. (n.d.). What is DAISY? Retrieved December 19, 2023

³ AEM Center. (n.d.). Assistive Technology. Retrieved December 19, 2023

assessment and individualized selection remain constant regardless of technological advances.

Using a valid assistive technology assessment and all available data to guide decision making can help ensure that students with visual impairments receive the appropriate assistive technology solutions to succeed in their studies. This can help improve their academic performance and increase their chances of success in school. Additionally, it can help students with visual impairments become more independent in their daily lives. By providing students with the tools they need to access information and communicate with others, assistive technology can help them become more self-sufficient and less reliant on others⁴.

Finally, it is important to note that the use of assistive technology is not a one-size-fits-all solution. The technology needs of students with visual impairments can vary widely depending on their individual needs and abilities. Therefore, it is important to work with students, families, and educators to identify the most appropriate assistive technology solutions for each student. By doing so, we can help ensure that students with visual impairments have the tools they need to succeed in school and beyond.

C.1 SETT Framework

The SETT Framework^{5,6} is a widely used method for evaluating assistive technology (AT) needs for students with disabilities. The acronym SETT stands for Student, Environment, Task, and Tools. The framework emphasizes the importance of understanding the student's characteristics, the environments in which they learn and grow, and the tasks required to be an active learner in those environments before identifying a system of tools that enables the student to actively engage in the tasks. A team-based collaborative assessment of needs will lead to determining the most promising system of tools for the student, with a consideration of the environments this learner is in⁷.

Recent applications of the SETT Framework have been particularly valuable in remote learning environments, a development that gained prominence during the COVID-19 pandemic and continues to be relevant as educational delivery models become more flexible. The framework's emphasis on environmental considerations has proven

⁴ Wisconsin Assistive Technology Initiative. (2010). Assistive technology consideration to assessment. Retrieved December 19, 2023

⁵ click on “resources/SETT Downloads” and see items below

⁶ cf., Minnesota Department of Administration. (n.d.). SETT Framework / Guide to Assistive Technology. [Webpage]. Minnesota’s State Portal

⁷ Hollingshead, A., Zabala, J., & Carson, J. (2020). The SETT Framework and Evaluating Assistive Technology Remotely. Council for Exceptional Children.

especially important as students now learn across multiple environments, from traditional classrooms to home settings and virtual spaces.

The SETT Framework is particularly relevant to evaluating and justifying assistive technology choices for the blind. For example, the framework can be used to identify the specific needs of a blind student, such as the need for a screen reader or a braille display. The framework can also help identify the specific tasks that the student needs to be able to do, such as reading textbooks or accessing online resources. By considering the student's characteristics, the environments in which they learn, and the tasks required to be an active learner in those environments, the framework can help identify the most appropriate assistive technology tools for the student^{8,9}.

The SETT Framework continues to be recognized as a foundational model for assistive technology decision-making, with ongoing research and applications demonstrating its continued relevance in contemporary educational settings. The framework's flexibility allows it to accommodate emerging technologies while maintaining its core focus on student-centered assessment and decision-making.

C.2 Assistive Technology Assessments

There are several assistive technology assessments available for use with blind or visually impaired people. Here are some of the most current and comprehensive assessment tools and resources:

- Snow, A. (n.d.). Assistive Technology Checklist for Assessment. Teaching Students with Visual Impairments. Retrieved July 2025
- Teaching Students with Visual Impairments. (n.d.). Assistive Technology Assessment for Students Who Are Blind or Visually Impaired. Retrieved July 2025
- Perkins School for the Blind. (n.d.). Basic Technology Assessment Template. Retrieved July 2025
- Presley, I., & D'Andrea, F. M. (2024). Assistive Technology for Students Who Are Blind or Visually Impaired: A Guide to Assessment (Updated Edition). American Foundation for the Blind.

⁸ Zabala, J. (2005). Ready, SETT, go! Getting started with the SETT framework. *Closing The Gap*, 24(6), 1-8.

