

*Published by the Assistive Technology Industry Association (ATIA)*

***Volume 17***

***Spring 2023***

# *Best Practices for the Design and Development of AT Products*

**Stephen Bauer**

**Guest Editor**

**Anya S. Evmenova**

**Editor-in-Chief**

**Carolyn P. Phillips**

**Associate Editor**

Copyright © 2023

Assistive Technology Industry Association

ISSN 1938-7261

Assistive Technology Outcomes and Benefits

Best Practices for the Design and Development of Assistive Technology Products

Volume 17, Spring 2023

**Editor in Chief**

Anya S. Evmenova *Professor*

George Mason University

**Publication Managers**

Victoria A. Hughes, Tools for Life

Georgia Institute of Technology

Caroline Van Howe

Assistive Technology Industry Association

Mishiel Ayub

UMass Boston

**Guest Editor**

Stephen Bauer

State University of NY at

Buffalo (retired)

**Associate Editor**

Carolyn P. Phillip

Tools for Life

Georgia Institute of Technology

**Copy Editor**

Lesley Porcelli

Assistive Technology Outcomes and Benefits (ATOB) is a collaborative peer-reviewed publication of the Assistive Technology Industry Association (ATIA). Editing policies of this issue are based on the Publication Manual of the American Psychological Association (7th edition) and may be found online at [www.atia.org/atob/editorialpolicy](http://www.atia.org/atob/editorialpolicy). The content does not reflect the position or policy of ATIA and no official endorsement should be inferred.

## **Editorial Board Members and Managing Editors**

David Banes

*Managing Director*

David Banes Access and Inclusion Services

Russell T. Cross

*Director of Clinical Operations*

Prentke Romich Company

Lori Geist

*Assistant Professor*

*Center for Literacy & Disability Studies*

UNC at Chapel Hill

William E. Janes

*Assistant Professor*

*Department of Occupational Therapy*

University of Missouri

Ben Satterfield

*Research Associate*

*Center for Inclusive Design & Innovation*

College of Design Georgia Institute of Technology

Judith Schoonover

*Occupational Therapist and AT Consultant,*

Holland, Michigan

Rachael Sessier Trinkowsky

*Technology Training & Vocational Manager/AT Program Coordinator*

Lighthouse for the Blind of the Palm Beaches UMass Boston

# Peer Reviewers for ATOB Volume 17

# Best Practices for the Design and Development of Assistive Technology Products

The Editorial Board would like to thank the peer reviewers who generously donated their time and talent to reviewing manuscripts for this Volume 17 of the ATOB.

Melissa Ainsworth

Sarah Elizabeth Baguhn

Christina Choi

Susan Fager

Jennifer Flagg

Christine Holyfield

Stacy Kelly

Filip Loncke

Daniel Phillips

Stephen Sutter

Gregg Vanderheiden

Corinne Vinopol

# Assistive Technology Outcomes and Benefits Editorial Policy

**Aim and Scope**

***Assistive Technology Outcomes and Benefits***, published by the Assistive Technology Industry Association, is an open access, peer-reviewed journal that publishes articles specifically addressing the benefits and outcomes of assistive technology (AT) for Persons with Disabilities across the lifespan. The journal’s purpose is to advance the AT industry by (a) fostering communication among stakeholders interested in the field of AT, including manufacturers, vendors, practitioners, policy makers, researchers, consumers with disabilities, and family members; (b) facilitating evidence-based demonstrations and case-based dialogue regarding effective AT devices and services; and (c) helping stakeholders advocate for effective AT devices and services.

***Assistive Technology Outcomes and Benefits*** invites for consideration submissions of original papers, reports and manuscripts that address outcomes and benefits related to AT devices and services. These may include (a) findings of original scientific research, including group studies and single subject designs; (b) qualitative and mixed methods studies, such as focus group and structured interview findings with consumers and their families regarding AT service delivery and associated outcomes and benefits; (c) marketing research related to AT demographics or devices and services; (d) technical notes and usability studies regarding AT product development findings; (e) project/program descriptions in which AT outcomes and benefits have been documented; (f) case-based reports on successful approaches to service delivery; and (g) consumer perspectives on AT devices and services.

**Submission Categories**

ATOB welcomes scholarly contributions. However, many stakeholders engaged in the field of AT do not have an academic background. ATOB offers a unique opportunity for these stakeholders to contribute their expertise and experience in the context of achieving successful outcomes and beneficial impacts. ATOB understands that many potential authors may lack experience in authoring papers for peer- reviewed journal publication. Therefore, the ATOB Editorial Board is pleased to offer assistance in preparing and refining relevant submissions. Articles may be submitted under three categories:

*Voices from the Field*

Articles submitted under this category should come from professionals who are involved in some aspect of AT service delivery with persons having disabilities, or from family members and/or consumers with disabilities. Submissions may include case studies, project or program descriptions, approaches to service delivery, or consumer perspective pieces. All submissions should have a clear message and be written with enough detail to allow replication of results. See [ATOB Editorial Policy](http://www.atia.org/atob/editorialpolicy) for more details.

*Voices from Industry*

Articles submitted under this category should come from professionals involved in developing and marketing

specific AT devices and services. Case studies, design, marketing research, or project/program descriptions are appropriate for this category. See [ATOB Editorial Policy](http://www.atia.org/atob/editorialpolicy) for more details.

*Voices from Academia*

Articles submitted under this category should come from professionals conducting research or development in an academic setting. Submissions are likely to include applied/clinical research, case studies, and project/program descriptions. See [ATOB Editorial Policy](http://www.atia.org/atob/editorialpolicy) for more details.

**Types of Articles**

Within each of the voices categories, authors have some latitude regarding the type of manuscript submitted and content to be included. However, ATOB will only accept original material that has not been published elsewhere and is not currently under review by other publishers. Additionally, all manuscripts should offer sufficient detail to allow for replication of the described work.

*Applied/Clinical Research:* This category includes original work presented with careful attention to research design, objective data analysis, and reference to the literature.

*Case Studies:* This category includes studies that involve only one or a few subjects or an informal protocol.

*Design:* This category includes descriptions of conceptual or physical design of new AT models, techniques, or devices.

*Marketing Research:* This category includes industry-based research related to specific AT devices and/or services, demographic reports, and identification of AT trends and future projections.

*Project/Program Description:* This category includes descriptions of grant projects, private foundation activities, institutes, and centers having specific goals and objectives related to AT outcomes and benefits.

*Approaches to Service Delivery:* This category includes descriptions of the application of assistive technology in any setting (educational, vocational, institutional, home-life) to improve quality of life for people with disabilities.

*Consumer and Caregiver Perspectives:* This category offers an opportunity for product end users, family members, and caregivers to share their experiences in achieving successful outcomes and benefits through the application or use of AT devices and services.

**Mandatory Components of All Articles**

Authors must include a section titled Outcomes and Benefits containing a discussion related to outcomes and benefits of the AT devices/services addressed in the article.

Authors must include a short description of the article’s target audience and indicate the article’s relevance to that target audience. Authors may describe their work as it relates to more than one audience and should specify the value that each group may derive from the work.

**Publishing Guidelines**

Review detailed [Manuscript Preparation for Authors](https://www.atia.org/atob/authorguidelines) for information on formatting requirements and submission guidelines.

**For More Information**

Please see [ATOB’s Editorial Policy at http://www.atia.org/at-resources/atob](http://www.atia.org/at-resources/atob) for more details regarding the submission and review process, ATOB’s Copyright Policy, and ATOB’s Publication Ethics and Malpractice Statement.

Assistive Technology Outcomes and Benefits  
Best Practices for the Design and Development of Assistive Technology Products

Volume 17, Spring 2023

**Table of Contents**

[Introduction to Volume 17 ix](#_Toc129617298)

[SBIR at the National Institute on Disability, Independent Living, and Rehabilitation Research 1](#_Toc129617300)

[Open-Source Design Platform For AAC Research: Project Open 31](#_Toc129617302)

[Provider Perspectives on Providing Mainstream Smart Home Technologies as Assistive Technology 45](#_Toc129617304)

[Reflections on the Design, Development, and Implementation of a Braille Mobile App 60](#_Toc129617306)

[What Users of AT Wish Developers Knew About Their Literary Experiences 80](#_Toc129617308)

[Participatory Design Approach to Creating an Accessible Nurse-Call/Hospital Room Control System for Individuals With Severe Physical Impairments 100](#_Toc129617310)

[Design Considerations for Aphasia Rehabilitation Technologies: How Linguistic Factors and Computer Interaction Designs Alter User Behaviors During Autonomous Practice 115](#_Toc129617312)

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. ix-xii

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Introduction to Volume 17

## **Stephen M. Bauer, Ph.D.**

## State University of New York at Buffalo (retired)

***Corresponding Author***

Stephen Bauer

5055 Morgan Parkway

Hamburg, NY 14075

Email: [sb20143@gmail.com](mailto:sb20143@gmail.com)

### Best Practices for the Design and Development of Assistive Technology Products

For many decades members of the industrial, university, and non-profit sectors have constructed diverse paradigms to design, develop, and commercialize assistive technology (AT) products. These paradigms have evolved to meet the complex needs and expectations of persons comprising niche disability markets, within diverse personal and environmental contexts, which are often tightly constrained by available resources, adequate funding, and market potential. Current product design and development continues to assimilate evolving concepts and tools, integrate emergent technologies, and build upon the capacities of ubiquitous information and communication technologies ICT) and other computing infrastructures.

Four concepts broadly relevant to these paradigms are usable design (UD), participatory design (PD), localization (LO), and sustainable development (SD). In UD, designers and developers consider the extent to which “a product can be used by specified users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use” (International Organization for Standardization (ISO/TS; 2018). In PD, product users work collaboratively with designers and developers at all stages to clarify needs and abilities, anticipate tasks and task flows, identify contextual and environmental factors, and operationalize usability concepts. In LO, product design, development, production, and distribution are optimized to fit localized individual, contextual, social, and economic needs, constraints, and resources. Finally, the ISO defines SD as meeting “the needs of the present without compromising the ability of future generations to meet their own needs”. SD is about “integrating the goals of a high quality of life, health and prosperity with social justice while maintaining the earth’s capacity to support life in all its diversity” (ISO, 2010). Additional concepts include recognition that individuals with disabilities can frequently benefit from mainstream products as part of AT product systems. Paradigms for effective AT service methods and tools is critical to facilitate the provision of complex AT product systems.

Volume 17 comprises seven articles. The first six articles responded to the solicitation. The seventh and concluding article is of general interest to our field.

The first five articles were authored by **Voices from Academia**. In our first double article, *SBIR at the National Institute on Disability, Independent Living, and Rehabilitation Research,* Stephen Bauer conducts a detailed analysis of NIDILRR’s Small Business Innovation Research program for the period 2006–2020. Findings include that NIDILRR’s SBIR program performance compared favorably to NIH and NSF SBIR program performances; NIDILRR SBIR Phase II grants effectively supported AT product development; and the distribution of Phase II grants and AT products reflected US disability demographics and NIDILRR’s mission. It was also found that NIDILRR’s capacity building efforts were insufficient. Recommendations were made to improve and strengthen organizational performance.

In our second article, *Open-Source Design Platform for AAC Research: Project Open,* Sofia Benson-Goldberg, Lori Geist, and Karen Erickson developed an open-source platform to be used by an open-source community to explore novel ideas, facilitate research, and speed the development, testing, diffusion, and adoption of needed AAC user interface technology. The web-based open-source platform is accessible (can be used remotely and synchronously or asynchronously) while the open-source platform is flexible (usable by persons with diverse function and disability).

In our third article**,** *Provider Perspectives on Delivering Mainstream Smart Home Technology as Assistive Technology*, Dan Ding and Lindsey Morris employed a case study design with four provider groups to explore the implementation of an AT service process for mainstream smart home technology (MSHT). Provider groups had different levels of experience, employed in-house AT service processes for delivery of MSHT, encountered common and unique challenges to AT services, and offered recommendations for how these challenges might be addressed. Study findings may feed into later efforts to develop tools supporting AT services for MSHT.

In our fourth article, *Design, Development, and Implementation of a Braille Mobile App*, Cheryl Kamei-Hannan employed usable design and participatory design strategies and a team-based approach to design, develop, and test the *Reading and Writing Adventure Time!*, an AT product prototype used to facilitate student acquisition of braille (for reading and writing). Over a two-year period, *Reading and Writing Adventure Time!* was tested by 35 teachers of braille literacy and received a positive evaluation for both braille reading and writing. Teachers often had limited experience with braille and received technical assistance, as needed, from the study team. On average, teachers received about 185 hours of technical assistance in year one and 96 hours of TA in year two.

In our fifth article, *What Users of AT Wish Developers Knew About Their Literacy Experiences*, Ben Satterfield used the Think Aloud and persona methodologies to identify design requirements for AT software applications supporting reading literacy. Seven students with high incidence disabilities performed a reading task using their preferred AT device and were asked to talk about what they were doing and experiencing. Each interview was recorded, transcribed, and analyzed. Two groups of students reported common and related reading challenges and strategies to overcome these challenges. Authors used data, associated with students in each of the two groups, to create two distinct personas that can be used by educators, AT software developers, and publishers of educational literature.

Our sixth article, a **Voice from the Field**, is *Participatory Design Approach to Creating an Accessible Nurse-Call/Hospital Room Control System for Individuals with Severe Physical Impairments*. In this study, Susan Fager, Judith Burnfield, and Tabatha Sorenson employed participatory design and other best practices to design, develop, and test a prototype Nurse-Call/Hospital Room Control System that was independently usable by persons with severe disabilities in call/hospital room settings. Findings from this study influenced a commercial product design.

Our seventh article, of general interest, is a **Voice from Academia**. In *A Case Study Relating Computer Interaction Designs, Linguistic Properties of Practice Words, and Autonomous User Engagement and Success*, Richard Steele, Michael de Riesthal, and Angel Ball considered how the human-computer interactions (HCI) and linguistic factors affect the observed behaviors of persons with aphasia and apraxia of speech while autonomously using a therapeutic rehabilitation technology. The study employed two HCI designs while linguistic factors included syllabic constituent typicalities and word frequencies of the lexical stimuli. HCI designs were found to interact with linguistic factors so as to predictably influence user engagement patterns and word repetition success rates. Drawing on study findings, suitably adaptive HCI designs might boost autonomous user engagement and the rehabilitative effectiveness of therapeutic software applications.

### Conclusions

Volume 17 contains topically diverse articles. Six articles demonstrate (some of the) best practices used in the design, development, transfer, and adoption of AT products or AT product systems. Four of these articles pertain to AT products for augmentative and alternative communication (Benson-Goldberg et al., 2023), braille literacy (Kamei-Hannan, 2023), reading literacy (Satterfield, 2023), and environmental control (Fager et al., 2023). One of these articles (Ding & Morris 2023) pertains to AT service provision for complex AT product systems (MSHT for independent living). In his study, Bauer (2023) examined NIDILRR’s SBIR program (grants to small AT companies to support AT product development and commercialization) and considers how NIDILRR’s capacity building efforts might be optimized. The seventh article (Steele et al., 2023) considers the impact of HCI design and lexical factors on observed behavior of persons with aphasia and apraxia while using a therapeutic rehabilitation technology. Persons with disability participating in or potentially benefitting from Volume 17 studies are broadly “part of” communication (Benson-Goldberg et al., 2023; Steele et al., 2023), visual (Kamei-Hannan, 2023), learning (Satterfield, 2023), physical (Ding & Morris, 2023) or “cross” (Bauer, 2023; Fager et al., 2023) disability populations. Numerous best practices are demonstrated in these articles; however, many additional studies are needed.

Assistive technology includes both AT services and AT products. Across diverse professions, AT service providers have repeatedly self-reported feeling well-qualified to assess an individual with disability’s function, disability(s), needs, and environmental constraints. However, AT service providers also self-reported feeling less qualified to identify, select, acquire, and customize suitable AT products. Many factors contribute to this problem (Arthanat et al., 2017; ATIA, 2011; Jans & Scherer, 2006; Kanny & Anson, 1998). If these critical deficiencies are not addressed, then individuals with disability will gain no or sub-optimal benefit from AT products—irrespective of whether such products were poorly or exceptionally designed (Elsaesser & Bauer, 2011). The need for best practice AT service methods and tools (especially) to support the provision of emergent and complex AT product systems is critical.

One Volume 17 article focuses on one federal agency (NIDILRR), employing one grant mechanism (SBIR program), to fund small one stakeholder group (AT small businesses), and to develop and commercialize of AT products (Bauer, 2023). NIDILRR’s (and analogous) SBIR programs have a substantial impact on the AT industry, AT product development and commercialization, and on individuals with disability who derive benefits from these products. However, other studies are needed to better understand how other federal agencies and other grant mechanisms support the design, development, and testing of AT prototype “inventions” by university and nonprofit researchers. These studies should consider intellectual property issues tied to the transfer of inventions to industry and subsequent product commercialization.

Numerous best practices are available to support the design, development, transfer, commercialization, and adoption of AT products and AT product systems. However, even readily available practices are inconsistently or insufficiently utilized by small AT businesses, university, and non-profit researchers. Studies are needed that concretely demonstrate strategies that effectively overcome barriers to stakeholders’ awareness of, persuasion of worth, decision to try, and long-term use and retention of current and emerging best practices for AT product design, development, transfer, and commercialization (Rogers, 2003). Additional **Voices from the Field**, **Voices from Academia**, and **Voices from Industry** are encouraged to submit manuscripts demonstrating the use and efficacy of best practices, and also addressing these additional important topics.

### References

Arthanat, S., Bauer, S., & Elsaesser, L. -J. (2017*).* A survey of assistive technology service providers in the United States*.* *Disability and Rehabilitation: Assistive Technology,* *12*(8), 789–800. <https://doi.org/10.1080/17483107.2016.1265015>

Assistive Technology Industry Association. (2011). *Critical need for knowledge and usage of AT and AAC among speech language pathologists: Survey white paper*. Assistive Technology Industry Association (ATIA). Retrieved January 16, 2023, from <https://www.atia.org/wp-content/uploads/2018/12/ATIA-SLP-Survey-2011.pdf>

Elsaesser, L. -J., & Bauer, S. M. (2011). Provision of assistive technology services method (ATSM) according to evidence-based information and knowledge management. *Disability & Rehabilitation: Assistive Technology, 6*(5), 386–401. <https://doi.org/10.3109/17483107.2011.557763>

International Standardization Organization. (2018). *Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts* (ISO 9241-11:2018, §3.1.1). Retrieved from <https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en>

International Standardization Organization. (2010). *Guidance on social responsibility* (ISO 26000-2:2010, §2.23). Retrieved from <https://www.iso.org/obp/ui/#iso:std:iso:26000:ed-1:v1:en>

Kanny, E. M., & Anson, D. K. (1998). Current trends in assistive technology education in entry-level occupational therapy curricula. *American Journal of Occupational Therapy, 52*(7), 586–91. <https://doi.org/10.5014/ajot.52.7.586>

Jans, L. H. & Scherer, M. J. (2006). Assistive technology training: Diverse audiences and multidisciplinary content. *Disability and Rehabilitation: Assistive Technology. 1*(1–2), 69–77. <https://doi.org/10.1080/09638280500167290>

Rogers, E. M. (2003). *Diffusion of innovations, 5th edition*. Free Press. ISBN 978-0-7432-2209-9.