⁹ Zabala, J. (2018). SETTing the stage for success: Building success through effective selection and use of assistive technology systems. In *Handbook of Research on Integrating Technology Into Contemporary Language Learning and Teaching* (pp. 1-22). IGI Global

- Wisconsin Assistive Technology Initiative. (2024). Assessing Students' Needs for Assistive Technology. Retrieved July 2025
- Illinois State Board of Education. (2024). Assistive Technology for Students who are Visually Impaired. Retrieved July 2025
- SETT Framework Resources^{10,11}
- QIAT Community. (2024). A Resource Guide to Assistive Technology for Students with Visual Impairments. Retrieved July 2025
- California School for the Blind. (2024). Assistive Technology - Instructional Services. Retrieved July 2025
- MIUSA. (2025). Assistive Technology for Blind or Low Vision Participants. Retrieved July 2025

Recent developments in assistive technology assessment include increased attention to the psychosocial impacts of assistive technologies, with new research protocols focusing on understanding how these tools affect the emotional and social well-being of users. Additionally, there has been growing recognition of the need for culturally responsive assessment practices that consider the diverse backgrounds and experiences of students with visual impairments.

The field continues to evolve with the integration of artificial intelligence and machine learning technologies, requiring assessments to consider not only traditional assistive technologies but also emerging AI-powered solutions that offer new possibilities for independence and academic success. Assessment teams are increasingly called upon to evaluate these newer technologies alongside established tools to ensure comprehensive and forward-thinking technology recommendations.

¹⁰ click on "resources/SETT Downloads" and see items below

¹¹ cf., Minnesota Department of Administration. (2025). SETT Framework / Guide to Assistive Technology. [Webpage]. Minnesota's State Portal

Appendix D

Instructional Programs & Materials

The Individuals with Disabilities Education Improvement Act (IDEIA) 2004 mandates that students with disabilities receive a free and appropriate public education (FAPE) in the least restrictive environment possible¹. To ensure that blind and low vision students have access to FAPE, there is a need for evidence-based specialized curriculum to teach screenreader usage, magnification usage, accessible typing programs, and accessible coding curricula to teach tech skills to blind/low vision students.

Screen readers are software programs that allow blind and visually impaired users to read the text that is displayed on a computer screen with a speech synthesizer or braille display². Magnification software enlarges the text and images on the screen for low vision users³. Accessible typing programs help students with disabilities learn to type using adaptive technology. Accessible coding curricula teach blind and low vision students how to code using specialized software that is designed to be accessible to them⁴.

Evidence-based specialized curriculum for teaching these skills is important because it ensures that students with disabilities have access to the same educational opportunities as their peers. It also helps to ensure that students with disabilities are able to develop the skills they need to succeed in the workforce. By providing students with disabilities with the tools they need to succeed, we can help to create a more inclusive society where everyone has the opportunity to reach their full potential.

¹ 20 U.S.C. § 1400, et.

² Paths to Literacy. (n.d.). Introduction to Screen Reader Instruction. Retrieved July 2025

³ American Foundation for the Blind. (n.d.). Magnification Software. Retrieved July 2025

⁴ FreeCodeCamp.org (2018). Helping blind people learn to code. Retrieved July 2025

D.1 Accessible Touch Typing Instruction

Learning to touch type is an essential skill for anyone who spends a significant amount of time typing. Touch typing can help you type more efficiently and accurately, which can save you time and reduce the risk of repetitive strain injuries. By using all ten fingers to type without looking at the keyboard, you can significantly increase your typing speed and reduce the number of errors you make. This can help you complete your typing tasks faster and with greater accuracy. Additionally, touch typing can help you use keystroke shortcuts more smoothly, which can help you navigate your computer more quickly and efficiently. Screen readers can also be used more effectively when you are able to touch type, as you can focus on the content being read rather than the keyboard. In summary, learning to touch type can help you become a more efficient and fluent typist, as well as improve your ability to navigate your computer and screen readers.

You may be thinking: My blind child has a Braille device. Why does she need to learn to type?

Even if your child has a Braille device such as the Braillenote Touch, typing is essential. The computer is the mainstream device that your child will need in order to be productive in school and in the workplace. When I meet a new blind student, parents often tell me, “My child needs to learn to use a screen reader.” The first question I ask is, “Does your child know how to type?” In order to use a screen reader such as JAWS effectively, you have to be able to type accurately. Braille is important, too, and it definitely has its uses in technology. But I believe that typing is as important as Braille.