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 1-29

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# SBIR at the National Institute on Disability, Independent Living, and Rehabilitation Research

## **Stephen M. Bauer, Ph.D.**

## State University of New York at Buffalo (retired)

***Corresponding Author***

Stephen Bauer

5055 Morgan Parkway

Hamburg, NY 14075

Email: [sb20143@gmail.com](mailto:sb20143@gmail.com)

### Abstract

As the government’s primary disability research agency, the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) supports diverse research and development activities that benefit individuals with disability. In particular, its Small Business Innovation Research (SBIR) program supports the development and commercialization of assistive products. While the National Academies of Science (NAS) has conducted repeated studies of the five largest federal SBIR programs (DOD, NIH, NSF, DOE, and NASA), there are few studies for smaller but still important federal SBIR programs. The current study evaluated NIDILRR’s SBIR program for the period 2006–2020. Evaluation comprised four parts: program performance *worth* (costs to develop and returns for commercialized assistive products), program performance *value* (importance of these assistive products), *capacity building* (agency actions to optimize program performance), and *outcomes* (proposed and achieved assistive products). Key findings: Significant *worth* (e.g., a high percentage of Phase II awards resulted in commercialized assistive products) and *value* (e.g., focus of Phase II awards and derived assistive products correlated strongly with disability demographics) were demonstrated. *Capacity building* had both strengths (e.g., provision of technical reviews to applicants benefitted many applicants) and weaknesses (e.g., provision of technical reviews post-competition did not benefit first-time applicants, constrained diversification of AT companies, and derived assistive products). *Outcomes* correlated with disability demographics but proposed and achieved assistive products were under-diversified. Recommendations were made to optimize NIDILRR’s important and generally high-performing SBIR program.

***Keywords:*** assistive, disability, NIDILRR, products, SBIR

### SBIR at the National Institute on Disability, Independent Living, and Rehabilitation Research

The mission of the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) “is to generate new knowledge and to promote its effective use to improve the abilities of individuals with disabilities to perform activities of their choice in the community and to expand society's capacity to provide full opportunities and accommodations for its citizens with disabilities.” NIDILRR achieves this mission (in part) by “promoting the transfer of, use and adoption of rehabilitation technology for individuals with disabilities in a timely manner” (Administration on Community Living, 2021a). By providing seed funding for product development directly to small businesses, NIDILLR’s Small Business Innovation Research (SBIR) program is critical to achieving this mission (Administration on Community Living, 2021b).

### Target Audience and Relevance

It is the intent of this study to help AT companies better understand and more successfully use NIDILRR’s SBIR program; to help academic researchers better understand the performance of and outcomes from NIDILRR’s SBIR program, spurring further research; and to clarify the importance of NIDILRR’s SBIR program and offer guidance for the purpose of program optimization. Finally, it is our hope that political leaders and persons with disability will better understand the importance of and practical benefits deriving from NIDILRR's SBIR program.

### Background

The SBIR program was established across federal agencies by the Small Business Innovation Development Act of 1982, P.L. 97-219 §2(b) (1982) and reauthorized and extended multiple times. The purpose of this Act was “(1) to stimulate technological innovation; (2) to use small businesses to meet Federal research and development needs; (3) to foster and encourage participation by minority and disadvantaged persons in technological innovation; and (4) to increase private sector commercialization innovations derived from Federal research and development.” The second purpose was particularly important as federal agencies have distinct missions, and SBIR program design, performance, and outcomes vary accordingly.

The US Small Business Administration (2021a) clarifies that to be eligible to participate in an SBIR program, small businesses must be “(1) organized for profit, with a place of business located within the US; (2) more than 50% owned and controlled by one or more individuals who are citizens or permanent resident aliens of the US; and (3) have no more than 500 employees, including affiliates”. Women- and minority-owned small businesses are encouraged to participate.

Congress found in the Small Business Innovation Research Reauthorization Act of 2000, P.L. 106-554 §102.(2) & §102.(3) (2000) that the SBIR program “made the cost-effective and unique research and development capabilities possessed by the small businesses of the Nation available to Federal agencies and departments; … produced innovations of critical importance in a wide variety of high-technology fields,” and “… is a catalyst in the promotion of research and development, the commercialization of innovative technology, and the development of new products and services”. The National Academies of Science (2008) found SBIR program strengths to also include: participating small businesses have interests that align with agency missions, submit bottom-up proposals thereby ensuring a strong commitment to positive R&D outcomes, own all inventions (and intellectual property of) deriving from SBIR grants, and have few private sector funding alternatives (pp. 35–37).

Federal agencies have great latitude when implementing their SBIR programs. The US Small Business Administration (2021b) describes three phases for basic SBIR programs. Phase I (PI) establishes “the technical merit, feasibility, and commercial potential of the proposed R/R&D efforts …”. Phase II (PII) continues “the R/R&D efforts initiated in Phase I. Funding is based on the results achieved in Phase I and the scientific and technical merit and commercial potential of the project proposed in Phase II. Typically, only Phase I awardees are eligible to apply for a Phase II award.” In Phase III (PIII), small businesses “pursue commercialization objectives resulting from the Phase I/II R/R&D activities. The SBIR/STTR programs do not fund Phase III.” At some agencies, PIII “may involve follow-on, non-SBIR/STTR funded R&D or production contracts for products, processes or services intended for use by the U.S. Government”. The US Small Business Administration (2021c) also states that SBIR programs may employ grants (investigators propose field-initiated R&D projects that align with an Agency’s mission to accomplish a public purpose) or contracts (investigators propose agency-directed R&D projects to produce goods or services that address an agency’s needs to accomplish a governmental purpose) funding mechanisms. The National Academies of Science (2015a) describes variations on the basic three phase SBIR program structure to include: Direct-to-Phase II (well-prepared companies may skip PI and apply directly to PII), Fast-Track (PI and PII applications are submitted and reviewed together as one proposal), PIIb (follow-on funding is provided or matched by agencies for completed PII projects that require extraordinary R&D) and other program variants (pp. 31-32).

The US Small Business Administration (2021d) offers information on SBIR program funding and dates the currency of such information. In FY2017, federal agencies with extramural research and development (R&D) budgets that exceeded $100 million were required to allocate 3.2% of their extramural R&D budget towards an SBIR program. Congress periodically adjusts adjust this percentage. As of November 2020, the Small Business Administration (SBA) capped all SBIR PI and PII awards at $259,613 and $1,730,751 respectively. Agencies with SBIR programs set the floor and maximum for their PI and PII awards up to these caps. On a case-by-case basis, agencies seek waivers from SBA to exceed funding caps (SBIR-STTR: America’s seed fund. About. Award funding amounts). From 2006–2020, NIDILRR’s total budget generally exceeded $100M per year and in FY2020 NIDILRR allocated 3.3% of its extramural budget to its SBIR program (B. Bard, personal communication, August 25, 2021).

SBIR programs are offered by federal departments and federal agencies (Small Business Administration, 2021e). *Federal departments* hosting one or more agencies with SBIR programs include Agriculture (USDA), Commerce (DOC), Defense (DOD), Education (ED), Energy (DOE), Health and Human Services (HHS), Homeland Security (DHS), and Transportation (DOT). *Federal agencies* with SBIR programs include the Environmental Protection Agency (EPA), National Institutes of Health (NIH), National Science Foundation (NSF), and National Aeronautics and Space Administration (SBIR-STTR: America’s seed fund. About: Participating federal agencies). NIDILRR is one of numerous agencies under the US Department of Health and Human Services with small SBIR programs. Federal agencies with extramural budget less than $100 million have the discretion to create and maintain SBIR programs supporting their mission.

Each agency’s SBIR program is contrived to attract small businesses with interests and capabilities to develop products to advance their mission and to serve the national interest. Desirable program outcomes comprise an agency-specific mix of products, patents, and licenses, follow-on funding, and peer-reviewed publications. Each agency must understand the challenges that participating small businesses will face and provide resources sufficient in scale and duration to overcome these challenges. Such challenges might pertain to markets (governmental versus non-governmental, size, heterogeneity, sales, revenue, etc.), industry characteristics (competitors, competitive practices, competing products, etc.), technical challenges (R&D scale, difficulty, duration and cost, manufacturability, etc.), regulatory requirements (clinical trials, standards, approvals, etc.), intellectual property (patents, copyrights, licensing, etc.), and so forth. Based upon their understanding, each agency seeks to optimize program construction. Substantial differences in agency missions, participating small businesses, contextual challenges, desired performance and outcomes, and program constructions obviate any simple more or less; better or worse, comparisons between SBIR programs. Nonetheless, federal agencies may face analogous challenges, and strategies pursued by one agency may be adapted to another agency’s benefit.

The Small Business Innovation Research Reauthorization Act of 2000, P.L. 106-554 §108(a)(1) (2000) tasked the National Research Council (NRC) with undertaking a “comprehensive study of how the SBIR program has stimulated technological innovation and used small business to meet federal research and development needs.” To this end, in 2003 the National Academies of Science (2008) initiated repeated studies of federal agencies with SBIR program budgets exceeding $50M that included (in decreasing order of program size) the Department of Defense, National Institutes of Health, Department of Energy, National Aeronautics and Space Administration, and the National Science Foundation (pp. 13-14). In discussions that follow, the NIH and NSF SBIR programs and inter-program comparisons are separately considered.

The National Institutes of Health (2021a) mission is “to seek fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to enhance health, lengthen life, and reduce the burdens of illness and disability.” The Small Business Administration (2021f) states that NIH, with a total budget of about $43B, allocated about $2.5B (about 6% of their *total* budget) to its combined SBIR/STTR program (The National Institutes of Health (2021b) stated that Phase I (6–12 months duration) and Phase II awards (24 months duration) had (typical) funding *floors* of $150K and $1M and *caps* of $225K and $1.5M respectively, and that NIH may seek SBA waivers. The National Academies of Science (2015a) further clarified that the NIH SBIR program used both grants and contracts, offered Three-Phase, Fast Track, PIIb, Direct-to-Phase II, and Bridge grant opportunities, may seek SBA waivers, and may offer supplemental funding (pp. 32-33).

The National Academies of Science (2015a) published its most recent study of the NIH STTR and SBIR programs for the period 2005–2014. Referencing the NIH RePorter database, the NAS found that about 46,700 PI proposals resulted in about 7150 PI awards (6480 grants and 670 contracts) with a 15.3% rate of success and average award size of about $197K. PI winners submitted about 5800 PII proposals that resulted in about 2575 Phase II grants with a 38.7% rate of success and average award size of about $1.2M. NIH also provided about 20 Fast Track and 50 PIIb awards per year. PII applications typically lagged PI awards by one year (Pearson *r* = 0.67) (pp. 105-122).

To assess commercialization outcomes, the National Academies of Science (2015a) selected 3,375 companies with completed II grants *or contracts*. NAS then successfully contacted 1652 companies, of which 726 companies completed commercialization surveys (a 43.9% “effective response rate”). Of respondent companies, 9% reported “some” product sales with associated revenue of < $100K (39%), $100K =< $500K (23%), $500K =< $1M (11%), and $1M+ (27%). Another 25% of respondents expected future product sales. The NAS found that “About one-third of companies submitting Phase I SBIR applications were new to the NIH SBIR program, and they accounted for between 20 and 25 percent of proposals.” That 33% of new companies submitted only 20–25% of total proposals probably reflects that repeat applicants submit more than one proposal on average. In addition, “these [new] companies also accounted for about 30 percent of Phase I awardees … which suggests that the program is open to new entrants and that existing companies do not have a substantial advantage in pursuing funding”. That is, first time applicants were somewhat *more successful* in winning Phase I awards than repeat applicants (pp. 2, 142-145, 109).

The National Academies of Science (2015a) also found that “The most prolific Phase I company … received 44 Phase I awards during the 10-year period. Overall, the top 20 awardees accounted for 7.7 percent of SBIR/STTR Phase I awards …. The [two] most prolific Phase II companies … each received 24 awards during the 10-year period. The top 20 Phase II awardees (plus one tie) accounted for 9.9 percent of SBIR/STTR Phase II awards.” Finally, survey respondents reported that the SBIR program had a transformative (62%) or positive (35%) impact (the two highest ratings) on their companies (pp. 132-133, 155). We next consider the National Science Foundation’s SBIR program.

The National Science Foundation (NSF) mission is “to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense and for other purposes” and the NSF envisions “a nation that capitalizes on new concepts in science and engineering and provides global leadership in advancing research and education” (National Science Foundation, 2021a). In 2021, the NSF had a total budget of about $8.5B (National Science Foundation, 2021b). From this budget, NSF allocated about $200M (about 3.4% of its $600B *extramural* budget) to a combined SBIR/STTR program. NSF PI (6–12 months) and PII awards (24 months) have funding floors of $150K and $1M and caps of $256K and $1M respectively, and NSF may request SBA waivers (National Science Foundation, 2021b; National Science Foundation, 2021c). The SBIR program employs grants, offers Three-Phase, Fast Track and PIIb grant opportunities, and may provide supplemental funding (National Science Foundation, 2021d).

In 2015, the National Academies of Science (2015b) also published its most recent study of the NSF SBIR and STTR programs for the period 2003–2012. Drawing on SBA awards data and NSF records, the NAS found that about 15,022 PI proposals resulted in 2600 PI awards (a 17.3% success rate) with an average award size of about $120K. PI winners submitted about 2,229 PII proposals that resulted in 981 PII awards (a 44.4% success rate) with an average award size of about $580K. PII applications were typically found to lag PI awards by about one year (Pearson *r* = 0.73) and 8.6% of PI applicants would subsequently win PI, PII, and PIIb awards (pp. 57–58, 68–69, 71, 83–85).

To assess commercialization outcomes, the National Academies of Science (2015b) contacted by email, a sample of 562 companies that had completed PII (281) or PIIb (281) grants. Following two rounds of contact verifications and re-contacts, NAS ultimately reached 458 companies. Of these companies, 120 of 242 PII awardees (a 48.3% “effective response rate”) and 112 of 216 PIIb awardees (a 50.9% “effective response rate”) provided complete or partial survey responses for a combined 50.7% “effective response rate” (pp. 219–220). Of these respondents 69.7% reported some product sales with revenue generation of <$1M (64.0%), $1M to $5M (27.2%), and >$5M (8.8%). Another 18.5% of these respondents “anticipated” product sales. On average, NSF allocated about 40% of SBIR funding to PI awards and 60% to PII awards (pp. 55, 88-89).

The National Academies of Science (2015b) found for the period 2008–2012 (when complete reliable data were available) that about 1,420 PI grants were awarded to companies that had no (documented) grants for the period 2003–2007. That is, about 70% of all PI awardees for the period 2003–2012 were *first-time applicants* and *first-time winners*. Overall, 2,009 different companies received 2896 PI awards. Of these companies, 1,504 (74.9%) received only one PI award, 483 (24.0%) received two to five PI awards, and 22 (1.1%) received six to nine PI awards. Companies with only one award received 51.9% of all awards, while companies with two to five awards received 1235 (42.6%) of all awards, and companies with six to nine awards received 157 (5.4 %) of all awards (pp. 60-61).

The National Academies of Science (2015a) also found for PII, that 787 different companies received 1,002 awards. Of these, 647 companies (82.2%) received only one award, 135 companies (17.1%) received two to four awards, and five companies (0.6%) received five to seven awards. Of the 1,002 PII awards, companies with one award received 647 (64.6%), companies with two to four awards received 328 (32.7%) and companies with five to seven awards received 27 (2.7 %). PII applications typically lag PI awards by about one year (Pearson *r* = 0.73) (pp. 71, 85). Finally, respondents indicated that the NSF SBIR program had a transformative (35%) or substantial positive long-term effect (54%) on their company and 45% indicated that their company was founded entirely or partially because of the NSF SBIR program (pp. 132-133, 155, 182-183). We now turn our attention to interagency comparisons.

A major study by Bauer and Arthanat (2010) examined assistive product development supported by SBIR and STTR programs at the National Institutes of Health, National Science Foundation, Department of Agriculture, Department of Transportation, and Department of Education (ED/NIDRR) for the period 1996–2005. Investigators employed an ICF-based framework, inclusion-exclusion criteria, and assignment heuristics to systematically classify SBIR grants and proposed assistive products. SBIR awards data were drawn from seven SBIR databases maintained by federal agencies and from the SBA’s Tech-*Net* database (now called SBA Award Data). Overall, about 17,000 SBIR Phase I and 6,000 Phase II grant and contract abstracts were reviewed. Across the five agencies, investigators identified 675 PI and 329 PII awards supporting assistive product development.

Bauer and Arthanat (2010) found that the number and percent of total PI awards supporting assistive product development was NIH (414, 61.3%), ED/NIDRR (206, 30.5%), NSF (46, 6.8%), USDA (8, 1.2%), and DOT (4, 0.6%). Similarly, the number and percent of total PII awards supporting assistive product development was NIH (220, 66.9%), ED/NIDRR (83, 25.2%), NSF (20, 6.1%), USDA (6, 1.8%), and DOT (0). Across these five agencies, 4.0% of their aggregate SBIR PI budgets and 5.9% of their aggregate PII budgets supported assistive product development. The “types” of assistive products that companies proposed to develop differed substantially across the NIH, NSF, and ED/NIDRR SBIR programs (pp. 58-59).

Bauer and Arthanat (2010) also compared the average funding levels for the NIH, ED/NIDRR, and NSF SBIR programs. For PI, the funding level ratios were: 1.78:1 (NIH to ED/NIDRR), 1.73:1 (NSF to ED/NIDRR), and 1.04:1 (NIH to NSF). For PII, the funding level ratios were: 2.4:1 (NIH to ED/NIDRR), 1.85:1 (NSF to ED/NIDRR) and 1.3:1 (NIH to NSF). Finally, the PI to PII conversion rates (PI winners also win PII awards) were: 0.48 (NIH), 0.45 (NSF), and 0.38 (ED/NIDRR) respectively. Finally, the between-agency *ratios* for the number of PII awards supporting assistive product development was 2.2:1 (NIH to ED/NIDRR) and 0.23:1 (ED/NIDRR to NSF). Given that the NIH and NSF SBIR programs are much larger (I.e., in terms of the number and size of PI and PII grants available to companies) than the NIDILRR SBIR program, this was a truly startling finding (pp. 58-59).

On further consideration of interagency PII awards ratio, if we assume that the NIH, NSF, and NIDRR SBIR programs are *equally attractive* to AT companies, then SBIR awards supporting assistive product development should be roughly proportional to the number of grants available from each program. Taking 2001 as the study midpoint, the NIH, NSF, and ED/NIDRR SBIR program budgets were about $400M, $80M, and $2M. Accounting for program budget size, PI and PII award size, and PI to PII conversion rates, the *expected* interagency PII awards ratio of would *roughly* favor NIH to ED/NIDRR (by >100 to 1) and NSF to ED/NIDRR (by >20 to 1). Comparing *expected* and *actual* interagency PII awards ratios, the ED/NIDRR SBIR program was *strongly preferred by* AT companies (National Institutes of Health, 2021b; National Science Foundation, 2021b; National Science Foundation, 2021c; Rehabilitation Services Administration, 2021).

The concepts of disability and assistive technology are central to the current study. The Americans with Disabilities Amendments Act of 2008, P.L. 110-325 §3(1)(A) & §3(2) (2008) defines “disability with respect to an individual” as “a physical or mental impairment that substantially limits one or more life activities of such individual”. The ADA then provides two non-enumerated listings of “major life activities.” Roughly speaking, under the ADA, a legal disability requires a person to have a significant physical, mental, or sensory (included in major life activity listings) body function impairment that is causative to a significant activity limitation.

The Assistive Technology Act of 2004 P.L. 108-324 §3(3) & §3(4) (2004) defines “assistive technology” to mean “technology designed to be utilized in an *assistive technology device* or *assistive technology service*”. The ATA further defines an assistive technology device to mean “Any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of *individuals with disabilities*”. That is, the ATA asserts that individuals with disability (as defined by the ADA) are the *intended users* of assistive products.

Building on the ADA and ATA definitions for disability and assistive technology, the International Classification of Functioning, Disability, and Health (ICF) can be used to define disability populations and to classify assistive technology products (World Health Organization, 2001). Specifically, the ICF provides “a unified and standard language and framework for the description of health and health-related states” for use in “various disciplines and different sectors” and “a scientific basis for understanding and studying health and health-related states,” and permits “the comparison of data across countries, health-care disciplines, services, and time. ICF applications include “as a statistical tool—in the collection and recording of data…” and “as a social policy tool…” (pp. 3, 5). The ICF hierarchy begins with two Parts: Part I: Functioning and Disability comprising Body Functions and Body Structures, and Activities and Participation, and Part II: Contextual Factors comprising External Influences on Functioning and Disability and Internal Influences on Functioning and Disability. Further details on the ICF hierarchy are presented next and subsequently used throughout the remainder of the paper.

Body Functions comprise eight chapters: Mental Functions, Sensory Functions and Pain, Voice and Speech Functions, Functions of the Cardiovascular, Hematological, Immunological and Respiratory Functions, Functions of the Digestive, Metabolic and Endocrine Systems, Genitourinary and Reproductive Functions, Neuromusculoskeletal and Movement-Related Functions, and Functions of the Skin and Related Structures. Body Structures comprise eight analogous chapters. Impairments are *problems* in body functions or structures with five levels of significance (no, mild, moderate, severe, and complete).

Activities and Participation comprise nine chapters: Learning and Applying Knowledge, General Tasks and Demands, Communication, Mobility, Self-care, Domestic Life, Interpersonal Interactions and Relationships, Major Life Areas, and Community, Social, and Civil Life. Every chapter is further broken into domains and sub-domains. Activity and Participation domains can be used to denote activities, participation, or both. Limitations are *difficulties* an individual may have in executing activities or participations with five levels of significance (no, mild, moderate, severe, and complete). Every Body Function or Activity chapter is further comprised of a hierarchy of domains, sub-domains, etc. Each hierarchical component is well-defined and has clear inclusion and exclusion criteria (World Health Organization, 2001).

Referring to the ADA disability definition, pairs (referred to as “intersections” when in matrix format) of Body Function chapters and Activity chapters: domains whose members share similar significant (moderate, severe, complete) impairments and limitations can be used to define disability populations. Such populations have the critical properties of being demographically disjoint and additive. Assistive products meeting similar functional needs then classify to the same or closely related disability population(s). The remainder of this paper employs the notational convention – [optional Part:] chapter name or acronym: [optional domain name or acronym]: [optional sub-domain name or acronym].

Of note that Contextual Factors: External Influences: Chapter 1 Products and Technology lists exemplar APs under 12 domains (e110 Products or substances for personal consumption, e115 Products and technology for personal use in daily living, etc. However, many of these Chapter 1 domains include APs that serve two or more disability populations. Consequently, Chapter 1 domains cannot be used for assistive product classification (World Health Organization, 2001). Similarly, the international standard ISO9999:2016 Assistive Products for Persons with Disability—Classification and Terminology defines disability in a manner consistent with the ADA and the United Nations Convention on the Rights of Persons with Disability. However, subsequent product classification by the ISO9999 does not employ this definition. Instead, products are placed into one of twelve ISO9999 classes (and their sub-classes) corresponding to “difficulties” (problems associated with activities or participations) with little regard to body function impairment (International Standardization Organization, 2016; United Nations, 2021). Consequently, products serving diverse disability *and non-disability* populations can be found in ISO9999:2016 classes. Bauer, Elsaesser, and Arthanat (2011) offer a more complete discussion of the ISO9999. We next consider disability demographics.

In Table 1, seven “disability” questions drawn from the American Community Survey (ACS) and US Census (USC) are corresponded to disability populations. Of the seven ACS and USC questions, two questions (Hearing, Vision) refer only to Body Function domains, leaving Activity domains implicit, and five questions (Cognitive, …Independent Living) refer only to Activity domains, leaving Body Function domains implicit.

Per ACS responses, 26.0% of the US citizens aged 18–64 self-report having one or more disabilities. However, persons responding positively to *any* of the six ACS disability questions, *on average* responded positively to 2.32 such questions. The added UCS question for expressive communication addresses a critical disability (ICF sub-chapter Communication: producing) that is not accounted for by the six ACS questions. Respondents to the UCS Communication question include persons reporting both “severe” and “non-severe” difficulties having their *productive speech understood*.

***Table 1: Disability Demographics by Body Function and Activity***

| **“Disability Domain”** | **Associated Survey Question** | **Percent (%) of US Population** | **Body Function Chapter: Domains** | **Activity Chapter(s): Domains** |
| --- | --- | --- | --- | --- |
| Visual1 | Is this person blind or does he/she have serious difficulty seeing even when wearing glasses? | 2.3 | Sensory: Vision | [One or More] |
| Hearing1 | Is this person deaf or does he/she have serious difficulty hearing? | 3.6 | Sensory: Hearing | [One or More] |
| Cognitive1 | Because of a physical, mental, or emotional condition, does this person have serious difficulty concentrating, remembering, or making decisions? | 5.1 | [One or More] | Learning and Applying Knowledge |
| Communication2 | Difficulty with speech? | 2.1 | [One or More] | Communication |
| Ambulatory1 | Does this person have serious difficulty walking or climbing stairs? | 6.8 | [One or More] | Mobility |
| Self-Care1 | Does this person have difficulty dressing or bathing? | 2.6 | [One or More] | Self-Care |
| Independent Living1 | Because of a physical, mental, or emotional condition, does this person have difficulty doing errands alone, such as visiting a doctor’s office of shopping? | 5.6 | [One or More] | Domestic Life |

*1American Community Survey (ACS) (Cornell University, 2018); 2US Census (USC) (United States Census Bureau, 2014)*

Our study also examined NIDILRR’s capacity building efforts for participants in its SBIR program. “Capacity building” has many *related* definitions; however, there is no *universal and standard* definition. Consequently, we employed the Wikipedia (2022) definition for *capacity building* as “the process by which individuals and organizations obtain, improve, and retain the skills, knowledge, tools, equipment and other resources needed to do their jobs competently or to a greater capacity (larger scale, larger audience, larger impact, etc.)”. To evaluate the effectiveness of NIDILRR’s capacity building efforts, proxies for capacity must also be measurable. For example, we will look at the impact of NIDILRR’s capacity building efforts on PI and PII success (an award is won) rates for single year (SY) and multi-year (MY) applicants, and on the composition and diversification of the applicant pool using NIDILRR’s SBIR program.

NIDILRR provides two capacity building opportunities for SBIR PI and PII applicants: a *pre-submission training session* and *post-competition technical reviews*. The pre-submission training session is constructed and intended so as to impart useful (though sometimes difficult to find) public knowledge to self-selecting applicants. Training sessions are led by project officers and cover, for example, grant opportunity description, grant logistics (e.g., funding levels, award duration, filing deadlines, fonts, formatting, and page length), contact information, proposal review criteria, sub-criteria and point assignments, peer review process, eligibility requirements (e.g., small US business, responsive to criteria), common applicant errors, and basic tips. Pre-submission training is constructed so that PI and PII competitions remain “unbiased” (i.e., applicants that *do* participate in training sessions do not gain a significant advantage over applicants that *do not*). As a practical matter, many applicants *choose not* to participate in the pre-submission training (though trainings are recorded and may be reviewed).

Post-competition Technical Reviews (TR) comprise detailed, proposal-specific feedback from expert peer-review panels with respect to SBIR review criteria. *Primary criteria* may include: the Importance of the Problem (max 20 pts), Quality of Project Design (max 50 pts), Project Staff (max 15 pts), Adequacy and Reasonableness of Budget (max 5 pts), and the Adequacy and Reasonableness of Resources (max 10 pts) (ACL, 2021). *Secondary criteria* operationalize primary criteria (i.e., issues covered, description of issues); however, secondary criteria weighting (i.e., importance as a primary criteria component) is left to reviewers’ judgements (a subjective exercise).

Five experts, comprising the *peer review panel*, normally assess each PI and PII proposal. The peer review *process* has two parts: *individual reviews* carried out by each expert and a *panel review* carried out by the entire panel. During individual reviews, experts assess each proposal with respect to primary criteria. For each primary criteria, experts then draft strength and weaknesses comments and assign a preliminary score. During the *panel review*, experts discuss each proposal on a criteria-by-criteria basis and can revise their comments and scores in light of panel discussions. Experts are asked to conduct all reviews (individual and panel) independently (review of one proposal should not influence on/have relevance to the review of another proposal). Finally, for each proposal, the panel writes (as a group) a summary comprising the consensus strengths and weaknesses. The final TR comprises five individual reviews (with detailed comments and scores) plus the panel summary (consensus comments). Applicants receive their TRs *after completion* of each PI and PII competition.

### Research Questions

SBIR program *performance* was assessed in terms of the *worth* (economic measures) and *value* (importance measures) of assistive products developed with NIDILRR SBIR funding, and later commercialized SBIR *capacity building* was assessed in terms of NIDILRR actions to optimize SBIR program performance. Review of NIH and NSF SBIR program construction, performance, and capacity building provided many useful insights.

RQ1: Does NIDILRR’s SBIR program provide significant *worth*? Measures of worth include, for example, the number of PI applications versus available PI grants, the number of PII applications versus available PII grants, the number of assistive products versus the number of PII grants, etc.

RQ2: Does NIDILRR’s SBIR program provide significant *value*? Measures of value include, for example, the number and distribution of PII grants versus disability populations, the number and distribution of assistive products versus disability populations, advancement of NIDILRR’s mission, etc.

RQ3: Do NIDILRR’s capacity building activities (online documentation, technical assistances, webinars, etc.) optimize SBIR program performance? Measures of capacity building include, for example, applicant diversification, assistive product diversification, PI and PII applicant success rates, value and worth of assistive products, etc.

### Method

The current study draws NIDILRR SBIR program data from four sources: NIDILRR records, the National Rehabilitation Information Center (NARIC) records, the US Small Business Administration (SBA), and direct correspondence with NIDILRR SBIR PII grantees (National Rehabilitation Information Center, 2021). On a yearly basis, NIDILRR records include small business applicants (winners and losers), proposals, titles and abstracts, investigators and contact information, TRs, rank ordered scores, and awardees. In addition, grantees complete annual performance reports that include status reports on product development and commercialization, product, and market descriptions, etc.

NARIC (under a NIDILRR contract) maintains a searchable database that includes “more than 2,800 current and completed projects” for the period 1986 to present (NARIC, 2021). The SBA, established by the Small Business Act of 1953 P.L. 85-536 §2(a) & §4(a) (1953), “aid[s], counsel[s], assist[s] and protect[s], insofar as is possible, the interests of small business concerns”. In 1983, the SBA incepted a searchable public database (called Award Data) for SBIR and STTR awards. Prior to 2012, however, it was optional for federal agencies to report their SBIR data to the SBA, and many agencies maintained independent SBIR databases (Small Business Administration, 2012). NARIC and SBA SBIR program records include the awarding agency, grant titles, numbers and abstracts, awardees, investigators and contact information, award phase, start and end years, and funding. Whenever possible, study investigators triangulated NIDILRR, NARIC, and SBA records to ensure accuracy and completeness. Losing PI and PII applicants were solely identified in NIDILRR records while PI and PII awards were generally identified in three sources.

All NIDILRR grantees are required to complete Annual Performance Reports (APR) until grant completion; however, assistive product commercialization typically lags PII completion. Consequently, NIDILRR PI and PII grantees (usually the PII investigator) were contacted (by email and phone) to confirm product introduction (if any) and associated patents (if any). A company’s “non-response” to these questions was conservatively judged to be equivalent to “no commercial product” and “no patent” produced. This minimized NIDILRR’s overall success rate producing a worst-case comparison to the NIH and NSF SBIR programs.

Aps successfully developed with NIDILRR PII support were classified using the ICF-based framework. A few PII grants supported the development of multiple successful assistive products that served the same disability population(s). In these cases, a single “exemplar” assistive product was conservatively classified to the ICF-based framework. Various descriptive statistics (e.g., Welch’s *t*-test, linear regression, Pearson correlation, relative advantage, etc.) were used to analyze quantitative data.

### Results

This section comprises two parts: *Program Performance* provides analysis primarily pertaining to RQ1 (value) and RQ2 (worth). *Grants and Products* provides analysis primarily pertaining to RQ3 (capacity building) and program outcomes (proposed and achieved assistive products).

#### Program Performance

From 2006–2020, 431 small businesses submitted 805 PI applications to the NIDILRR SBIR program resulting in 194 (24.1% winning) awards (Table2). By win cohort, 51% of all PI awards went to companies with one (1) or two (2) awards while 49% of awards went to companies with three or more (3+) awards. No company won 6, 9–12, or 14–21 PI awards. The top eight companies won 75 awards (39.2% of all wins). NIDILRR’s SBIR program averaged 54 PI applications per year with a maximum of 79 (2006) and minimum of 17 (2020). The number of PI applications decreased from 2006 to 2020 (correlation: *r* = -0.55) by about 2 applications per year (linear regression: *m* = -2.14 grants per year, *b* = 71 grants).

***Table 2: Phase I – Companies by Win Cohort***

| **Win Cohort** | **0** | **1** | **2** | **3** | **4** | **5** | **7** | **8** | **13** | **22** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Number of Companies** | 340 | 79 | 10 | 5 | 1 | 2 | 1 | 3 | 1 | 1 |
| **Number of Wins** | 0 | 79 | 20 | 15 | 4 | 10 | 7 | 24 | 13 | 22 |
| **Percent (%) of Wins** | 0 | 40.7 | 10.3 | 7.7 | 2.1 | 5.2 | 3.6 | 12.4 | 6,7 | 11.3 |

To better understand how companies used NIDILRR’s SBIR program (Table 3), PI applicants were initially assigned to three cohorts: Companies submitting a single application (try) in a single year (SY-ST), multiple applications (tries) in a single year (SY-MT), and multiple applications (tries) over two or more years (MY-MT). Overall, SY-ST companies submitted 327 proposals and won 32 awards; 12 SY-MT companies submitted 28 proposals and won 3 awards; and 91 MY-MT companies submitted 450 proposals and won 150 awards. On average, MY companies submitted 4.91 Phase I proposals. The top eight MY companies won between 5 and 22 Phase I grants (inclusive) and 76 in total (39.2% of all).

***Table 3: Phase I – SY and MY Companies***

|  | **SY-ST** | **SY-MT** | **MY-MT** | **Aggregate** |
| --- | --- | --- | --- | --- |
| **Number of Companies** | 327 | 12 | 91 | 431 |
| **Percent (%) of Companies** | 75.9 | 2.8 | 21.1 |  |
| **Number of Tries** | 327 | 28 | 450 | 805 |
| **Percent (%) of Tries** | 40.6 | 3.5 | 55.9 |  |
| **Number of Wins** | 32 | 3 | 150 | 185 |
| **Percent (%) of Wins** | 9.8 | 10.7 | 33.3 | 23.0 |

Significant differences *were not found* between the aggregate score distributions of SY-ST and SY-MT (*p* one-tailed < 0.1, *p* two-tailed < 0.1) PI applicants. However, significant differences *were found* between the score distributions of MY-MT PI applicants and both SY-ST and SY-MT PI applicants (*p* one-tailed = 0.0005, *p* two-tailed = 0.001). Consequently, SY-ST and SY-MT data were combined into a single year (SY) cohort and MY-MT was redesignated as the multi-year (MY) cohort. *In aggregate,* 339 SY applicants submitted 355 PI applications and received 35 (9.86% winning) awards.

Score distributions for SY and MY PI applicants were next evaluated on a year-by-year and aggregate basis using one- and two-tailed Welch's *t*-tests (Table 4). On a year-by-year basis, excepting 2008 (*p* one-tailed = 0.1, *p* two tailed = 0.1) and 2015 (*p* one-tailed > 0.1, *p* two tailed > 0.1), SY applicants scored significantly lower than MY applicants.

***Table 4: Phase I – SY and MY Scoring***

| **Year** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **<SY>** | 61.0 | 63.1 | 67 | 61 | 64 | 52.8 | 73.6 | 64.3 | 68.7 | 72.3 | 68.9 | 71.7 | 63 | 70.1 | 74.1 |
| **#SY** | 43 | 26 | 14 | 38 | 37 | 13 | 12 | 20 | 21 | 14 | 27 | 36 | 20 | 22 | 10 |
| **<MY>** | 76.3 | 78.1 | 74.4 | 83.7 | 80.6 | 84.2 | 84.5 | 86.3 | 81.7 | 78 | 81 | 81.6 | 79.7 | 82.1 | 87.5 |
| **#MY** | 36 | 37 | 30 | 38 | 39 | 24 | 25 | 33 | 42 | 34 | 30 | 33 | 21 | 19 | 7 |
| **t-1** | A | A | C | A | A | A | A | A | B | C | B | A | A | A | B |
| **t-2** | A | A | C | A | A | A | B | A | B | C | B | B | B | B | B |

*<SY> average score SY, <MY> average score MY, t-1 (t-test, 1-tailed), t-2 (t-test, 2-tailed)*

*A(p<=0.001), B(0.001<p<=0.05), C(p=>0.05)*

In aggregate, MY applicants won about 80% of all PI awards. The *MY cohort* (91 members) had a 2.8:1 relative advantage versus the *SY cohort* (339 members) by number of PI awards. Normal distributions for SY and MY PI applicants were assumed on a year-by-year basis (Table 5). PI cut scores were referenced (NIDILRR records) and the expected number of E[SY] and E[MY] wins calculated. On a year-by-year basis, the relative advantage for MY versus SY applicants to win PI awards ranged from 1.39:1 (2008) to 5.93:1 (2011).

***Table 5: Phase I - MY versus SY Relative Advantage***

| **Year** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cut-Score** | 90.2 | 87.2 | 81.8 | 90 | 87.6 | 83.6 | 87.2 | 93.4 | 91 | 84.6 | 88 | 88 | 90.8 | 88.4 | 86.2 |
| **Number of Wins** | 12 | 15 | 16 | 15 | 15 | 17 | 13 | 10 | 10 | 13 | 10 | 11 | 10 | 11 | 9 |
| **E[SY]** | 2.53 | 3.95 | 6.69 | 2.73 | 3.79 | 2.46 | 3.37 | 1.60 | 2.93 | 4.89 | 3.48 | 3.63 | 2.82 | 3.31 | 2.46 |
| **E[MY]** | 9.47 | 11.05 | 9.31 | 12.27 | 11.21 | 14.54 | 9.63 | 8.40 | 7.07 | 8.11 | 6.52 | 7.37 | 7.18 | 7.69 | 6.54 |
| **RA** | 3.74 | 2.80 | 1.39 | 4.49 | 2.96 | 5.93 | 2.85 | 5.27 | 2.42 | 1.66 | 1.88 | 2.03 | 2.54 | 2.32 | 2.66 |

The study considered how the number of MY PI applications correlated with the likelihood of winning (Table 6). One would expect (but needs to confirm) that NIDILRR capacity building and practice effects would increase the likelihood of winning PI awards. MY “Try Cohorts” submitted from 2 to 59 applications. The number of MY companies in Try Cohorts 12, 16–19, or 23–58 was zero. Overall, the % Wins by Try Cohort was found to be very weakly, though positively, correlated (*r* = 0.061) with Try Cohort number and % Wins increased about 0.06% per added Try (linear estimate: *m* = 0.0025 Win % per Try and *b* = 0.293 Win %. On close examination, the % Wins for “lower end” Try Cohorts 3–6, 8–9, 13 and 15 is less than the % Wins for Try Cohort 2 while the % Wins for “upper end” Try Cohorts 7, 10–11, 14, 20–22 and 59 exceed the % Wins for Try Cohort = 2. This explains the seeming paradox that the linear estimate for % Wins increases with Try Cohort # but never reaches the % Wins for Try Cohort 2.