Typing allows blind students to use mainstream devices. They can use a laptop or desktop computer, or they can connect a keyboard to a tablet. When I use my iPhone and type in text messages, my keyboarding skills help me use the screen, even without a Braille display.

– Treva Olivero National Federation of the Blind. (2019). The Braille Monitor, January 1997. Retrieved July 2025

There are a number of options available for teaching touch typing skills to students with visual impairments.

- Typio⁵
- Ballyland Keyboarding⁶

⁵ This product was specifically developed for use with the blind and features 130 guided lessons with audio feedback

⁶ Specifically designed for blind and visually impaired students

- TypeAbility⁷
- Sao Mai Typing Tutor⁸
- Keystroke⁹
- APH Typer Online¹⁰
- Typing Club¹¹
- Touch-Type Read and Spell (TTRS)¹²
- KAZ Typing Software¹³

D.2 AndroidOS/iOS/iPadOS Gesture Training

Learning VoiceOver and TalkBack gestures on tablets and phones is essential for users with visual impairments. VoiceOver is a screen reader that comes pre-installed on Apple devices, while TalkBack is a screen reader that comes pre-installed on Android devices^{14,15}. Both screen readers include gesture-based controls and braille keyboard support. While these screen readers are useful tools, they depend on accurate text alternatives for non-text content. Learning VoiceOver and TalkBack gestures can help users navigate their devices more efficiently and effectively¹⁶. For instance, TalkBack gestures can help users navigate and perform frequent actions on their Android devices, such as moving to the next item on the screen, selecting an item, and activating screen search.¹⁷ Similarly, VoiceOver gestures can help users navigate and perform frequent actions on their Apple devices, such as opening the app switcher, accessing the control center, and activating Siri. Competency with VoiceOver and TalkBack gestures can enable users to access the same activities as their peers, manage eye fatigue, and use good posture and a good viewing distance.

⁷ Teaches the entire computer keyboard in 99 user-friendly lessons, updated as of 2025

⁸ Specifically designed for blind users

⁹ Developed by the Commission for the Blind

¹⁰ Formerly known as Talking Typer, maintained by APH

¹¹ Mainstream typing program with accessibility features

¹² This resource has been specifically shown to be effective for blind students through independent research

¹³ Specifically designed for visually impaired and blind users with voice prompts

¹⁴ Bureau of Internet Accessibility. (n.d.). Understanding How People With Disabilities Use Mobile Devices. Bureau of Internet Accessibility.

¹⁵ Bureau of Internet Accessibility. (n.d.). Google TalkBack: An Overview of Android's Free Screen Reader. Bureau of Internet Accessibility.

¹⁶ Apple. (2022, December 20). Turn on and Practice VoiceOver. Apple Support.

¹⁷ Google. (n.d.). Use TalkBack on your Android device. Google.

- ScreenReader App¹⁸
- Ballyland Apps
- The Screen Reader Training Website¹⁹
- Listen with TalkBack Series from Hadley
- Listen with VoiceOver Series from Hadley

D.3 Screenreader Training

Learning advanced methods of navigating the computer with a screen reader such as JAWS, Windows Narrator, or NVDA is essential for users with visual impairments. Recent developments in 2024-2025 show that NVDA continues to gain popularity, with NVDA 2025.1 introducing remote access capabilities and enhanced performance. JAWS 2025 includes significant performance optimizations and better compatibility with resource-intensive applications. While arrow keys and Tab can be useful for basic navigation, advanced methods can provide more efficient and comprehensive navigation. For instance, JAWS provides a feature called "Virtual Cursor" that allows users to navigate web pages and documents by line, word, character, or even by paragraph²⁰. Similarly, Windows Narrator provides a feature called "Scan Mode" that allows users to navigate web pages and documents by headings, links, tables, and landmarks.^{21,22}. NVDA provides a feature called "Object Navigation" that allows users to navigate web pages and documents by objects such as buttons, checkboxes, and text fields²³. Learning advanced methods of navigation can help users save time and effort, and increase productivity. It is important to note that while screen readers can be helpful, they should not replace other assistive technologies such as screen magnifiers. Therefore, it is important to learn advanced methods of navigating the computer with a screen reader to take full advantage of its benefits.