***Table 6: Win Percent by MY Try Cohort***

| **MY Try Cohort** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **13** | **14** | **15** | **20** | **21** | **22** | **59** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Number of Companies** | 47 | 11 | 8 | 8 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Number of Tries** | 94 | 33 | 32 | 40 | 18 | 14 | 16 | 18 | 10 | 11 | 13 | 14 | 15 | 20 | 21 | 22 | 59 |
| **Number of Wins** | 32 | 8 | 5 | 8 | 3 | 8 | 5 | 4 | 8 | 5 | 2 | 8 | 3 | 7 | 8 | 13 | 22 |
| **Percent (%) of Wins** | 34 | 24 | 16 | 20 | 17 | 57 | 31 | 22 | 80 | 45 | 15 | 57 | 20 | 35 | 38 | 59 | 37 |

The study also considered whether *prior success* (defined within the study as winning one or more PI or PII awards from another federal agency) would affect the *subsequent likelihood* of winning a *first* NIDILRR PI award. Of 339 SY companies, 84 *had prior success,* and 18 of these companies (21.4%) subsequently won PI awards. Of 255 SY companies *without prior success*, only 19 (7.5%) subsequently won PI awards. Of the 18 SY PI winners that *had prior success*, 3 of these companies (16.7%) also won PII awards. Of the 19 SY PI winners *without prior success*, none (0%) won PII awards.

The study next considered PII awards data (Table 7). SY and MY PI winners “PII Try Cohorts” submitted from 1 to 30 PII applications. The number of companies in PI Try Cohorts 9–10, 12–17, or 20–29 was zero. Overall, 91 SY and MY companies won 150 PI awards, submitted 221 PII proposals, and won 68 PII awards (30.7% wins). In detail, 35 SY companies submitted 27 PII proposals (six reapplications included) and won 3 PII awards (11.1% wins). And 56 MY companies won 115 PI awards, submitted 194 PI proposals (one or more), and won 65 PII awards (33.5% wins). In their *first* PII competition, the 91 MY and SY companies won 25 PII awards (29.8% wins) and for *subsequent* PII competitions won 43 PII awards (33.1% wins).

***Table 7: Phase II - SY and MY Companies by Try Cohort***

| **Try Cohort** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **11** | **19** | **30** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Number of Companies** | 55 | 22 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 |
| **Number of Tries** | 55 | 44 | 6 | 8 | 5 | 12 | 7 | 24 | 11 | 19 | 30 |
| **Number of Wins** | 12 | 13 | 5 | 3 | 2 | 7 | 2 | 11 | 3 | 6 | 4 |
| **Percent of Wins** | 21.8 | 29.5 | 83 | 37.5 | 40 | 58.3 | 28.6 | 45.8 | 27.3 | 21.6 | 13.3 |

Calculation of PI to PII *conversion rates* (PI winners also win PII awards) in Table 7 required a small number of exclusions: companies that won PI awards in 2020 before submitting 2021 PII proposals (year after study scope); companies that won PII awards in 2006 after winning PI awards in 2005 (year before study scope); and companies that won 2006–2019 PI awards from other agencies before submitting 2007–2020 PII proposals (inter-agency is outside study scope). Included in the analysis, 11 SY and two MY companies won PI awards but *did not apply* for PII awards. Finally, six SY and two MY companies lost PII competitions, received TRs, and then reapplied. Two of the SY applicants (33%) and one of the MY applicants (50%) then won PII awards. In comparison, about 10% of all SY applicants and 33% of all MY applicants win PII awards. While this finding is suggestive, numbers are small and other factors may pertain (E.g., practice effects, selection bias [companies that reapply may have high “losing” scores], etc.).

Finally, we considered the distribution of PII applicants and PII grant winners (Table 8). From 2006–2019, 91 different companies won *one or more* PI awards and submitted PII proposals. Fifty-four companies (59.3%) failed to win PII awards. Twenty-nine companies (31.9%) won 1 or 2 PII awards and 36 in total (52.9% of awards). Eight companies (8.8%) won 3 to 6 PII awards and 32 in total (47.1% of awards).

***Table 8: Phase II – SY and MY Companies by Wins Cohort***

| **Awards Cohort** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **Total** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Number of Companies** | 54 | 22 | 7 | 3 | 3 | 1 | 1 | 91 |
| **Percent of Companies** | 59.5 | 24.2 | 7.7 | 3.3 | 3.3 | 1.1 | 1.1 |  |
| **Number of Wins** | 0 | 22 | 14 | 9 | 12 | 5 | 6 | 68 |
| **Percent of Wins** | 0 | 32.4 | 20.6 | 13.2 | 17.6 | 7.4 | 8.8 |  |

#### Grants and Products

NIDILRR funded 68 PII grants between 2006 and 2020. When contacted, 67 of 68 PII grantees (98.5%) responded. Of the responding companies, 34 completed PII grants and produced products, two completed PII grants with product development "in process," 15 had “ongoing” PII grants, 18 completed PII grants but did not produce products, and one PII awardee was “non-responsive.” Following NAS methodology, two ongoing PII grants (which might or might not produce assistive products) and one non-responsive PII awardee (with a grant period crossing the studies timeframe) were excluded from the effective sample, which now comprised 65 companies. Ongoing PII grants were indeterminate (might or might not produce assistive products). Of 65 companies in the effective sample, 34 (52.3%) *produced*, 18 (27.7%) *did not produce*, and 15 (23.1%) *may or may not* produce assistive products.

The 68 PII grants were classified with respect to ICF Body Function (impairment) and Activity (limitation) chapters and domains (Tables 9 and 10). Referring to Table 9, three Body Function chapters: SF (38.2%), NMR (25.0%), and MF (22.1%) accounted for 85.3% of all PII grants. Five Body Function chapters: VS (0%), CHIR (1.5%), DME (1.5%), GR (2.9%), and SR (2.9%) accounted for 8.8% of all PII grants. Each of the eight Body Function chapters corresponds to disjoint disability populations. Four PII grants (5.9%) classified to two or more Body Function chapters (MUL) and populations. One Body Function chapter (SF) was decomposed into two disjoint Body Function domains (SF: S, SF: H) and sub-populations.

***Table 9: Phase – Grants by ICF Body Function Chapters and Domains***

|  | | | **Grants** | | |
| --- | --- | --- | --- | --- | --- |
| **Body Function**  **Chapters** | **Body Function:**  **Domains** | | **Number in Domain** | **Number in Chapter** | **Percent in Chapter** |
| Mental functions (MF) | | |  | 15 | 22.1 |
| Sensory functions and pain (SF) | Seeing (SF: S) | | 14 | 26 | 38.2 |
| Hearing (SF: H) | | 12 |
| Voice & speech (VS) | | |  | 0 | 0 |
| Cardiovascular, hematological,  immunological, and respiratory (CHIR) | | |  | 1 | 1.5 |
| Digestive, metabolic, and endocrine (DME) | | |  | 1 | 1.5 |
| Genitourinary and reproductive (GR) | | |  | 2 | 2.9 |
| Neuromusculoskeletal and movement related (NMR) | | |  | 17 | 25.0 |
| Skin and related (SR) | | |  | 2 | 2.9 |
| Multiple (MUL) | | |  | 4 | 5.9 |
| **Total** | |  | | 68 |  |

Referring to Table 10, four Activity chapters, MOB (39.7%), COM (14.7%), LAK (13.3%), and SC (10.3%), accounted for 78.0% of all PII grants. Five Activity chapters, GTD (1.5%), DL (1.5%), IIR (4.4%), MLA (7.4%), and CSCL (1.5%), accounted for16.3% of all PII grants. Assistive products for computer access (designated LAK+COM) were aggregated with LAK (judged the primary Activity) rather than COM (judged the secondary Activity). Each of the nine Activity chapters corresponds to disjoint disability sub-populations. Four PII grants (5.9%) classified to two or more Activity chapters (MUL) and populations. Four Activity chapters (COM, MOB, SC, MLA) were further decomposed into 11 disjoint Activity domains (MOB: CMBP, …) and sub-populations.

Referring to Table11*,* disability populations/sub-populations corresponding to PII grants are mapped to ALS and UCS disability demographic questions. Curly brackets ({}) include sets of disability populations/sub-populations that correspond to one or more PII grants *and* implicit elements of ALS or USC demographic questions. Many implicit elements are not listed simply because a (relatively) small number of PII grants are mapped.

***Table 10: Phase II – Grants by ICF Activity Chapters and Domains***

|  |  | | **Grants** | | |
| --- | --- | --- | --- | --- | --- |
| **Activity  Chapters** | **Activity:  Domains** | | **Number in Domain** | **Number in Chapter** | **Percent in Chapter** |
| Learning and Applying Knowledge (LAK) | | | | 5 | 13.3 |
| Learning and Applying Knowledge + Communication (LAK + COM) | | | | 4 |  |
| General Tasks & Demands (GTD) | | |  | 1 | 1.5 |
| Communication (COM) | Productive (COM: P) | | 5 | 10 | 14.7 |
| Receptive (COM: R) | | 5 |
| Mobility (MOB) | Changing and maintaining body posture (MOB: CMBP) | | 1 | 27 | 39.7 |
| Carrying, moving, and handling objects (MOB: CMHO) | | 6 |
| Walking (MOB: W) | | 8 |
| Moving around in different locations  (MOB: MADL) | | 9 |
| Moving around using equipment  (MOB: MAUE) | | 3 |
| Self-Care (SC) | Eating, drinking, toileting, washing…  (SC: EDTW) | | 3 | 7 | 10.3 |
| Taking care of one’s health (SC: TCOH) | | 4 |
| Domestic Life (DL) |  | |  | 1 | 1.5 |
| Interpersonal Interactions and Relationships (IIR) | | |  | 3 | 4.4 |
| Major Life Areas (MLA) | Education (MLA: E) | | 2 | 5 | 7.4 |
| Employment (MLA: W) | | 3 |
| Community, Social, and Civic Life (CSCL) | | |  | 1 | 1.5 |
| Multiple (MUL) |  | |  | 4 | 5.9 |
| **Total** | |  | | 68 |  |

Of note, the intersection of ACS Visual and Hearing questions (corresponding to Body Function chapters: domains) with curly-bracketed Activity chapters: domains define disability populations/sub-populations in a *one-to-many* fashion. Similarly, the intersection of ACS Cognitive and Self-Care, and UCS Communication questions (corresponding to Activity chapters: domains) with curly bracketed Body Function chapters: domains define disability populations/sub-populations in a *many-to-one* fashion. In both instances, disability demographics is ill-defined.

Setting aside the ill-defined ACS Independent Living question and a single PII grant mapped to this question, 54 of 67 PII grants map to the remaining six ACS and UCS questions. That is, 80.1% of PII grants map to ACS and UCS questions (and associated disability populations) and 19.9% of PII grants do not. Due solely to the implicit construction of ACS and UCS questions, of the 54 PII grants, 23 map to *two or more* of the six ACS and UCS questions. That is, the mapping between PII grants and ACS and UCS questions is non-disjoint. In spite of this problem (non-disjoint mappings weaken correlation), a moderately strong correlation (Pearson *r* = 0.70) was found between the PII grant distribution and the disability population distribution associated with ACS and UCS questions.

***Table 11: Phase II – Grants versus Disability Demographics***

| **“Disability” Questions** | **% Disability population** | **Impairment Chapter(s): [Domain(s)]** | | **Limitation Chapter(s)** | **PII Grants mapped** | |
| --- | --- | --- | --- | --- | --- | --- |
| Visual1 | 2.3 | Sensory: Seeing | | {LAK, LAK+COM, MOB, DL, CSCL} | 14 | |
| Hearing1 | 3.6 | Sensory: Hearing | | {GTD, COM, MOB} | 12 | |
| Cognitive1 | 5.1 | {MF, SF: S} | | Learning and Applying Knowledge | 9 | |
| Communication2 | 2.1 | {MUL, SF: H} | | Communication | 10 | |
| Ambulatory1 | 6.8 | {NMR} | | Mobility | 27 | |
| Self-Care1 | 2.6 | {MUL, MF, GR} | | Self-Care | 7 | |
| Independent Living1 | 5.6 | {SF: S} | | Domestic Life | 1 | |
| **Total** | | |  | | | 80 |

*1American Community Survey (Cornell, 2021)*

*2US Census, includes persons with “severe” and “mild” communication difficulties (USCB, 2014)*

Referring to Table 12, PII grants (assistive products *proposed*) and assistive products available (assistive products *in the market)* are classified with respect to disability populations [to be] served. Recall that disjoint disability populations are defined by the intersection of Body Function chapters: [domains] and Activity chapters: [domains]. Curly, half round, and square brackets demarcate the number of {*completed PII grants with products*}, (*completed PII grants without products* PLUS *non-responsive PII awardees*), and [*ongoing PII grants* PLUS *completed PII grants still “in process”*] in each cell of this matrix.

Table 12 provides a concise, disjoint, and hierarchic visual summary of NIDILRR’s investment in assistive product development with respect to disability populations served. Of 180 cells in Table 12 that are bordered by solid or dashed lines, 28 cells (15.6%) include one or more PII grants. This “higher resolution matrix” provides detailed information about the “types” of assistive products [to be] developed with NIDILRR PII grant support. For example, there are six different “types” of MOB assistive products at this resolution. If every cell in Table 12 with a domain-level Body Function or Activity component was collapsed into a chapter-level Body Function and Activity cell, a “lower resolution” matrix with 90 cells would be produced in which 22 cells (24.4%) would include one or more PII grants. However, MOB assistive products would also collapse to a single cell with loss of AP “type” information. Keys for Body Function and Activities acronyms follow Table 12.

Tables 13 and 14 provide a simple visual summary to quickly describe NIDILRR’s investment in assistive product development with respect to the disability populations served by proposed APs. Readers are invited to review Tables 13 and 14 to confirm the face validity of the ICF-based assistive product classification. Please refer to NARIC and SBA Awards Data for full public descriptions of proposed assistive products.

***Table 12: Phase II - Grants and Assistive Products by Disability Population***

|  | |  | **Activity (Limitation Chapters)** | | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **MUL-A** | **LAK** | **LAK+COM** | **GTD** | **COM: P** | **COM: R** | **MOB: CMBP** | **MOB: CMHO** | **MOB: W** | **MOB: MADL** | **MOB: MAUE** | **SC: EDTWB** | **SC: TCOH** | **DL** | **IIR** | **MLA: E** | **MLA: W** | **CSCL** |
| **Body Function (impairment) Chapters[:Sub-Domains]** | **MUL- BF** | {0} (1)  [0] |  |  |  | {1} (1)  [0] |  |  |  |  |  |  |  | {0} (2) [1] |  |  |  |  |  |
| **MF** | {1} (1)  [0] | {0} (1) [1] | {0} (1)  [0] |  |  |  |  |  |  |  |  | {3} (3)  [0] |  |  | {0} (2) [1] | {2} (2)  [0] | {0}  (0) [3] |  |
| **SF:S** |  | {2} (2) [1] | {3} (3) [0] |  |  |  |  |  |  | {3} (6) [0] |  |  |  | {1} (1)  [0] |  |  |  | {1} (1)  [0] |
| **SF:H** |  |  |  | {1} (1)  [0] | {3} (4)  [0] | {1} (4) [1] |  |  |  | {1} (2)  [0] |  |  |  |  |  |  |  |  |
| **VS** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **CVR** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **DME** | {1} (1)  [0] |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **GR** |  |  |  |  |  |  |  |  |  |  |  | {0} (0) [1] | {1} (1)  [2] |  |  |  |  |  |
| **NMR** |  |  |  |  |  |  | {1} (1)  [0] | {5} (6)  [0] | {2} (3) [3] | {1} (1)  [0] | {0} (2) [1] |  |  |  |  |  |  |  |
| **SR** |  |  |  |  |  |  |  |  | {0} (1) [1] |  |  |  |  |  |  |  |  |  |

***KEY for Body Function Chapters and Domains Acronyms****: MUL-BF = Multiple Body Functions, MF = Mental, SF: V = Sensory: Seeing, SF: H = Sensory: Hearing, VS = Voice & Speech, CVR = Cardiovascular & Respiratory Systems, DME = Digestive & Metabolic, GR = Genitourinary & Reproductive, NMR = Neuromusculoskeletal & Movement Related, SR = Skin & Related*

***KEY for Activity Chapters and Domains Acronyms****: MUL-A = Multiple Activities, LAK = Learning & Applying Knowledge, GTD = General Tasks & Demands, COM: P = Communication: Producing, COM: R = Communication: Receiving, MOB: CMBP = Mobility: Changing & Maintaining Body Position, MOB: CMHO = Mobility: Carrying, Moving, & Handling Objects, MOB: W = Mobility: Walking & Moving, MOB: MADL = Mobility: Moving Around [to/in] Different Locations, MOB: MAUE = Mobility: Moving Around Using Equipment, SC: EDTWB = Self-Care: Washing, Body Care, Toileting, Eating, & Drinking, SC: TCOH = Self-Care: Taking Care of One’s Health, DL = Domestic Life, IIR = Interpersonal Interactions & Relationships, MLA: E = Major Life Activities: Education, MLA: W = Major Life Activities: Work, CSCL = Community, Social, & Civic Life*

***Table 13: Assistive Product Exemplars by Disability Population***

|  | | **Activity Domains: [Sub-Domains]** | | | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MUL** | **LAK** | **LAK + COM** | **GTD** | **COM: P** | **COM: R** | **MOB: CMBP** | **MOB: CMHO** | **MOB: W** | **MOB: MADL** | **MOB: MAUE** | **SC: EDTW** | **SC: TCOH** | **DL** | **IIR** | **MLA: E** | **MLA: W** | **CSCL** |
| **Body Function Domains: [Sub-Domains]** | **MUL** | A |  |  |  | B |  |  |  |  |  |  |  | C |  |  |  |  |  |
| **MF** | D | E | F |  |  |  |  |  |  |  |  | G |  |  | H | I | J |  |
| **SF:S** |  | K | L |  |  |  |  |  |  | M |  |  |  | N |  |  |  | O |
| **SF:H** |  |  |  | P | Q | R |  |  |  | S |  |  |  |  |  |  |  |  |
| **VS** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **CVR** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **DME** | T |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **GR** |  |  |  |  |  |  |  |  |  |  |  | U | V |  |  |  |  |  |
| **NMR** |  |  |  |  |  |  | W | X | Y | Z | AA |  |  |  |  |  |  |  |
| **SR** |  |  |  |  |  |  |  |  | BB |  |  |  |  |  |  |  |  |  |

***Table 14: Assistive Technology Exemplar Look-Up for Table 13***

| **Assistive Product Exemplars** | |
| --- | --- |
| A – provider skills training | O – read, write, and perform music |
| B – telehealth services | P – emergency notification, crisis management |
| C – disease and rehab management, diabetes monitoring | Q – ASL, signing math and science dictionaries |
| D – goal setting, tracking, and self-management, mindfulness | R – hearing aids, mobiles hearing applications, connectivity |
| E – learning | S – sound identification, alerting |
| F – computer access | T – portable metabolic colling |
| G – daily living | U – disposable urinary catheters |
| H – social skills training | V – portable hemodialysis |
| I – educational performance assessment | W – trunk orthosis |
| J – vocational skills training | X – upper body prosthesis and orthosis, rehab robotics, wheelchair accessories |
| K – learning | Y – lower body prosthesis and orthosis, rehab robotics |
| L – computer access | Z – route planning and wayfinding |
| M – object recognition, proximity sensing, audio-tactile maps, route-planning, and wayfinding | AA – wheelchairs, batteries, power sources |
| N – environmental control | BB – intermittent socket compression, footwear |

### Discussion

We begin by considering program performance (RQ1 and RQ2). The relative size of the NIH, NSF, and NIDILRR SBIR program budgets (about 760 to 60 to 1 in FY2021) precludes simple inter-program comparisons between “inputs” (e.g., PI and PII applicants) and “outputs” (e.g., PI and PII winners; products, patents, and licenses) comparisons. Instead, ratio measures (e.g., PI winners/PI applicants, PII winners/PI winners, products/PII winners) were used to help normalize for program scale. Among commercialization outcomes (e.g., commercialized products, invention patents, follow-on funding, etc.) only “commercial products” were considered, as few AT companies seek patent protection or receive follow-on funding. The impact of PI and PII award size on program performance cannot be directly assessed but is certainly important. For example, larger NIH and NSF awards probably attract larger companies with greater technical resources, staffing, and financial capacities to develop products to serve large (likely mainstream) markets. In contrast, small AT companies with lesser capacities and developing assistive products to serve small (disability) markets are probably less competitive to win NIH and NSF awards.