- Surf's Up²⁴

¹⁸ Users are invited to add any missing information to either screenreader-android for Android TalkBack or screenreader-ios for VoiceOver

¹⁹ This targets VoiceOver, but can be used for TalkBack with assistance

²⁰ Freedom Scientific. (n.d.). JAWS Screen Reader. Freedom Scientific.

²¹ Microsoft. (2022, December 31). Narrator User Guide. Microsoft.

²² Microsoft. (2022, December 31) Use a screen reader to navigate Windows 11. Microsoft.

²³ NV Access. (2022, December 31). NVDA User Guide. NV Access.

²⁴ Offline version available for download as a zipped file at this link

- The Screen Reader Training Website²⁵
- Windows Narrator Series from Hadley
- NVDA Series from Hadley
- Windows Screen Reader Primer^{26,27}
- Access Technology Institute, LLC. Courses²⁸
- NVDA Training Materials²⁹
- JAWS Basic Training
- Working with Text from eyeTvision³⁰
- Basic Internet Navigation from eyeTvision³¹
- Windows Screen Reader Keystroke Compendium 2024³²

D.4 Screen Magnifier Training

Specialized screen magnification software like ZoomText, Fusion, Windows Magnifier, and Dolphin SuperNova are designed to provide a more comprehensive and customizable experience than the built-in magnification tools. While the built-in magnification tools can be useful for basic tasks, they may not be sufficient for users with more complex needs³³. Specialized software can provide features such as color filtering, cursor enhancements, and text-to-speech capabilities³⁴. Additionally, specialized software can help users manage eye fatigue, use good posture and a good viewing distance, and access the same activities as their peers. Competency with specialized screen magnification software can enable students to succeed in postsecondary education and

²⁵ This site is an update to the Surf's Up curriculum undertaken by the California School for the Blind that has been expanded to cover NVDA, JAWS, and VoiceOver

²⁶ in 2nd Ed. as of July 6, 2025

²⁷ This primer covers use of Windows Narrator, NVDA, and JAWS

²⁸ Sells training, textbooks, and subscription-based content about JAWS and NVDA

²⁹ Includes Basic Screenreader Training and Specific Training for Outlook, Word, Excel, and PowerPoint use with NVDA

³⁰ Covers NVDA, JAWS, and ChromeVox Screenreaders

³¹ Covers NVDA, JAWS, and ChromeVox Screenreaders

³² Comprehensive keystroke reference for JAWS, NVDA, and Narrator updated for 2024

³³ Bureau of Internet Accessibility. (n.d.). Screen Magnifiers: Who and How They Help. Bureau of Internet Accessibility.

³⁴ Perkins School for the Blind. (2022, August 17). Getting started with screen magnification. Retrieved July 2025

jobs³⁵. It is important to note that while specialized screen magnification software can be helpful, it should not replace other assistive technologies such as screen readers. Therefore, it is important to learn how to use specialized screen magnification software to take full advantage of its benefits³⁶.

- ZoomText Resources from Freedom Scientific
- Fusion Resources from Freedom Scientific
- Dolphin Supernova Training Materials

D.5 Braille Display Use

Learning how to use a refreshable braille display is essential for emerging braille readers. Refreshable Braille Displays are peripheral devices that display braille characters, usually by raising and lowering dots through holes in a flat surface. Users can input braille using either the 6 or 8 key Perkins-style braille keyboard or, more recently, a QWERTY keyboard.

While it may be tempting to use only the minimum functions of a braille display, being explicitly taught how to use it can provide many benefits. For instance, it can help improve finger strength and isolated finger control, which are crucial for writing³⁷. Additionally, using a braille display can help emerging readers with tactile discrimination and make it easier to read. Furthermore, pairing a braille display with a computer, tablet, or smartphone can provide instant auditory feedback as the student types, which can help with motivation. Recent developments in 2024-2025 include innovations in haptic feedback technology and improvements in braille display connectivity.