For RQ1 (*program worth*): The ratio of PI winners/PI applicants favors NIDILRR (23.3%) versus NIH (15.3%) and NSF (17.3%). However, PII winners/PI winning applicants favors NIH (38.7%) and NSF (44.4%) versus NIDILRR (33.2%). That is, in comparison to NIDILRR, a lesser proportion of high-quality NIH and NSF PI applicants win PI awards, and a greater proportion of NIH and NSF PI winners also win PII awards. Further supporting PII winners in later-stage product development, NIH and NSF provide follow-on funding opportunities, may seek SBA funding waivers, and may offer supplemental funding, while NIDILRR does not.

We next consider commercialization outcomes. In the NIH and NSF studies, the NAS excluded companies that did not respond to contacts (e.g., perhaps the company has failed?) and companies that did not complete commercialization surveys (e.g., perhaps the company has nothing positive to report?) from their effective samples. It is counterintuitive to think, however, that excluded companies have product commercialization rates comparable to included companies that respond to contacts (e.g., the company is in business) and complete commercialization surveys (e.g., perhaps the company has something positive to report?). Actual product commercialization rates in the NIH and NSF studies are likely bounded below by (sample response rate) x (effective sample, product commercialization rate) and bounded above by (effective sample, product commercialization rate). Given this assumption, product commercialization *ranges* by agency are NSF (69.7 – 29.1%), NIDILRR (52.3 – 51.5%), and NIH (41.8 – 10.5%). That is, NIDILRR’s product commercialization rate was near the midpoint of NSF’s range and above the high-end of NIH’s range.

Considering the multiplicative product of conversion rates and ranges [(PI awards/PII applications) x (PII awards/PI winners) x (commercialized products/PII awards)], the percent of PI applicants that also produced commercial products was NSF (5.4–2.2%), NIDILRR (4.0–4.0%), and NIH (2.5–0.6%). These product commercialization ranges provide a comparative snapshot of NIH, NSF, and NIDILRR program performance independent of major factors such as program construction, markets, industries, and applicant pools.

Of course, these factors cannot be disregarded. In their 2010 study, Bauer and Arthanat found that the number of grants (both PI and PII) *available to small businesses* favored NIH to NIDILRR (> 100 to 1) and NSF to NIDILRR (> 20 to 1). However, the number of grants (both PI and PII) *supporting assistive product development* favored NIH to NIDILRR (about 2 to 1) and actually favored NIDILRR to NSF (about 3 to 1) (Bauer & Arthanat, 2010).

Findings from the current and former studies strongly support that AT companies prefer NIDILRR’s SBIR program despite that *most* factors (e.g., number and size of PI and PII awards; availability of adjunct grants, SBA funding waivers, and supplemental funding) should bias company interest towards the NIH and NSF SBIR programs. Consequently, other factors such as NIDILRR’s mission must play a crucial role in attracting AT companies (and perhaps dissuading applications from mainstream companies). We conclude for RQ1, that NIDILRR’s SBIR program demonstrated substantial *worth*, though insufficient applicant, grantee, and assistive product diversification may be concerns.

We next consider RQ2 (*program value*). An ICF-based classification was first used to estimate US disability populations from the response statistics for seven “disability questions” found in the American Community Survey (ACS) and US Census (USC). With respect to the two-part ADA disability definition for disability, every ACS and UCS question left either Body Function (impairment) domains or Activity (limitation) domains *implicit* (Tables 9 and 10). Consequently, response statistics for ACS and UCS questions were *necessarily* non-disjoint and the associated disability populations are non-additive (Table 11). The ACS “independent living” question was particularly problematic and was not used for this reason. The six ACS and UCS questions used in this study accounted for about 80% of the nominal US disability population.

The ICF-based classification was next used to classify PII grants to US disability populations as established by ACS and UCS response statistics. A moderately strong correlation (*r* = 0.7) was found between the distribution of NIDILRR PII grants and disability populations (Table K) irrespective that non-disjoint ACS and UCS responses *weakened* this correlation. Sixty-eight NIDILRR PII SBIR grants were classified by status (completed grant with product, completed grant with ongoing product development, completed grant without product (Table 12) and descriptions (Tables 13 & 14) by disability population. Conservatively, more than 50% of NIDILRR PII grants produced commercial assistive products.

Referring to Tables 13 & 14 and correlations between proposed APs and ACS and UCS survey demographics, PII grants and proposed APs are broadly well-matched to disability populations. Consistent with NIDILRR’s mission, APs derived from its SBIR program improve “…the abilities of individuals with disabilities to perform activities of their choice in the community,” “…expand society's capacity to provide full opportunities and accommodations for its citizens with disabilities,” and facilitates “the transfer of, use and adoption of rehabilitation technology for individuals with disabilities in a timely manner.” We conclude for RQ2, that NIDILRR’s SBIR program has demonstrated substantial *value*, though again applicant, grantee, and assistive product diversification may again be concerns.

Finally, we consider RQ3 (*program capacity building*). The population of PI applicants included 349 SY applicants and 91 MY applicants. The average PI scores for SY and MY applicants were 63 and 82 respectively. In a typical year, 35 SY applicants won about 3 PII grants and 15 MY applicants won about 9 PII grants. Disregarding cohort size, the MY *cohort* had a 2.8 to 1 advantage for PI success relative to the SY *cohort*. Accounting for cohort size, *individual applicants* in the MY cohort had a 6.5 to 1 advantage for PI success relative to *individual applicants* in the SY cohort. The MY cohort’s advantage continued into PII where about 9% of SY PI winners and 35% of MY PI winners also won PII awards.

Overall, about 10% of SY applicants and 33% of MY applicants won PI awards. However, SY applicants comprised two distinct sub-cohorts. Companies were considered to have *prior success* if they won a PI or PII award(s) from another federal agency prior to submitting their first NIDILRR PI application. About 7% of SY applicants *without* prior success won PI awards while 20% of SY applicants *with* prior success won PI awards. Consequently, *prior success* appears to provide effective capacity building to companies that was *not NIDILRR mediated*.

NIDILRR mediated capacity building now consists of providing Technical Reviews (TR) to all applicants *following* PI or PII competitions. Consequently, we might expect that the success rate for MY applicants on their *first try* at PI competition (before getting their first TR) would range between 7% (analogous to an SY applicant *without prior success*) and 20% (analogous to an SY applicants *with prior success*). Strikingly, MY success rate on their *first try* was about 29%, suggesting that the capacities of companies in the SY and MY cohorts to compose competitive PI proposals were quite different. We considered whether the knowledge base (E.g., of markets, needs and potential, competitors and competing products, design and development capabilities, regulatory requirements, funding and reimbursement, marketing, and distribution, etc.) of companies in SY and MY cohorts *might* be a factor. PI applicants were reviewed. The SY cohort appeared to include many startup AT companies and established non-AT companies while the MY cohort appeared to include many established, well-known AT companies. If this assessment is broadly correct, then many SY companies would *lack* *critical knowledge* to compose competitive PI proposals while many MY companies would *have* such knowledge. Further study is warranted.

We next examined the NIDILRR, NIH, and NSF, PI and PII award distributions. For NIDILRR in PI, 327 SY and 91 MY companies submitted 355 and 450 proposals, won 35 and 150 awards, and had success rates of 10% and 33%, respectively. The top eight PI companies (all MY) won 3–22 PI awards, 91 in total (49% of all PI awards). The top two PI winners won 13 and 22 awards (23% of all PI awards). In PII, 35 SY and 91 MY companies submitted 27 and 194 proposals, won 3 and 65 PII awards (success rates of 11% and 30%), respectively. The top eight PII companies (all MY) won 3–6 PII awards, 32 in total (47% of all PII awards). The top two PII companies won 5 and 6 PII awards (16% of all PII awards). Seven of the top PII winners were also among the top eight PI winners. Overall, 430 companies (339 SY and 91 MY) participated in NIDILRR’s SBIR program with 3 SY and 34 MY companies winning one or more PII awards.

For NIH in PI, “new” [SY] companies submitted 20–25% of all PI proposals and won 33% of PI awards. The 20 top companies won 7.7% of SBIR (and STTR) PI awards while the top company won 44 PI awards. In PII, the top 20 companies accounted for 9.9% of NIH SBIR (and STTR) PII awards while the top two companies each won 24 PII awards.

For NSF in PI, 2009 companies [SY and MY] won 2896 PI awards. About 75% won one PI award, 24% had two to five PI awards, and 1% had six to nine PI awards. Some 1504 [SY] companies (about 75% of all companies) won one award (about 52% of all PI awards) and 505 [MY] companies (about 25% of all companies) won two to nine PI awards (about 48% of all PI awards). In PII, 787 companies won 1002 PII awards: 82.2% with one PII award, 17.1% with two to four PII awards, and 0.6% with five to seven PII awards.

Comparing the three SBIR programs, NIDILLR awards were biased towards companies in the MY cohort in PI and PII, thereby narrowing the NIDILLR PI and PII applicant pools. NIH awards were biased towards companies in the SY cohort in PI, thereby diversifying the NIH PII applicant pool. NSF awards were biased towards companies in the SY cohort in PI, and companies in the SY *and* MY cohorts that won *single PII awards*, thereby diversifying the NSF applicant pool. Altogether, NIDILRR had less diversified PI and PII applicant pools than NIH and NSF. Assuming that small businesses prefer to develop and commercialize products serving one or a few markets, then products derived from NIDILRR’s SBIR program were probably less diverse (in terms of distinct markets served) than products derived from the NIH and NSF SBIR programs. While this conclusion is *reasonable*, again, further study is warranted.

NIDILRR capacity building now consists of providing all SY and MY applicants with TR *after* PI and PII competitions conclude. Only those companies that win or lose a PI or PII competition and then participate in a subsequent PI or PII competition can benefit. Consequently, companies in the SY cohort that lose PI competitions and *do not submit future* PI or PII proposals *cannot benefit* from PI TRs. In contrast, companies in the MY cohort that win or lose PI and PII competitions and submit future PI or PII proposals can benefit (i.e., increased likelihood of winning subsequent NIDILRR competitions) from their PI and PII TRs.

One might *wrongly* conclude from correlation (*r* = 0.061; MY Win % versus # Tries) and linear regression (*m* = 0.0025 MY added Win % per Try and b = 0.293 MY Win % First Try) findings that TRs provide little *actual benefit* to MY applicants. However, on average, companies in the MY cohort score much higher than companies in the SY cohort for both PI and PII competitions. The differential benefit of TRs to companies *within* the MY cohorts (correlation and linear regression findings), is small. However, every company in the MY cohort gains cumulative benefit from TRs while every company in the SY cohort gains no benefit from TRs (for future PI competitions). Consequently, NIDILRR TRs (as now provided) *maintain or widen* the competitive gap between companies in the MY cohort and companies in the SY cohort.

The importance of TRs was also suggested by the improved success of six SY and two MY companies that lost PII competitions, received TRs, and reapplied. Two of the six SY applicants (33%) and one of the two MY applicants (50%) won PII awards on their second try. In comparison, only 10% of all SY applicants and 33% of all MY applicants won PII awards. Again, numbers are small and other factors may pertain (e.g., practice effects, selection bias [companies that reapply may have high “losing” scores], etc.).

Overall, provision of TRs to SY and MY companies *after* PI and PII competitions and lack of capacity building opportunities *before* PI and PII competitions reduced diversification of AT companies that won PI and PII awards, and assistive products proposed and commercialized, thereby negatively impacting both the *worth* (RQ1) and *value* (RQ2) of NIDILRR’s SBIR program. We conclude for RQ3 (*capacity building*), that NIDILRR’s capacity building is currently *insufficient*.

### Outcomes and Benefits

In the NAS studies, 75% of NIH and 68% of NSF PII awardees, in their responses to commercialization surveys, reported that new product development *would not have been started* without SBIR program support. In addition, 44% of NIH and 45% of NSF respondents also reported that their company *was founded* in whole or part because of the SBIR program (National Academies of Science, 2015a pp. 183, 244; National Academies of Science, 2015b, pp. 104, 112). In 2011, the NIDILRR SBIR program was second to the NIH SBIR program in terms of the number of PI and PII grants awarded to AT companies and that these AT companies often proposed to develop different assistive product “types” (Bauer & Arthanat, 2010). Consequently, the absence of NIDILRR’s SBIR program could significantly reduce the overall number and diversity of AT companies and assistive products available to PWD.

The NAS studies also found that, NIH and NSF PII awardees attracted substantial follow-on investment from diverse public and private sources (National Academies of Science 2015a, pp. 144 – 146; National Academies of Science 2015b, pp. 148 - 149). However, most AT companies are unlikely to benefit from such sources. A 2002 study published by the National Institute on Standards Technology (NIST) categorized follow-on funding sources (with ranged percent of total funding available) for early-stage technology development (ESTD) to include corporations (32–47%), angel investors (24–28%), the federal government (21–25%), venture capitalists (2–8%), state governments (2–5%), and universities (3–4%) (Branscomb & Auerswald, 2002, p. 23).

Considering the top funding sources individually, corporations “are systematically disinclined to support technological innovations that challenge existing lines of business, require a fundamental shift of business model, or depend on the creation of new complementary infrastructure.” Small AT companies share the same disinclinations but also lack the resources, staffing, and financial capacities of large corporations. *Venture capitalists* generate profit for their investors by buying and selling firms that have rapid growth and profit potential. And, while they “do support technology-based enterprises, [they] prefer to support ones that have at least proceeded beyond the [early] product development stage-that is, firms that have … completed ESTD.” (Branscomb & Auerswald, 2002, p. 5). AT companies seeking to develop assistive products for small disability markets are unlikely to have the “rapid growth and profit potential” necessary to attract venture capitalists. *Angel investors* finance small startups or entrepreneurs in exchange for company equity they anticipate will grow rapidly. Angel investors “make the vast majority of their investments close to home. [Consequently,] early-stage technology development activities, particularly those of smaller firms, are likely to be concentrated in regions with active communities of tech-savvy angels” (Branscomb & Auerswald, 2002, p. 8). AT companies generally have little potential for rapid growth and are not regionally concentrated. Overall, AT companies have few practical funding options aside from the federal government, personal equity (financing from self, family, and friends), bank loans, product sales revenue, and company equity (e.g., patent licensing). Branscomb and Auerswald noted that the “federal role in early-stage technology development is *far more significant* than may be suggested by aggregate R&D statistics” (Branscomb & Auerswald, 2002, p. 10). Consequently, NIDILRR SBIR grants (federal funding) may be *essential* for many AT companies to initiate (and sustain) early stage technology development (ESTD) for assistive products.

Broadly speaking, our study supports that NIDILRR’s SBIR program provides substantial *worth* (RQ1) and *value* (RQ2) to AT companies and the disability markets they serve. However, program performance may be negatively impacted by NIDILRR’s lack of adjunct grant and supplemental funding opportunities (particularly important when clinical trials or intensive longer-term R&D is required), and by insufficient capacity building opportunities.

Turning now to recommendations, SY applicants *without prior success* comprise the largest PI applicant cohort and score very poorly (on average) with respect to both SY applicants *with prior success* and MY applicants. To address this issue, potential applicants (SY and MY) should have access to comprehensive SBIR grantsmanship training (e.g., recorded webinars, interactive webinars, conference presentations, access to winning SBIR proposals, peer mentoring). They should also have access to exemplar *winning* (demonstrating strong proposal elements) and *non-winning* (demonstrating weak proposal elements) PI and PII proposals and associated TRs (demonstrating review criteria and their use by panel experts). This would involve obtaining releases from selected proposal investigators and reviewers. As proof of concept, NIH SBIR proposals are publicly available. Finally, after losing a PI or PII competition, applicants should be *strongly urged* to reapply (with a much-improved chance of winning!).

NIDILRR has recognized that AT company demand exceeds SBIR program capacity and explored other mechanisms by which AT companies might develop certain “types” of assistive product. For example, in 2015 NIDILRR funded a five year “App Factory” project (as part of a larger grant) to develop mobile software applications (Shepherd Center, 2021). The App Factory model offers a flexible and effective approach to [carry out] research and development in an era of rapid technological advancement, relies on secondary dispersal of grant funds to sub-awardees through a competitive selection process, and provides incentives to deliver successful products in a cost-effective manner” (Jones, Mueller & Morris 2017). Other NIDILRR funded grants and grant projects now employ the App Factory model but differ in detail.

Broadly speaking, App Factories target disability-specific needs, solicit and screen proposals (often by panels comprised of PWD), and provide technical support. Sub-awardees often have due diligence requirements (e.g., to assure that process and reporting milestones are met), and testing and trialing requirements (e.g., to assure that design, performance, usability, and other technical goals are met). Since 2015, App Factory projects successfully developed and commercialized many diverse mobile applications. Starting in FY21 (for the SBIR solicitations published in early 2020), proposals for mobile application development were *excluded from* NIDILRR’s SBIR program. Instead, AT companies wishing to develop mobile applications may be referred to an App Factory project or center.

From 1993 through 2023, NIDLRR (then NIDRR) supported five national Technology Transfer Centers (TTC) on five-year cycles. These TTC achieved a deep understanding of the actors, mechanisms, barriers, and facilitators pertaining to federally funded technology development and transfer, private-sector product hardening and commercialization, and market adoption. TTCs focused particularly on the challenging domain of technologies and assistive products serving niche disability markets. The State University of New York at Buffalo hosted TTCs from 1993 through 2018, concluding with the Disability Rehabilitation Research Project (DRRP) on Knowledge Translation for Technology Transfer (KT4TT) Center (State University of New York at Buffalo, 2021). In 2018, the Impact Center DRRP continued this exceptionally important work at Pittsburgh University (Pittsburgh University, 2021). Recent TTCs were tasked with developing models, tools, and trainings for and providing technical assistance to NIDILRR applicants and grantees. Unfortunately, few of these applicants are aware of, seek out, and receive technical assistance from NIDILRR’s TTCs. In addition, these TTCs lack knowledge of SBIR applicants until post-competition and then only winning applicants. Consequently, TTCs cannot proactively contact and technically assist SBIR applicants. If, however, PI applicants (especially) could broadly obtain technical assistance, then the “success gap” between SY and MY PI applicants could be substantially reduced. That is, only MY PI applicants now benefit from *post-competition* TRs. In contrast, TTC technical assistance would provide a critical *pre-competition* capacity building opportunity for SY PI applicants. NIDILLR could easily promote TTC technical assistance in grant proposal solicitations, applicant trainings, online guidance, web and conference presentations, and direct communications with NIDILRR project officers.