- APH Mantis Q40 Braille Display & Notetaker from Washington School for the Blind
- APH Chameleon 20 Braille Display & Notetaker from Washington School for the Blind
- BrailleSense 6 Training from WCBVI AT
- BrailleSense 6 Training from California School of the Blind
- BrailleNote Touch Plus Training from California School of the Blind
- Diving Into Braille Displays from eyeTvision

³⁵ American Foundation for the Blind. (2022, August 17). Screen Magnification. American Foundation for the Blind.

³⁶ Low Vision Center. (n.d.). Introduction to Screen Reading and Magnification Software: A Comprehensive Guide to Assistive Technology Assessment. Low Vision Center.

³⁷ Perkins School for the Blind. (n.d.). Benefits of Using a Braille Display with Emerging Readers. Retrieved July 2025

D.6 Accessible Coding Curricula

It is possible for blind students to learn computer programming. In fact, there are many resources available to help them learn, with significant developments in 2024-2025 making coding more accessible than ever before. Recent initiatives include partnerships between Code.org and accessible programming language developers, as well as new AI-powered tools for accessibility testing. For instance, the Perkins School for the Blind provides information on Quorum, an accessible programming language, as well as other resources and information related to blind programmers and coders³⁸. Additionally, EarSketch, a platform designed to teach students to code in Python or JavaScript through music and creative discovery, continues to be adapted for blind and visually impaired youth³⁹. Microsoft has also developed Code Jumper, a coding language for children who are blind or visually impaired, which is comprised of modular, physical pieces that students can string together to create code⁴⁰. New accessible tools such as KaiBot and enhanced CodeQuest applications are being integrated into mainstream K-12 education. It's worth noting that blind people can be successful software developers, with 1 out of every 200 software developers being blind⁴¹. With the right resources and support, blind students can learn computer programming and pursue a career in software development.^{42,43}

The following list contains the current list of accessible coding options available for students with visual impairment/blindness, updated with 2024-2025 developments.

- APH Connect Center Coding Course taught by Florian Beijers⁴⁴
- CodeHS⁴⁵
- Code Academy⁴⁶

³⁸ Perkins School for the Blind. (n.d.). Blind programmers and coders. Perkins School for the Blind.

³⁹ Georgia Tech. (2022, August 24). EarSketch. Georgia Tech

⁴⁰ Microsoft. (n.d.). Code Jumper. Microsoft.

⁴¹ FreeCodeCamp. (2017, November 14). How blind people code. FreeCodeCamp.

⁴² cf., Hadwen-Bennett, Alex & Sentance, Sue & Morrison, Cecily. (2018). Making Programming Accessible to Learners with Visual Impairments: A Literature Review. International Journal of Computer Science Education in Schools. 2. 10.21585/ijcses.v2i2.25.

⁴³ Alotaibi, Hind & Al-Khalifa, Hend & AlSaeed, Duaa. (2020). Teaching Programming to Students with Vision Impairment: Impact of Tactile Teaching Strategies on Student's Achievements and Perceptions. Sustainability. 12. 10.3390/su12135320.

⁴⁴ Florian Beijers is a blind computer programmer who ran this course for APH. This link goes to the archived site that contains links to the lectures and archives all the course materials.

⁴⁵ Mainstream coding platform with enhanced accessibility features

⁴⁶ Popular coding platform with screen reader compatibility

- APH CodeJumper^{47,48}
- Code Quest⁴⁹
- APH Code & Go Mouse⁵⁰
- EarSketch⁵¹
- Code.org Accessibility Resources⁵²
- Quorum Programming Language⁵³
- KaiBot⁵⁴

D.7 Emerging Technologies and Future Directions

The landscape of assistive technology for students with visual impairments continues to evolve rapidly. Recent developments in 2024-2025 include significant advances in AI-powered accessibility tools, haptic feedback devices, and innovative approaches to digital content access. These emerging technologies promise to further enhance educational opportunities for blind and low vision students.

Key developments include:

- AI-powered accessibility testing tools such as Axe DevTools AI for automated web content accessibility
- Enhanced haptic feedback devices for accessing digital content and touchscreen interfaces
- Innovations in braille technology and display connectivity
- Integration of accessible coding tools into mainstream K-12 curricula
- Development of more sophisticated screen reader remote access capabilities
- Advances in voice-controlled interfaces and natural language processing for educational applications

⁴⁷ A Microsoft Training Module is available to teach CodeJumper to teachers

⁴⁸ Specifically Designed by Microsoft and APH for use by the blind

⁴⁹ Accessible coding app designed for blind students

⁵⁰ Physical coding toy designed for blind students

⁵¹ Freely available Teaching Resources for Teachers

⁵² Comprehensive documentation and accessible Hour of Code lessons, updated 2024-2025

⁵³ Accessible programming language designed for blind students, partnered with Code.org

⁵⁴ New accessible robotics platform for K-12 coding education

Educational institutions and assistive technology providers continue to collaborate on developing more inclusive and accessible learning environments. The emphasis on universal design principles ensures that accessibility improvements benefit all students, not just those with visual impairments. As these technologies mature, they will provide even more opportunities for students with visual impairments to participate fully in educational and professional activities.

Appendix E

Accessible Fonts

Accessible typography is crucial for individuals with visual impairments, such as low vision or reading disabilities like dyslexia. Accessible fonts are designed to be easy to read by a diverse audience, including people with visual impairments. The use of accessible typefaces like Atkinson Hyperlegible and APHont can significantly improve the legibility and readability of text for people with visual impairments. These typefaces have features like increased letter spacing, bold outlines, higher contrast ratios, and wider characters, which make them easier to read. The Section 508 Standards¹ and other regulations require sans-serif fonts in certain places, and typography choices have a huge impact on accessibility². By using accessible typography, textual information can be made accessible to all users, irrespective of their abilities or disabilities^{3,4}.

There are a number of options available for accessible fonts. These are presented with font information and then followed by a thorough demonstration of the font readability⁵

¹ Section508.gov. (n.d.). Understanding Accessible Fonts and Typography for Section 508 Compliance. Retrieved January 12, 2024

² accessiBe. (2023, May 14). How to Choose ADA-Compliant Fonts in 2024: A Complete Guide. accessiBe BLOG

³ The Readability Group. (2020, August 14). A Guide to Understanding What Makes a Typeface Accessible and How to Make Informed Decisions. Medium. Retrieved January 12, 2024

⁴ HubSpot. (n.d.). Accessibility Fonts: How to Choose the Right Typeface for Your Website. Retrieved January 12, 2024

⁵ Empty box characters mean a particular font does not contain that type of character. This is seen for all of the fonts below except JetBrains Mono with subscript characters

E.1 Atkinson Hyperlegible Font

Developed by the Braille Institute **Strengths:** Designed specifically for low vision, excellent character differentiation (e.g., distinct 'l', 'I', '1' and 'Ø', 'O'). Very open apertures. **Weaknesses:** May appear wider than standard fonts, potentially leading to less text per line.

E.1.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001II B8 DØ G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçééëïíñòóôöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, ØOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.1.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel

fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.

- **Numbers & Similar Characters:** 0O1I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** llI, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.2 Atkinson Hyperlegible Mono

Developed by the Braille Institute (Monospaced variant) **Strengths:** Retains the excellent character distinctiveness of its proportional counterpart. Monospaced nature can aid users who benefit from predictable character widths, especially for code or data. **Weaknesses:** Monospaced fonts generally take up more horizontal space, potentially reducing reading speed for some users in long prose.

E.2.1 Regular

- **General Text:** *Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.*
- **Numbers & Similar Characters:** 0011I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** ¹₁²₂³₃⁴₄⁵₅. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëííîñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** Il1, 00o, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.2.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëïïñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, QOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.3 Atkinson Hyperlegible Next

Developed by the Braille Institute (Next variant) **Strengths:** Similar accessibility features to the original Hyperlegible, with potential refinements for modern digital contexts. **Weaknesses:** Similar to the original Hyperlegible, its design choices for accessibility might make it less compact than other fonts.

E.3.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- Numbers & Similar Characters: 0O1lI B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- Superscripts/Subscripts: 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- Punctuation & Symbols: \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- Character Distinctiveness Test (Lowercase): a e o c s r n m u v w. How distinct are they?
- Character Distinctiveness Test (Uppercase): I J L T V W X Y Z. How distinct are they?
- Accented Characters: àáâãäåæçééëïíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- Problematic Pairs/Triplets: Il1, Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- Dense Text Example: "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.3.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel

fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.