The NIDILRR SBIR program appears to be a good fit for many AT companies. However, NIDILRR PII grants may provide insufficient support to carry out clinical trials (e.g., for assistive products considered by the Food and Drug Administration to be medical devices), or intensive long-term research and development efforts (e.g., for highly innovative products, products based on emergent technologies, first-in-market products, etc.). As Phase III funding is proscribed, NSF and NIH support clinical trials and intensive R&D by providing companies with follow-on grant opportunities, seeking SBA funding cap waivers, and offering supplemental funding. NIDILRR, with its small budget, cannot replicate NIH and NSF strategies, but might mimic these strategies. For example, supplemental funding (when available) might target AT companies with incomplete PII grants, to develop assistive product(s) that will address critical need(s). Follow-on grant opportunities might be offered to AT companies with completed PII grants, through NIDILRR’s Disability and Rehabilitation Research Projects (DRRP) and Field Initiated Development (FID) programs. An AT company’s interest to develop assistive products that require clinical trials or intensive R&D after their PII grant completes will typically be finite (perhaps a year or two). Consequently, the pool of AT companies interested in NIDILRR’s follow-on grant opportunities will regularly empty and refill. Recognizing AT companies’ tight product development cycles, targeted DRRP or FI grant opportunities could be offered on short (E.g., FI grants yearly and DRRP grants on alternating years) predictable cycles.

Summarizing the capacity building discussion, NIDIRR’s adoption of robust capacity building strategies (including but perhaps beyond those advocated) would almost certainly diversify SBIR PI and PII grant recipients, derived assistive products, and benefitted disability populations. By strengthening its capacity building efforts, NIDILRR’s already strong SBIR program would better serve NIDILRR’s mission. Capacity building recommendations do not appear to be dependent on major changes to NIDILRR’s overall budget or grant programs. The reader is directed to the National Academies of Science NIH, and NSF studies, which offer additional important insights.

Overall, this study considered the performance (value, worth, and capacity building) and outcomes (proposed and commercialized assistive products, benefitted disability populations) for NIDILRR’s SBIR program. Findings from this study are expected to benefit NIDILRR, Assistive Technology (AT) companies, academic researchers, and persons with disability.

### Declarations

This content is solely the responsibility of the author and does not necessarily represent the official views of ATIA. No financial relationships were disclosed by the author of this paper. Dr. Bauer disclosed a non-financial relationship. He is a guest editor for Assistive Technology Outcomes and Benefits Volume 17.

### References

Administration on Community Living. (2021a). *About the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR)*. Retrieved January 20, 2021 from <https://acl.gov/about-acl/about-national-institute-disability-independent-living-and-rehabilitation-research>

Administration on Community Living. (2021b). *Small business innovation research program (SBIR) phase II (HHS-2021-ACL-NIDILRR-BISB-0026).* Department of Health and Human Services. Retrieved July 30, 2021, from <https://www.grants.gov/web/grants/search-grants.html?keywords=nidilrr%20sbir>

Americans with Disabilities Amendments Act of 2008, P.L. 110-325 (2008).Retrieved May 10, 2021, from <https://www.congress.gov/110/plaws/publ325/PLAW-110publ325.pdf>

Assistive Technology Act of 2004, P.L.108-364 (2004). Retrieved May 10, 2021, from <https://www.govinfo.gov/content/pkg/STATUTE-118/pdf/STATUTE-118-Pg1707.pdf>

Bauer, S. M., & Arthanat, S. (2010). SBIR and STTR programs for assistive technology device development: Evaluation of the impact using an ICF-based classification. *Assistive Technology Outcomes & Benefits, Focused Issue: State of the Science for Technology Transfer, 6*(1), 39–72. <https://www.atia.org/home/at-resources/atob/>

Bauer, S. M., Elsaesser, L. -J., & Arthanat, S. (2011). Assistive technology device classification based upon the World Health Organization’s, International Classification of Functioning, Disability and Health (ICF). *Disability & Rehabilitation: Assistive Technology, 6*(3), 243–259. <https://doi.org/10.3109/17483107.2010.529631>

Branscomb, L., & Auerswald, P. (2002). *Between invention and innovation: An analysis of funding for early-stage technology development*. National Institute of Standards and Technology.

Cornell University. (2018). *American community survey*. *Disability statistics: Prevalence.* Online Resource for U.S. Disability Statistics. Retrieved January 20, 2021, from <https://www.disabilitystatistics.org/reports/acs.cfm?statistic=1>

International Standardization Organization. (2016). *ISO 9999:2016 assistive products for persons with disability – classification and terminology*. Retrieved May 10, 2021, from <https://www.iso.org/standard/60547.html>

Jones, M., Mueller, J., & Morris, J. (2017). App Factory: A flexible approach to rehabilitation engineering in an era of rapid technology development. *Assistive Technology, 29* (2), 85-90. <https://doi.org/10.1080/10400435.2016.1211201>

National Academies of Science. (2008). *An assessment of the SBIR program.* National Academies Press. Retrieved May 10, 2021, from <http://nap.edu/11989>

National Academies of Science. (2015a). *SBIR/STTR at the National Institutes of Health*. National Academies Press. Retrieved May 10, 2021, from <https://nap.nationalacademies.org/catalog/21811/sbirsttr-at-the-national-institutes-of-health>

National Academies of Science. (2015b). *SBIR at the National Science Foundation*. National Academies Press. Retrieved May 10, 2021, from <https://nap.nationalacademies.org/catalog/18944/sbir-at-the-national-science-foundation>

National Institutes of Health. (2021a). *The NIH mission – It’s about life*. Retrieved January 21, 2021, from <https://tinyurl.com/4yvx9x5r>

National Institutes of Health. (2021b). *NIH SBIR/STTR. Frequently asked questions: Budgets*. Retrieved January 20, 2021, from <https://sbir.nih.gov/faqs#budgets-sec1>

National Institutes of Health. (2021c). *NIH report: NIH data book: Small business research (SBIR/STTR).* Retrieved July 15, 2021, from <https://report.nih.gov/nihdatabook/category/8>

National Science Foundation. (2021c). *2020 statistics overview*. Retrieved July 15, 2021, from <https://www.nsf.gov/statistics/2020/nsf20308/overview.htm>

National Science Foundation. (2021a). *The NSF statutory mission and vision*. Retrieved January 21, 2021, from <https://www.nsf.gov/pubs/2014/nsf14002/pdf/02_mission_vision.pdf>

National Science Foundation. (2021d). *America’s seed fund: SBIR-STTR. About*. *Our Program.* Retrieved January 20, 2022, from <https://seedfund.nsf.gov/our-program/>

National Science Foundation (NSF). (2021b). *About NSF: NSF budget requests to congress and annual appropriations.* Retrieved July 15, 2021, from <https://www.nsf.gov/about/budget/>

National Rehabilitation Information Center. (2021). *National Rehabilitation Information Center (NARIC)*. Retrieved January 20, 2021, from <http://www.naric.com>

Rehabilitation Services Administration. (2021). *Annual report: Fiscal year 2001*. Rehabilitation Services Administration. Retrieved July 15, 2021, from <https://rsa.ed.gov/sites/default/files/publications/ARC%20to%20Congress/rsa-2001-annual-report.pdf>

Shepherd Center. (2021). *LiveWell RERC*. Shepherd Center. Retrieved August 25, 2022, from <https://www.livewellrerc.org/>

Small Business Act as Amended, P.L. 85-536 (1953). Retrieved January 15, 2022, from <https://www.govinfo.gov/content/pkg/COMPS-1834/pdf/COMPS-1834.pdf>

Small Business Administration. (2012). *Key changes in SBIR and STTR policy directives*. Retrieved January 20, 2021, from <https://www.sba.gov/content/key-changes-sbir-and-sttr-policy-directives>

Small Business Administration. (2021a). *SBIR-STTR: America’s seed fund. Tutorial 2: Am I eligible to participate in the SBIR & STTR programs?* Retrieved January 20, 2021 from <https://www.sbir.gov/tutorials/>

Small Business Administration. (2021b). *SBIR-STTR: America’s seed fund. About: The three phases of SBIR/STTR.* Retrieved January 20, 2021, from <https://www.sbir.gov/about/>

Small Business Administration. (2021c). *SBIR-STTR: America’s seed fund. Tutorial 6: Contracts versus grants.* Retrieved January 20, 2021, from <https://www.sbir.gov/tutorial/>

Small Business Administration. (2021d). *SBIR-STTR: America’s seed fund. About: Award funding amounts.* Referenced January 20, 2021, from <https://www.sbir.gov/about/>

Small Business Administration. (2021e). *SBIR-STTR: America’s seed fund. About: Participating federal agencies.* Retrieved January 20, 2021, from <https://www.sbir.gov/agencies-landing/>

Small Business Administration. (2021f). *SBIR-STTR: America’s seed fund. Course 2: Agency introductions. Tutorial 5: Department of health and human services (HHS).* Retrieved January 20, 2021, from <https://www.sbir.gov/tutorials/individual-agency-requirements/HHS/>

Small Business Administration. (2021g). *SBIR-STTR America’s seed fund: Awards data*. Retrieved January 20, 2021, from <http://www.sba.gov>

Small Business Innovation Development Act of 1982, P.L. 97-219, (1982). Retrieved January 20, 2021, from <https://www.sba.gov/sites/default/files/2019-03/Small_Business_Act.pdf>

Small Business Innovation Research Reauthorization Act of 2000, P.L. 106-554, Title I*.* §102. Retrieved January 20, 2021, from <https://www.govinfo.gov/content/pkg/PLAW-106publ554/pdf/PLAW-106publ554.pdf>

State University of New York at Buffalo (2021). *Knowledge translation 4 technology transfer DRRP*. State University of New York at Buffalo. Retrieved August 20, 2021, from <https://publichealth.buffalo.edu/cat/kt4tt.html>

United Nations. (2021). *Convention on the Rights of Persons with Disability*. United Nations. Retrieved January 20, 2022, from <https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html>

University of Pittsburgh (2021). *IMPACT Center DRRP*. University of Pittsburgh. Referenced August 20, 2021. URL: <http://idea2impact.org>

United States Census Bureau. (2014). *Americans with disabilities: US household survey (Table1)*. Retrieved January 20, 2021, from <https://www.census.gov/content/dam/Census/library/publications/2018/demo/p70-152.pdf>

Wikipedia. (2022). *Capacity building*. Wikipedia. Retrieved December 1, 2022, from <https://en.wikipedia.org/wiki/Capacity_building>

World Health Organization. (2011). *International classification of functioning, disability, and health*. Retrieved May 10, 2021, from <https://www.who.int/standards/classifications/international-classification-of-functioning-disability-and-health>

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 30-42

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# Open-Source Design Platform for AAC Research: Project Open

## **Sofia Benson-Goldberg, Lori Geist, and Karen Erickson**

## Center for Literacy and Disability Studies Department of Allied Health Sciences School of Medicine University of North Carolina at Chapel Hill

***Corresponding Author***

Sofia Benson-Goldberg

University of North Carolina and Chapel Hill

CB #7335 UNC-CH

Chapel Hill, NO 27599-7335

Email: [sofiabg@med.unc.edu](mailto:sofiabg@med.unc.edu)

### Abstract

Project Open (<https://project-openaac.com/>) is aimed at improving in-person expressive communication for individuals with complex communication needs who use augmentative and alternative communication (AAC). The project includes intersecting research and development tracks. The development track aims to create an accessible, open-source set of tools that researchers and designers can use to develop and test AAC user interfaces. These tools are combined in a web-based platform called the Open-Source Design and Programmer Interface (OS-DPI) and situated for use within an inclusive Project Open Design Community. Benefits of open-source models to support innovation through collaboration among stakeholders, particularly in the early stages of design work, are reviewed. A detailed overview of the OS-DPI, associated Community, and future directions are discussed.

***Keywords:*** Open-source, AAC designs, user-interface testing, protype development

### Open-Source Design Platform for AAC Research: Project Open

[Project Open (https://project-openaac.com)](file:///C:\Users\trink\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\W1QZGRQ9\Project%20Open%20(https:\project-openaac.com)) is a federally funded initiative with a long-term goal of improving the expressive communication of individuals with complex communication needs who use augmentative and alternative communication (AAC) during in-person conversations and interactions. As a part of this effort, the project team has developed an open-source AAC design and development platform for research purposes, with a commitment to accessibility, social responsiveness, and sustainability. The platform supports contributions from those with and without expertise in computer programming, specifically targeting designers and researchers from a broad range of clinical and technical backgrounds, including those with lived experience using AAC.

The platform is called the Open-Source Design and Programmer Interface (OS-DPI) and it is situated for use within an inclusive community called the Project Open Design Community ([Community; see (https://github.com/UNC-Project-Open-AAC/OS-DPI/wiki)](https://github.com/UNC-Project-Open-AAC/OS-DPI/wiki). The collective purpose of the OS-DPI and the Community is to promote collaboration among stakeholders and realize the benefits that can come from inclusive design practices. The expectation is that the availability of open-source software and tools, shared among a community of researchers and designers, will increase the rate and volume of research related to AAC design. In this manuscript, we provide a detailed overview of the OS-DPI, associated Community, and future directions.

#### Open-Source Software

Software is commonly sold and licensed to consumers as a finished product, with updates and innovations managed by the company producing and selling the software. In contrast, open-source software refers to computer software with a source code that is available without restrictions. Open-source software is freely modifiable, and users can run the software for any purpose, including to study and modify it (Fortunato & Galassi, 2021). Additionally, open-source software development typically relies on virtual communities of users who contribute to the source code in ways that fit their own needs, while simultaneously benefiting as others share their innovations (von Hippel, 2001). These communities may comprise a variety of stakeholders, including computer programmers, manufacturers, and end-users. Importantly, communities are sustained by members who are intrinsically motivated (Lakhani & von Hippel, 2003; Liu et al., 2017) and invested in the potential of the program to contribute to both the social good and their specific objectives (Steinmacher et al., 2019).

von Krogh and colleagues (2003) suggest that “open-source software development has characteristics of collective action aimed at producing a public good” (p. 1235). Collective action relies on developer communities to produce and sustain the software to achieve the intended public good. Unfortunately, there are often barriers to joining and sustaining developer communities. Most obviously, software development requires high levels of domain-specific knowledge and experience to contribute to source code (Waterson et al., 1997). The more complex software is, the more challenging it is to integrate newcomers into the community (Fichman & Kemerer, 1997). Without incorporating new members, projects run the risk of concentrating knowledge to a few members, which in turn risks stifling innovation. This suggests that developer communities need to be thoughtfully constructed to reduce contribution barriers, especially when recruiting participation from a broad coalition of stakeholders.

Most tech innovation in the field of AAC has been led by commercial companies and disseminated as proprietary software (Higginbotham et al., 2009). Proprietary software has copyright limits on modification and requires use under predefined conditions. This creates barriers to using software for novel research purposes or for developing early proof of concept designs to demonstrate feasibility and inform further investment of resources. In contrast, open-source models support innovation through collaboration among stakeholders, particularly in the early stages of design work (Ebert, 2007). To date, open-source software has been used to develop a variety of assistive technology tools, including screen readers (Gaal et al., 2008), mobility navigation systems (Pereira et al., 2015), prosthetics (Niezen et al., 2016), and AAC applications (OpenAAC, 2020). Open-source software and tools offer potential for creating and adjusting AAC designs in unique ways and supporting the transfer of technology between research and commercial products (Higginbotham et al., 2009).

#### Community and Inclusive Design

Engaged open-source communities are central to developing and sustaining open-source platforms like the OS-DPI (Gamalielsson & Lundell, 2014). Therefore, starting new open-source communities relies in large part on an initial code-base and content that attracts members to join and contribute.

Inclusive design practices consider the full range of human diversity with respect to ability, language, culture, gender, age, and other forms of human difference (Inclusive Design Research Centre, 2020; Pullin et al., 2017). Inclusive design is aimed at making a product or service accessible to, and usable by, the broadest range of people possible (British Standards Institute, 2005), applying practices that are open and include the perspectives of people with limited ability to use current designs for their intended purposes (Treviranus, 2018). Inclusive design starts by recognizing who is currently being excluded from the design process (Microsoft, 2016; Pullin, 2009; Pullin et al., 2017). With respect to AAC design, individuals who use AAC, particularly those with requirements that do not conform to the current features of available products and design environments, are largely excluded from the design process. Additionally, researchers seeking to manipulate AAC variables, particularly those aimed at solving problems for small groups of individuals or with untested product potential, are largely excluded from the design process. Finally, designers without computer science backgrounds or programming expertise are largely excluded from the design process, particularly at the early stages of development. With overlap across these groups, designers of AAC solutions can be differentiated based on knowledge and skill in the areas of (a) computer science and programming, (b) user experience design practices, (c) clinical expertise related to AAC implementation, and (d) lived experience using AAC to support one’s own communication. Each of these subgroups brings important perspectives and expertise to the AAC design process, yet the early stages of design tend to be driven almost exclusively by designers with computer science and programming backgrounds, given practical constraints that limit involvement of those who are not trained to write software code. A main target of the OS-DPI is to lessen these contribution barriers by providing an accessible platform, with flexible and adaptable tools that do not require computer science expertise to explore, design, and test AAC user-interfaces.

### Target Audience and Relevance

Two primary groups are the target audience for the work described here: (1) those who use AAC to support their communication and (2) *anyone* who designs AAC solutions. Designers of AAC solutions can be differentiated based on knowledge and skill in the areas of (a) computer science and programming, (b) user experience (UX) design practices, (c) clinical and/or educational profiles of AAC users, and (d) lived experience using AAC. Each of these subgroups brings important expertise to the AAC design process, yet the early stages of design tend to be led by teams made up predominantly of members with computer science and programming expertise, with practical constraints often limiting involvement of those who are not trained to write software code. The team developing the OS-DPI is led by a computer scientist with extensive programming expertise, but it also includes individuals with lived experience using AAC, speech language pathologists and special educators with clinical expertise in supporting individuals who use AAC, including experience designing and developing user interfaces, as well as researchers with a history of work in the area of AAC. Our collective goal in developing the OS-DPI is to make designing AAC solutions accessible to those without computer science and programming expertise, as well as to those with disabilities who are often excluded from the design process, and clinicians, educators, and researchers interested in investigating novel AAC solutions.

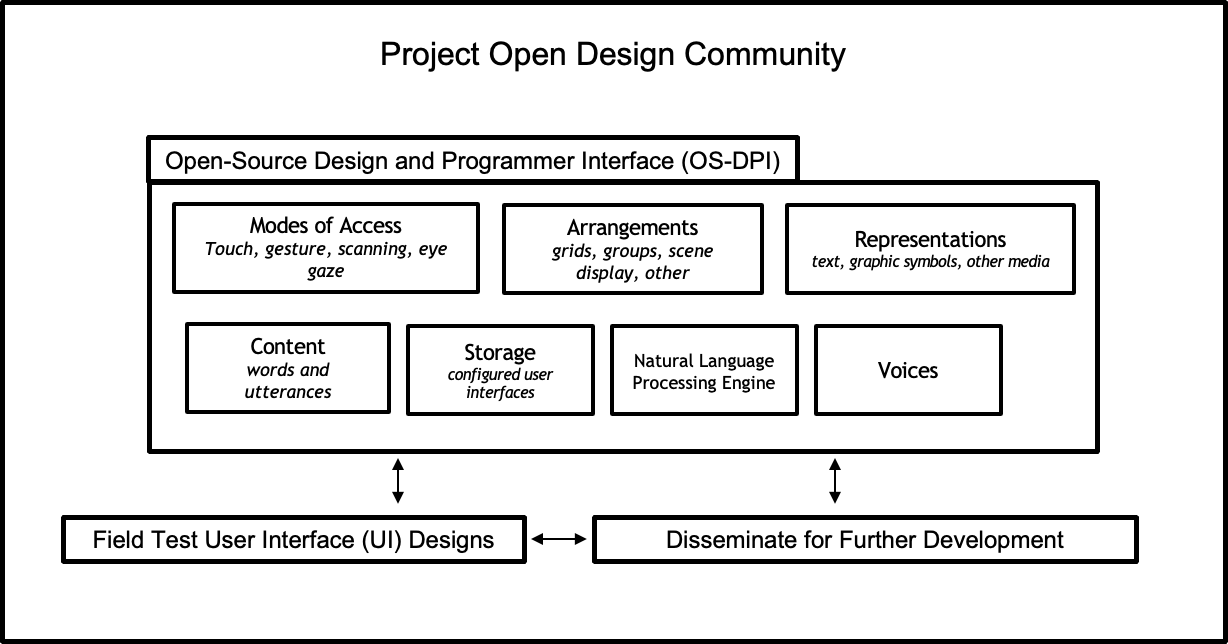
### Method

#### The Open-Source Design and Programmer Interface

The OS-DPI is in iterative development using Google's Chrome progressive web application, operating across a variety of other commercial web browsers and a full range of computers and mobile technologies. The cloud-based service provided by GitHub is used for sharing access to the OS-DPI’s designer interface and source code, demonstrating user interface layouts, supporting documentation, and facilitating community conversations. GitHub was selected in part because it provides important accessibility options. For example, GitHub offers support for adding text descriptions to images and customizing the keyboard commands used to access content within GitHub itself.