- **Numbers & Similar Characters:** 001I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** llI, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.4 APHont

Developed by the American Printing House for the Blind, font download here **Strengths:** Explicitly designed for large print and low vision. Features clear, wide characters and good letter spacing. **Weaknesses:** May appear somewhat informal due to its design. Its wide characters consume more space, which can be an issue for page count or display on smaller screens.

E.4.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ¡ º < > © ® ™ \$ £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëïíñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.4.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëïïñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, QOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.5 Comic Sans MS

Strengths: Often cited as beneficial for some dyslexic readers due to its informal, handwritten-like characters, which can reduce visual crowding and increase character differentiation. **Weaknesses:** Highly controversial and often considered unprofessional for formal documents. Its informal appearance can detract from the content's perceived seriousness. Not universally preferred for accessibility.

E.5.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåçéêëíőőñòóôôööøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.5.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel

fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.

- **Numbers & Similar Characters:** 0O1I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** llI, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.6 JetBrains Mono⁶

Strengths: Excellent for code readability due to clear differentiation of similar characters (e.g., 'Ø' and 'O', 'l', 'I', '1'). Good open apertures and designed for extended screen reading. Excellent ligature support for programming. **Weaknesses:** As a monospaced font, it's not ideal for long blocks of prose due to its uniform character width, which can make reading less fluid. Subscript characters might appear as empty boxes if the font isn't fully supported by your LaTeX setup for these symbols.

E.6.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001lI B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ? ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçéêëííïíñòóôõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** Il1, 00o, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common

⁶ Font created for monospace/coding needs

standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.6.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 0O1II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** $1^1 2_2 3^1 3_2 4^1 4_2 5^1 5_2$. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.7 OpenDyslexic

Developed by Abelardo Gonzalez, designed for dyslexia. Free and open source: <https://opendyslexic.org/> **Strengths:** Specifically designed to aid dyslexic readers with unique letterforms that prevent common reading errors (e.g., weighted bottoms to prevent letter reversal, distinct letter shapes). **Weaknesses:** Its highly distinctive letterforms can be distracting for non-dyslexic readers. Not everyone with dyslexia finds it beneficial, as accessibility needs vary greatly.

E.7.1 Regular

- **General Text:** `Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.`
- **Numbers & Similar Characters:** `00111 B8 D0 G6 MNNN pPqQ S5 Z2.` Try to distinguish these characters.
- **Superscripts/Subscripts:** `112122313241425152.` (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** `\{} () [] # * : ; ! ? ☐ ° < > © ® ™ $ € £ ¥.`
- **Character Distinctiveness Test (Lowercase):** `a e o c s r n m u v w.` How distinct are they?
- **Character Distinctiveness Test (Uppercase):** `I J L T V W X Y Z.` How distinct are they?
- **Accented Characters:** `àáââäâæçééëìíîñòóôöøùúûüýþÿ.` (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** `ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl.` (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum

age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.7.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 0O1I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéëìíñòóôöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.8 Tiresias

Designed for visually impaired users. Free for non-commercial use:

<https://www.tiresias.org/fonts/> **Strengths:** Developed with input from visually impaired individuals. Features include clear, unambiguous characters and generous spacing. Often used in broadcasting and public information systems.

Weaknesses: Its design might feel somewhat dated or less aesthetically pleasing to some users compared to more modern sans-serif fonts.

E.8.1 Regular

- **General Text:** *Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.*
- **Numbers & Similar Characters:** 001lI B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☺ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéëïíñòóôõøùúûüýÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** Il1, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.8.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëïïñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, QOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.9 Verdana

Widely recognized for readability on screens. Pre-installed on many systems.

Strengths: Designed by Microsoft for on-screen readability, featuring a large x-height, distinct characters, and generous letter spacing. Very common and generally well-supported. **Weaknesses:** Can appear somewhat wide and takes up more space than some other fonts, which might be a concern for print layouts or limited screen real estate.