##### Underlying Functionality

***Figure 1: OS-DPI Components in Relation to Project Open Design Community***



The OS-DPI will provide the underlying functionality common across AAC software applications, with a designer interface aimed at supporting the creation of demonstration user interfaces for testing purposes. It is important to note that the OS-DPI is not intended for creating long-term, end-user AAC solutions, but rather to support early prototype and proof of concept designs. This has the potential to benefit companies seeking to refine their technology or test new solutions, researchers seeking to investigate AAC, and individuals who use AAC and the professionals who serve them seeking to test novel solutions before investing in them permanently. The solutions created might exist permanently as open-source prototypes or they may be transferred to proprietary AAC products by members of the community with the terms of the OS-DPI open-source license requiring nothing more than attribution. Figure 1 illustrates each of the components of the OS-DPI and situates the OS-DPI to the larger design community.

***Content, Arrangements, and Representations.*** Using the OS-DPI, designers can create user interfaces with wide ranging content, arrangements, and representations. For example, content can be arranged in row-column grids, by far the most common approach applied on current AAC systems. Grids can range from a single cell to 120 or more cells. Cell size and the uniformity of groupings can be varied on a single page or across pages to promote efficient access through physical touch, eye gaze, or scanning. Additionally, visual scene displays (VSDs) can be created with words, phrases, or sentences embedded within a photograph or image that are subsequently accessed with hotspots. In structured research contexts, VSDs have led to increases in symbolic communication and interaction for individuals at early stages of language learning and adults with acquired CCN and aphasia (Fager et al., 2019; Light et al., 2019). The OS-DPI will allow designers and researchers to create novel applications of VSDs for future research.

Content in grid arrangements can be represented by graphics, single letters, and/or text. Graphic symbols can include the use of photographs, line drawings (e.g., OpenSymbols), or other media (e.g., videos, animations). Additionally, multi-meaning symbol sequences (e.g., Minspeak) can be represented. Each of these graphic forms offer a visual representation of language with potential benefits across groups. For individuals with limited literacy abilities, the use of graphic symbols is especially useful for communication purposes. There are a growing number of graphic symbol sets to choose from to create user interfaces. Most are licensed by AAC manufacturers (e.g., Picture Communication Symbols (PCS) from Tobii Dynavox, SymbolStix from News2You, and Pixons and Minspeak symbols from PRC-Saltillo), but there is an emerging set of open-source symbols (e.g., OpenSymbols). While there are distinct design differences across these symbol sets, there is little empirical evidence that one symbol set is superior to another (Barton et al., 2006; Sevcik et al., 2018; Worah et al., 2015). Designers using the OS-DPI can use open-source symbols or symbols for which they hold a license. In all cases, the content is stored locally or in personal cloud space, not in the OS-DPI itself.

Content can be organized according to topic, context, grammatical structure, and/or instructional objectives. Spreadsheets are used to organize content, with attributes like a cell label and graphic symbol defined in columns. As content changes or additions are made, spreadsheets are reloaded into the OS-DPI and updates are subsequently reflected in the corresponding layouts of the user interface.

***Modes of Access.*** The OS-DPI supports the creation of user interfaces aimed at optimal use by touch (e.g., mouse-click, finger pointing), switch scanning, and eye gaze interaction. All modes of access can be implemented to select letters on a keyboard, utterances on a text-based user interface, symbols to combine words on a graphic-based system, or messages embedded in a visual scene. For touch access, designers can adjust for users who (a) make quick and accurate selections using a finger or mouse, (b) use a hold- or dwell-time to reduce accidental selections, or (c) drag a finger, pointer, or mouse across a screen, with selections made upon release. For eye-gaze access, designers can create user interfaces to work with eye-gaze devices that make selections based on length of visual fixation, switch activation, or blink. For scanning, designers can (a) identify if using switches or keyboard keys; (b) set standard patterns (e.g., linear, row-column) or assign groups; and (c) define how the scan advances (e.g., automatically, switch), which options are presented (e.g., highlight, audio), and what selections are made (e.g., 1-switch, 2-switch, dwell).

#### Designing with the OS-DPI

The OS-DPI provides access to tools to define actions, load content (defined in spreadsheets), upload media, and adjust modes of access to either create user interfaces from scratch or manipulate existing layouts. Implementation of the capabilities of the designer interface requires a willingness to learn and use declarative programming. Declarative programming is a non-imperative style of programming that requires users to describe the intended results without listing the specific commands or steps that must be performed. The OS-DPI design interface uses declarative programming with the intention of providing expressive power for exploring novel design ideas, without requiring expertise in writing in a conventional programming language. See Table 1 for declarative programming terminology and examples.

***Table 1: Declarative Programming Terminology and Examples***

| **Term** | **Definition** | **Programming** | **Example** |
| --- | --- | --- | --- |
| State | a variable that is shared among controls | begin with $ | $Display is the default state for the display content |
| Field | a named column from a spreadsheet that contains content | begin with # | #label refers to the column of content that indicates the text for a button/cell |
| Condition | a comparison involving States and Fields intended to produce an action | OS-DPI Actions tab provides structure for creating statements | Identifying a single button to clear the display by writing conditional statement that if the #label = ‘CLEAR’ then empty display |
| Action | a user-initiated event | Event that occurs when changes to the state match any programmed conditions | When the user presses the CLEAR button the contents from the display window are erased. |

### The Project Open Design Community

The OS-DPI is situated for use and continued development within a newly formed, inclusive Project Open Design Community. Goals for the Community include (a)supporting collaboration among stakeholders as OS-DPI users experiment with ideas and features, (b) informing the expansion of the features and capabilities of the OS-DPI platform, (c) providing a forum to produce and share useful help content and documentation for the OS-DPI, and (d) recruiting support from programmers interested in contributing to the source code.

The forming of the Community was initiated in November of 2021 by the Project Open team. Initial efforts included developing a diverse email list, publicizing at national and international conferences, encouraging members to invite others within their professional networks to join, scheduling Community meetings, and making materials openly available on established open-source data sharing platforms (e.g., GitHub). During this building phase, the Project Open team has been cognizant that the Community cannot be inclusive if it is not accessible and continues to seek expanded membership and engagement.

#### Meetings

Community meetings are intended to foster relationships between stakeholders with interests in AAC design for research purposes, including stakeholders working in academia, industry, or the field. In the early stages of Community formation, members of the Project Open team have taken the lead facilitating the meetings, providing demonstrations and updates, and asking explicitly for feedback. Initially, the intent was to schedule quarterly meetings to coincide with major conferences and events (e.g., ATIA, ISAAC) that draw a mix of stakeholders. However, due to the COVID-19 pandemic, initial meetings have been held virtually to allow members to participate without requiring travel. Although virtual meetings offer certain advantages with respect to access, a noted constraint of the virtual meeting format is limited screen space to provide side-by-side support and how-to demonstrations of the OS-DPI. Incorporating in-person events will offer opportunities to work together while interacting simultaneously with the OS-DPI. In the future, we will schedule some in-person meetings while also providing a virtual option to support continued remote participation. Regardless of opportunities to hold in-person events, we are committed to holding virtual meetings on a biannual basis.

The Project Open team is striving to host inclusive, accessible meetings that enable all participants to engage fully. Input from community members who use AAC has informed our current approach to facilitating meetings. In advance of each meeting, the agenda is provided and likely opportunities to contribute during the group discussions are outlined. This allows participants to consider and/or prepare messages in advance if this is their preference. However, preparation of anticipated contributions in advance is not expected, nor is it feasible for topics of discussion derived from member contributions during the meeting. We are prioritizing agendas that promote involvement of all participants and reduce the risk of participants feeling rushed or limited in opportunities to share their ideas. Throughout the meeting, participating members are invited to unmute their microphones and take the floor to ask questions or contribute to the discussion, or type messages into the chat to be read aloud by a meeting facilitator. Captioning is enabled using Zoom’s automated captions. Meetings are recorded, and the video with captions is uploaded and shared using YouTube. The meeting videos, transcripts, slides, and related documents are made publicly available through GitHub (see <https://github.com/UNC-Project-Open-AAC/OS-DPI/discussions>). Participants are encouraged to share their ideas before and after meetings using the discussion forum on the OS-DPI GitHub site. This is the preferred communication channel because it offers the benefit of shared Community access.

### Results

#### OS-DPI

Project Open team members without computer programming backgrounds or expertise have used the current design interface to develop a variety of simple demonstration user interfaces. Preliminary approaches to documentation have been used to successfully support members of the research team who have not been involved in the development of the OS-DPI in creating user interfaces.

##### Demonstration User Interfaces

Through the current iteration of the OS-DPI, members of the research team have used declarative programming to design a variety of user interfaces. These grid- and VSD-based designs highlight the current capabilities of the OS-DPI. As a team, we have found that a variety of different programming solutions can be used to create layouts with comparable content and functions from the perspective of the user. See Table 2 for examples of prototype user interfaces created using declarative programming and the current build of the OS-DPI.

***Table 2: Visual Layout of Prototype User Interfaces and Highlights of Declarative Programming Solutions to Create Each***

| **Visual Layout of UI Landing Page** | **Declarative Programming Highlights** |
| --- | --- |
| A picture of a 60- location symbol based layout with a message window across the top.  Single Words with Morphs | **Arrangement:** A single grid with a message window. The number and placement of cells were defined in a corresponding spreadsheet. Empty cells reflect empty rows in the spreadsheet.  **Content:** Graphic symbols to represent word-based content were uploaded as media. The spreadsheet contained a column for the name of each graphic symbol file to display in each cell in the grid. Declarative programming was used to create a rule that when a verb is double clicked, inflected forms are offered to replace the verb in the message window.  **Message Window/Speak:** Symbol-based words were programmed to be added to the message window, and a single cell was programmed to Speak the contents of the message window when selected. |
| A picture of a QWERTY keyboard in a 60- location layout with a word prediction bar and message window across the top.  Keyboard with Word Prediction | **Arrangement:** Two grids stacked below a message window. Top grid number of rows (1) and columns (7) defined within OS-DPI and set to fill content from spreadsheet. Navigation buttons automatically added when the grid is set to fill with more content than there are rows and columns.  **Content:** Words for prediction were uploaded in a spreadsheet, and declarative programming used to create rules about updating the words in the prediction row based on the letters currently in the message window. Rules were also written about adding spaces after punctuation.  **Message Window/Speak:** Declarative programming was used to set a rule that letters in combination in the message window are spoken as words, single letters are spoken as letter names. |
| A picture of a layout with a grid on top of phrases. In the middle is a message window and on the bottom is a keyboard.  Text-based Example | **Arrangement:** A stack from top to bottom with (a) a grid with tabs, (b) message window, (c) a grid for word prediction, (d) a grid for keyboard, (e) a button for space, and (f) a button for speak. The OS-DPI allowed for adjustments to the relative scale for each component of the arrangement.  **Content:** Different sheets were created in a spreadsheet with the content needed for each grid and button in the arrangement. The source sheet for each was defined in the OS-DPI.  **Message Window/Speak:** Phrases were programmed to be spoken upon selection. In contrast, word-based content was programmed to be added to the message window. A single button was programmed to speak the contents when selected. |
| A picture of a visual scene display of a picnic with red boxes around hot spots. There are four tabs across the bottom to take you to other visual scene displays.  Visual Scene Display | **Arrangement:** A VSD stacked onto a grid that acts as navigation tabs to display other unique images with embedded content.  **Content:** Images for each VSD uploaded as media and unique VSDs created in the OS-DPI. Words or phrases were entered into the spreadsheet followed by columns that indicated the placement of the hotspot that should contain that word or phrase. Columns to specify the x and y coordinates and the height and width of each hotspot were provided.  **Message Window/Speak:** Declarative programming used to indicate hotspots should speak the contents upon selection. No message window added to layout. |

*Accessing Prototypes:* All prototypes above can be found on [GitHub (https://github.com/UNC-Project-Open-AAC/OS-DPI/blob/main/README.md)](file:///C:\Users\trink\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\W1QZGRQ9\GitHub%20(https:\github.com\UNC-Project-Open-AAC\OS-DPI\blob\main\README.md))

##### Documentation

Documentation for the OS-DPI has been written for non-programmers to support learning to use declarative programming. Initial step-by-step guides for using and modifying demonstration user interfaces, as well as step-by-step guides for creating new user interfaces, are available through the OS-DPI GitHub site. Within the research team, these documents have been successful at supporting those unfamiliar with programming generally, and the OS-DPI specifically, in using declarative programming to produce simple user interfaces.

Documentation describes the features of the OS-DPI with examples of the ways they can be combined and recombined to address different needs. Further support for utilization of the OS-DPI is provided through the communication capabilities built-in to the OS-DPI GitHub site, which allow all members of the Project Open Community to ask, answer, follow, and edit information about application of the OS-DPI across research and development projects. A tutorial for creating a simple grid with a message display, as well as all necessary data, can be found on GitHub (<https://github.com/UNC-Project-Open-AAC/OS-DPI/wiki/Tutorial-to-Create-a-Simple-Grid-plus-Display-Bar>).

#### Project Open Design Community Meetings

To date, two community meetings have been held. Both meetings were held in a virtual format, with participants sent information in advance about the format, structure, and content of the meetings. The purpose of these initial meetings was to begin to establish relationships with the Community, demonstrate the current capabilities of the OS-DPI, elicit feedback, and promote member involvement. Beyond members of the Project Open research team, a total of 28 different participants have joined the Community meetings, 23 attending the first meeting (November 2021) and 13 attending the second (March 2022). Representation across targeted stakeholders included 5 participants who use AAC, 21 who have university affiliations, 7 who work in industry, and 1 who has a clinical practice. Participating designers with lived experience using AAC included 3 affiliated with a university, 1 affiliated with an AAC company, and 1 affiliated with both a university and an AAC company.

#### Joining the Community

AAC designers who are interested in exchanging ideas with others and contributing to the development of the OS-DPI and supporting materials can join the Project Open Design Community by visiting the Project Open website and signing up to receive notifications about upcoming meetings and important announcements (see <https://project-openaac.com/community/>). They can also explore the OS-DPI GitHub site to freely access the latest versions of the designer interface, demonstration user interfaces, support documentation, community conversations, and source code (see <https://github.com/UNC-Project-Open-AAC/OS-DPI>).

### Outcomes and Benefits

The OS-DPI and the Community offer potential to increase inclusive design of novel AAC user interfaces for testing hypotheses and demonstrating proofs of concept for product ideas. The targeted outcomes include increasing (a) involvement of a broader range of stakeholders in all stages of design, including those who use AAC to support their own communication; (b) collaboration among stakeholders; and (c) the rate and volume of research conducted on AAC features. The intended longer-term benefits are improved expressive communication of individuals with complex communication needs using AAC through innovative user interfaces that address the composition delays, breakdowns, and miscommunications that frequently occur during in-person interactions mediated by AAC.

### Future Directions

Implementation of the OS-DPI will be evaluated and iteratively developed based on input from the Community. The iterative development process is designed in part to optimize it for future research and continued public use. Detailed documentation of the source code, as well as tutorial-like documentation and videos demonstrating potential application of the OS-DPI, will be provided. As part of the overarching Project Open effort, aimed at cataloging problems with AAC-mediated communication and proposing design solutions, prototype user interfaces will be implemented in the OS-DPI and field tested with research participants. The integrated components that make up each text- and graphic-based user interface created for field testing will be delivered through the OS-DPI GitHub site to be accessed by participating individuals who use AAC by loading the user interfaces on a variety of hardware (e.g., smartphones, tablets, computers). Field testing will inform iterative development and the prototype user interfaces will be shared with the Community as open-source files that can be edited within the OS-DPI. Future capabilities of the OS-DPI will also include natural language processing to support features such as context-specific message prediction and data logging to support various aspects of research and development. Each of these steps will maximize outcomes and benefits for individuals who use AAC, researchers in the field of AAC, and the industry that supports the two.

### Conclusion

The OS-DPI and Community aim to foster inclusive research and development through collaboration and innovation. The open-source model offers promising potential to support researchers from academia, industry, and the field who wish to explore design options and novel configurations. Developing in a web environment ensures that the OS-DPI will be useful across mobile- and computer-platforms, on and offline, and allows researchers to experiment with features in a product-agnostic manner. A main target of the OS-DPI is to reduce contribution barriers by providing an accessible and flexible platform that does not require computer science expertise to explore, design, and test AAC user interfaces. Declarative programming enables researchers without expertise with conventional programming languages to explore novel design ideas, as evidenced by the Project Open team’s initial implementation of demonstration user interfaces. The Community plays a central role in realizing and sustaining use of the OS-DPI as a platform for collaboration and innovation among stakeholders with interests in AAC design.

### Declarations

This content is solely the responsibility of the author(s) and does not necessarily represent the official views of ATIA. This article was produced under a grant from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR grant number 90DPCP0007). The views expressed herein do not necessarily represent the positions or policies of NIDILRR, ACL, or HHS. No official endorsement by NIDILRR of any product, commodity, service, or enterprise mentioned in this publication is intended or should be inferred. The second author disclosed two non-financial relationships. She is a member of the Editorial Board for the Assistive Technology Outcomes and Benefits journal and a strand advisor for the Assistive Technology Industry Association.

### References

Barton, A., Sevcik, R. A., & Romski, M. A. (2006). Exploring visual-graphic symbol acquisition by pre-school age children with developmental and language delays. *Augmentative and Alternative Communication, 22*(1), 10–20. <https://doi.org/10.1080/07434610500238206>

British Standards Institute. (2005). *Design management systems - part 6: Managing inclusive design - guide.* British Standards Institution.