E.9.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- Numbers & Similar Characters: 0O1II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- Superscripts/Subscripts: 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- Punctuation & Symbols: \{} () [] # * : ; ! ? □ ° < > © ® ™ \$ € £ ¥.
- Character Distinctiveness Test (Lowercase): a e o c s r n m u v w. How distinct are they?
- Character Distinctiveness Test (Uppercase): I J L T V W X Y Z. How distinct are they?
- Accented Characters: àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- Problematic Pairs/Triplets: Il1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- Dense Text Example: "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.9.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëïïñòóôõõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, QOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.10 Arial / Arial Unicode MS

Commonly recommended for accessibility due to clarity and sans-serif design.

Pre-installed on many systems. **Strengths:** A widely available, neutral sans-serif font. Its familiarity and broad character set (especially Arial Unicode MS) make it a safe default for general accessibility. **Weaknesses:** While clear, some characters (like 'I', 'l', and '1') can be less distinct than in fonts specifically designed for accessibility. Its uniform appearance can make it less engaging for some readers.

E.10.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- Numbers & Similar Characters: 0O1II B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- Superscripts/Subscripts: 1¹2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- Punctuation & Symbols: \{} () [] # * : ; ! ? ? ° < > © ® ™ \$ € £ ¥.
- Character Distinctiveness Test (Lowercase): a e o c s r n m u v w. How distinct are they?
- Character Distinctiveness Test (Uppercase): I J L T V W X Y Z. How distinct are they?
- Accented Characters: àáâãäåæçèéêëíîñòóôõøøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- Problematic Pairs/Triplets: ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- Dense Text Example: "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.10.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do

etiam tempus incidunt ut labore et dolore magna aliqua. Facilisis leo vel
fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam
eget felis.

- **Numbers & Similar Characters:** 0O1I I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.11 Calibri

Microsoft's default sans-serif, designed for screen readability. Pre-installed on many systems. **Strengths:** Modern, clean sans-serif with good readability, particularly on digital screens. Relatively open apertures and a friendly aesthetic. **Weaknesses:** Similar to Arial, its general-purpose design might mean that character differentiation for problematic pairs is not as optimized as in specialized accessible fonts.

E.11.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 001lI B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ¡ º < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçéêëíîñòóôõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, OOo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.11.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.

- **Numbers & Similar Characters:** 0O1I I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.12 Century Gothic

Recommended by some accessibility guidelines for its clarity. Common in Microsoft Office. **Strengths:** A geometric sans-serif font with a clean, open design and good legibility. Its distinct letterforms can be helpful for some readers. **Weaknesses:** Its perfectly circular 'o' and generally wider characters can sometimes make it less space-efficient. The simple geometric shapes might not provide enough distinctiveness for some problematic character pairs.

E.12.1 Regular

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 0O1॥ B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? □ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéëïïñòóôõöøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, 0Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

E.12.2 Italic

- **General Text:** Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Facilisis leo vel fringilla est ullamcorper eget nulla facilisi. Nec ullamcorper sit amet risus nullam eget felis.
- **Numbers & Similar Characters:** 0O1I I B8 D0 G6 MNNN pPqQ S5 Z2. Try to distinguish these characters.
- **Superscripts/Subscripts:** 1¹1₂2¹2₂3¹3₂4¹4₂5¹5₂. (Note: Math mode is often handled by a different font, so this tests the font's math support or fallback.)
- **Punctuation & Symbols:** \{} () [] # * : ; ! ? ☰ ° < > © ® ™ \$ € £ ¥.
- **Character Distinctiveness Test (Lowercase):** a e o c s r n m u v w. How distinct are they?
- **Character Distinctiveness Test (Uppercase):** I J L T V W X Y Z. How distinct are they?
- **Accented Characters:** àáâãäåæçèéêëìíñòóôõøùúûüýþÿ. (Tests Latin-1 Supplement coverage)
- **Problematic Pairs/Triplets:** ll1, Oo, cl, rn, fi, fl, ff, ffi, ffl. (Highlights common confusion points and ligatures)
- **Dense Text Example:** "Minimum wage is no guarantee. It isn't maximum security, or minimum age. It's just a common standard, often ambiguous." (To check letter and word spacing in a compact sentence.)

Back Matter

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For additional information please contact me at ryhunsaker@dsdmail.net