Ebert, C. (2007). Open source drives innovation. *IEEE Software, 24*(3), 105–109. <https://doi.org/10.1109/MS.2007.83>

Fager, S. K., Fried-Oken, M., Jakobs, T., & Beukelman, D. R. (2019). New and emerging access technologies for adults with complex communication needs and severe motor impairments: State of the science. *Augmentative and Alternative Communication*, *35*(1), 13–25. <https://doi.org/10.1080/07434618.2018.1556730>

Fichman, R. G., & Kemerer, C. F. (1997). The assimilation of software process innovations: An organizational learning perspective. *Management Science, 43*(10), 1329–1468. <https://doi.org/10.1287/mnsc.43.10.1345>

Fortunato, L., & Galassi, M. (2021). The case for free and open source software in research and scholarship. *Philosophical Transactions of the Royal Society A, 379*(2197). <https://doi.org/10.1098/rsta.2020.0079>

Gaal, A., Jaworek, G., Klaus, J., Weicht, M., Zenker, F., Bruder, I., Dusterhoft, A., & Heuer, A. (2008). Towards an open source screen reader: Screenreader usability extensions (SUE). In K. Miesenberger, J. Klaus, W. Zagler, & A. Karshmer, (Eds.). *Computers helping people with special needs.* Springer. <https://doi.org/10.1007/978-3-540-70540-6_118>

Gamalielsson, J., & Lundell, B. (2014). Sustainability of open source software communities beyond a fork: How and why has the LibreOffice project evolved? *The Journal of Systems and Software, 89*(1), 128–145. <https://doi.org/10.1016/j.jss.2013.11.1077>

Higginbotham, D. J., Beukelman, D., Blackstone, S., Bryen, D., Caves, K., Deruyter, F., Jakobs, T., Light J., McNaughton, D., Moulton, B., Shane, H., & Williams, M. B. (2009). AAC technology transfer: An AAC-RERC report. *Augmentative and Alternative Communication, 25*(1), 68–76. <https://doi.org/10.1080/07434610902724886>

Inclusive Design Research Centre. (n.d.). <https://idrc.ocadu.ca/about-the-idrc/49-resources/online-resources/articles-and-papers/443-whatisinclusivedesign>

Lakhani, K. R., & von Hippel, E. (2003). How open source software works: “Free” user-to-user assistance. *Research Policy, 32*(6), 923–943. <https://doi.org/10.1016/S0048-7333(02)00095-1>

Light, J., McNaughton, D., Beukelman, D., Koch Fager, S., Jakobs, T., & Jacobs, E. (2019). Challenges and opportunities in augmentative and alternative communication: Research and technology development to enhance communication and participation for individuals with complex communication needs. *Augmentative and Alternative Communication, 35*(1), 1–12. <https://doi.org/10.1080/07434618.2018.1556732>

Liu, M., Hull, C. E., & Hung, Y. C. (2017). Starting open source collaborative innovation: The antecedents of network formation in community service. *Information Systems Journal, 27*(5), 643–670. <https://doi.org/10.1111/isj.12113>

Microsoft. (2016). Inclusive 101. <https://www.microsoft.com/design/inclusive/>

Niezen, G. (2016). Open-source hardware for medical devices. *Medical Devices, 2*(1), 78–83. <https://doi.org/10.1136/bmjinnov-2015-000080>

OpenAAC. (2020). <https://www.project-openaac.org/>

Pereira, C., Sousa, A., & Filipe, V. (2015). Open-source indoor navigation system adapted to users with motor disabilities. *Procedia Computer Science, 67*(1), 38–47. <https://doi.org/10.1016/j.procs.2015.09.247>

Pullin, G. (2009). *Design meets disability*. MIT Press.

Pullin, G., Treviranus, J., Patel. R., & Higginbotham, J. (2017). Designing interaction, voice, and inclusion in AAC research. *Augmentative and Alternative Communication*, *33*(3), 139–148. <https://doi.org/10.1080/07434618.2017.1342690>

Sevcik, R. A., Barton-Hulsey, A., Romski, M. A., & Hyatt Fonseca, A. (2018). Visual-graphic symbol acquisition in school age children with developmental and language delays. *Augmentative and Alternative Communication,* *34*(4), 265–275. <https://doi.org/10.1080/07434618.2018.1522547>

Steinmacher, I., Gerosa, M., Conte, T. U., & Remiles, D. F. (2019). Overcoming social barriers when contributing to open source software projects. *Computer Supported Cooperative Work, 28*, 246–290. <https://doi.org/10.1007/s10606-018-9335-z>

Treviranus, J. (2018) *The three dimensions of inclusive design: Part one.* <http://openresearch.ocadu.ca/id/eprint/2216/>

von Hippel, E. (2001). Innovation by user communities: Learning from open-source software. *MIT Sloan management review*, *42*(4), 82–86. <https://sloanreview.mit.edu/article/innovation-by-user-communities-learning-from-opensource-software/>

von Krogh, G., Sapeth, S., & Lakhani, K. R. (2003). Community, joining, and specialization in open source software innovation: A case study. *Research Policy, 32*(7), 1217–1241. <https://doi.org/10.1016/S0048-7333(03)00050-7>

Waterson, P. E., Clegg, C. W., & Axtell, C. M. (1997). The dynamics of work organization, knowledge and technology during software development. *International Journal of Human-Computer Studies 46*(1), 81–103. <https://doi.org/10.1006/ijhc.1996.0084>

Worah, S., McNaughton, D., Light, J., & Benedek-Wood, E. (2015). A comparison of two approaches for representing AAC vocabulary for young children. *Augmentative and Alternative Communication, 17*(5), 460–469. <https://doi.org/10.3109/17549507.2014.987817>

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 43-56

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# Provider Perspectives on Providing Mainstream Smart Home Technologies as Assistive Technology

## **Dan Ding, Ph.D. and Lindsey Morris, OTD, OTR/L**

## Department of Rehabilitation Science and Technology University of Pittsburgh

## Human Engineering Research Laboratories VA Pittsburgh Healthcare System

***Corresponding Author***

Dan Ding

Department of Rehabilitation Science and Technology

Suite 401

6425 Penn Ave

Pittsburgh, PA 15206

Email: [dad5@pitt.edu](mailto:dad5@pitt.edu)

Phone: (412) 624-1964

### Abstract

This study examined the challenges in implementing a service delivery process of mainstream smart home technology (MSHT) as assistive technology devices (ATDs) among four provider groups using a systems thinking approach. Researchers conducted semi-structured interviews with each group using guiding questions based on the assistive technology service delivery process and summarized the challenges as case studies.All four provider groups intended to follow a current assistive technology service delivery process when delivering MSHT as ATDs. While the populations they serve and the funding environments are different, they all faced challenges with the assessment and technology recommendations for MSHT. In addition, the provision services including installation/setup, customization, and training are usually bundled, which often leaves no or less time for customization and training. The study provided insights into areas where support is likely needed for providing MSHT services to people with disabilities.

***Keywords:*** mainstream smart home technology, assistive technology, service delivery, people with disabilities, semi-structured interviews

### Provider Perspectives on Delivering Mainstream Smart Home Technology as Assistive Technology

Our society is undergoing a massive digital transformation process, and the demand for digital tech solutions has been growing rapidly. Mainstream smart home technologies (MSHTs) as a popular type of digital tech solutions, are becoming increasingly prevalent, especially with the COVID-19 pandemic forcing people to reconsider their relationships with their homes and invest in things that make their homes more comfortable. MSHT in this paper refers to smart home controllers such as smartphones, smart speakers, and smart home hubs, as well as smart home devices such as smart light bulbs, smart plugs, smart switches, smart door locks, smart doorbells, smart appliances, smart blinds, smart cameras, and smart sensors. While MSHTs provide convenience and comfort to the general population, they could function as assistive technology devices (ATDs) to promote independence and participation with increased safety and quality of life for people with disabilities and older adults (Forchuk et al., 2022; Kelley & Roberts, 2021; Stanek, 2019).

The Assistive Technology Act of 2004 defines “assistive technology (AT)” as technology designed to be utilized in an ATD or assistive technology service (ATS; Assistive Technology Act of 2004). An ATD is any item, piece of equipment, or product system that is used to increase, maintain, or improve functional capabilities of individuals with disabilities, and ATS refers to any service that directly assists an individual with a disability in the selection, acquisition, or use of an ATD (Assistive Technology Act of 2004). Although MSHTs could be used as ATDs, there is a shortage of ATS to assist people with disabilities in choosing, obtaining, or utilizing MSHTs (Jamwal et al., 2020). Prior to MSHTs, environment control units (ECUs) and early home automation technology such as X10 had been provided to people with disabilities. Despite some research studies that demonstrated the benefits of such technologies, there is a shortage of information on how services were provided for these ATDs (Etingen et al., 2017; Myburg et al., 2015; Tomita et al., 2007). MSHTs are now replacing these earlier technologies by offering users enhanced capabilities, more options, and Greater diversity. However, it also introduces a greater level of complexity in terms of selecting the most appropriate products, customizing them to meet individual needs, and providing adequate training for proper and sustained use.

The World Health Organization (WHO)’s Global Collaboration on Assistive Technology (GATE) program published a commentary on systems thinking of AT, where the users of AT are supported by four main strategic drivers, including products, personnel, provision, and policy (MacLachlan & Scherer, 2018). This systems thinking approach could allow for the benefits of AT to be equitably and effectively distributed across the population and life course. In the case of traditional seating and mobility, the benefit to the users is affected by products (i.e., seating and mobility devices that are designed to address different user needs and abilities), personnel (i.e., therapists who conduct a comprehensive assessment for prescribing appropriate products and features that meet user needs and abilities), provision (i.e., suppliers and manufacturer representatives who assist with fitting, setting up, and training of the recommended products), and policy (i.e., funding for seating and mobility devices as well as associated services such as assessment). However, in the context of MSHTs, all four strategic drivers are lacking. First, MSHTs are not designed for people with different types of impairments; and thus, these individuals may not be able to interact effectively with the devices at their default settings. Second, MSHTs are not typically covered in the curricula of any health professions, and the rapid advancement of such technologies and the expanding range of products and features present challenges for the professionals to keep up and learn. Third, provision of MSHTs relies on customer support personnel of

MSHT manufacturers who usually have limited or no training on accessibility and disability. Lastly, the funding sources for MSHTs and associated services are not well-established. As a result, service delivery for MSHTs as ATDs are almost non-existent.

It is worth noting that providing an MSHT ATD system can be challenging, as it involves diverse types of MSHT devices and device controllers, as well as consideration of compatibility among devices and device controllers, compatibility with traditional ATDs and living environment, and diverse customization options. Previous research has revealed that providers of traditional ATDs are often not adequately trained in identifying, selecting, and fitting ATDs, and do not adhere to standard ATS models (Arthanat et al., 2017; Jans & Scherer, 2006; Kanny & Anson, 1998). Elsaesser and Bauer (2011) critiqued the lack of modern ATS models and constructed the Assistive Technology Services Method (ATSM) process standard for ATS. While the ATSM outlines the steps that AT service provision should include, it is not clear how these steps should be implemented for provision of MSHT, a multi-type ATD system, to people with disabilities.

There has been a shortage of research on MSHT delivery to people with disabilities. Our research group interviewed 15 practitioners from 14 different institutions (e.g., hospitals, state AT programs, disability organizations, and small businesses) on their current MSHT delivery process (Ding et al., 2021). All participants acknowledged the potential advantages of MSHTs for individuals with disabilities; however, most used an informal service delivery process and faced various difficulties, such as maintaining technology updates and compatibility, keeping abreast of technology advancements, obtaining funding for MSHTs and services, client Internet/Wi-Fi access and quality, and as security and privacy issues. Wallock and Cerny (2021) reported a MSHT pilot involving a fixed set of devices with 36 individuals with ALS from the field. Based on feedback received from 19 participants, 18 reported having a positive experience with the integration of MSHTs into their daily routines, and the MSHTs, along with training and support, helped balance the device complexity and user capability. A recent report from Australia on the role of smart home assistive technologies in supporting aging in place and disability housing stated that “the lack of clear policy frameworks and insufficient coordination has resulted in an ad-hoc and piecemeal implementation practice with many who could potentially benefit not having the skill, knowledge or financial ability to invest” (Bridge et al., 2021, p. 2). The report also mentioned that people with more complex needs would require modifications outside the manufacturer’s settings to achieve the same operable functionalities, and sustainable investment in education and training is needed for sustained uptake and effective use of MSHT ATDs.

Another recent report from UK on smart homes for independent living also pointed out that many people with disabilities and older adults had not benefited from the dramatic growth of the consumer smart home market due to a combination of a lack of appropriate support and a technology sector that has consistently failed to respond to their needs (Gilbert, 2022). A 2020 scoping review on smart home and communication technology for people with disabilities concluded that “Smart technology, when implemented and supported effectively, allows government funds to be saved, support worker resourcing to be more meaningfully allocated, and true level of independence of people with disabilities to be sustained and enjoyed” (Jamwal et al., 2020, p. 20).

Recognizing the importance of using the systemic approach to deliver MSHTs, we are working on developing MSHT service delivery models for different settings. As part of this development process, we conducted this exploratory study with four provider groups with whom we plan to pilot MSHT service delivery models. In this paper, we describe the methods and findings from the interviews and provide insights into areas where support is likely needed for these provider groups.

### Target Audience and Relevance

MSHTs have great potential to support individuals with various types of disabilities, giving them control over their home environments, improving safety and security, promoting participation, and making their day-to-day living more efficient (Corso, 2021; Jamwal et al., 2020; Wallock & Cerny, 2021). This paper will be of relevance to professionals and providers who work in either clinical or community settings on providing ATS to people with disabilities and are interested in providing MSHTs as ATDs. It will also be of relevance to policy makers and potential payers such as Medicaid managed care organizations (MCOs), AT researchers, AT and MSHT manufacturers, and professional, trade, and government funded programs. The findings of this study will inform these stakeholders of the current practice in different settings and potential areas of improvements needed to ensure that MSHTs are adequately provided and supported to achieve high levels of performance for people with disabilities. These potential areas could include the development of tools, resources, and educational materials for supporting efficient and effective provision of MSHT services.

### Method

#### Study Design

This is an exploratory qualitative case study. We conducted semi-structured small group interviews with four provider groups including a regional Center for Independent Living (CIL; (Group 1), a statewide nonprofit organization that partners with a Medicaid MCO (Group 2), a Veterans Affairs (VA) wheelchair clinic (Group 3), and a university-based outpatient AT clinic (Group 4). The purpose of this study is to examine the challenges and needs at each site and help develop a new MSHT service delivery model for the sites. The four provider groups are currently delivering or intend to deliver MSHT to people with disabilities, and are willing to pilot a new service delivery model. As the study is not to extract common themes from the four unique sites, we adopted the case study approach (Crowe et al., 2011) which allows in-depth and multi-faceted explorations of issues in the current MSHR delivery process of each site.

The Institutional Review Board (IRB) of the University of Pittsburgh approved the protocol. Informed consent was obtained prior to the start of the study. Participants were asked to complete an online demographics questionnaire before their scheduled session. The meeting sessions with each provider group were administered remotely via the videotelephony software Zoom (Zoom Video Communications, Inc.). They were all facilitated by the second author with the first author being present to assist when needed between July and August 2022. A PowerPoint presentation developed by the investigators was used to organize and guide the small group interviews. This presentation guide was developed based on two prior studies where we interviewed 15 professionals nationwide who had experience delivering MSHT services (Ding et al., 2021b) and 15 individuals with complex disabilities who receive Medicaid home and community-based services (HCBS; Ding et al., 2021a). Each meeting session lasted approximately 90 minutes and was recorded via Zoom.

#### Data Collection

The demographics questionnaire included questions on race, gender, ethnicity, education/training, licensure and professional certifications, and years of experience in providing services regarding traditional AT, MSHT, and home modification and accessibility, respectively.

Each interview session started with the study purpose, followed by guiding questions on the characteristics of the provider organization, the client characteristics served by the organization, and challenges experienced for each step of the service delivery, including referral, funding, assessment, device recommendation, device installation/setup, customization, training, and follow-up, as well as the types of professionals involved in each step.

#### Data Analysis

Descriptive statistics were used to summarize participant demographics. Audio files from all interview sessions were extracted and transcribed verbatim with pseudonyms for each participant. As the purpose of this case study is to inform the MSHT service delivery development for each site, we did not employ the qualitative thematic analysis to extract common themes. Instead, the first and second authors worked together to summarize the key discoveries and challenges to the existing MSHT service delivery process for each provider group, and present them in a case study format (Crowe et al., 2011).

### Results

A total of four provider groups participated in this study. Group 1 represents the regional CIL that provides both home modification services and AT services for a managed care organization for Community HealthChoices (CHC-MCO), Pennsylvania’s Medicaid managed care program. Group 2 is a statewide nonprofit organization that partners with another CHC-MCO which intends to implement a new process for MSHT delivery. Group 3 and Group 4 provide MSHT services on an occasional basis upon client requests. We recruited all personnel who are involved in MSHT service delivery at each site in the study. As Group 2 is in the planning phase, only the two lead persons were recruited. Table 1 provides the detailed participant demographics of the four groups. A total of 13 professionals from the four groups participated in the interviews.

There are three CHC-MCOs in the State of Pennsylvania. Group 1 and Group 2 each work with a different CHC-MCO. Participants in the CHC are 21 years of age and older who qualify for Medicaid financially and functionally meet the criteria of Nursing Facility Clinically Eligible (NFCE). These individuals are eligible for the Long-Term Services and Supports (LTSS) benefit package which includes 37 service offerings, with AT being one of them. The AT services include assessment, device purchase, installation and setup, and training. As of January 1st, 2021, an amendment to the CHC waiver modified the AT definition to add MSHT. Participants in a CHC-MCO could request AT, including MSHT, through their service coordinators. They may mention their need or desire for AT, including MSHT, during their periodic comprehensive assessments or person-centered planning meetings, or at any time. The MSHT products covered under the CHC waiver include electronic systems that enable a participant with functional limitations and identified needs to control various appliances, lights, doors, and security systems in their room, home, or other surroundings, electronic devices that assist a participant with communication or prompting needs such as tablets, computers, and electronic communication aids, along with software, mobile apps and hubs for the proper functioning of ATDs. The interviews with Group 1 and Group 2 revealed that both CHC-MCOs currently do not have a well-established service delivery process for AT, including MSHT.

Group 1 included five professionals from a regional CIL who have been providing home modification services to clients with physical disabilities in one of the CHC-MCOs. These clients may also have other difficulties in cognitive and sensory domains. Group 1 recently started providing the AT (including MSHT) services as contracted by this CHC-MCO, and their services primarily focus on acquisition, installation/setup, customization, and training. Group 1 is not involved in AT service provision for MSHT, including assessment and technology selection, which is performed by licensed therapists from another group contracted by this CHC-MCO. We were not able to recruit a licensed therapist from this group and a representative from this CHC-MCO. Group 1 brought up several challenges.

***Table 1: Demographic Characteristics of the Study Participants***

| **Provider Group** | **Characteristics** |
| --- | --- |
| Group 1 (*N* = 5)  A regional Center for Independent Living | 3 Female 2 Male; 5 Caucasian  Role:   * Director of Home Adaptations and Modifications Division * Home Modifications Supervisor (who used to cover AT services) * AT specialist for MSHT delivery (new hire for AT services) * Independent living specialist supervisor * AT specialist for the AT resource center |
| Group 2 (*N* = 2)  A non-profit partnered with a CHC-MCO | 2 Female; 2 Caucasian  Role:   * CEO of the non-profit organization * Service Director of a CHC-MCO |
| Group 3 (*N* = 3)  A VA Wheelchair Clinic | 2 Female 1 Male; 3 Caucasian  Role:   * Supervisor * Occupational Therapist * Speech Language Pathologist |
| Group 4 (*N* = 3)  A university-based outpatient AT clinic | 2 Female 1 Male; 2 Caucasian; 1 Hispanic  Role:   * Director of the clinic * Rehab engineer * Speech Language Pathologist |

#### Group 1

***Inadequate Assessment Process.*** *“Our job is to provide what is recommended.”* However, the inadequate assessment process has led to incomplete or inappropriate technology recommendations that make it difficult for Group 1 to carry out their services. The specialist who provides the ATS commented: *“This probably happens, and it is not an exaggeration, 85% of my cases…”* They provided examples when the recommended products did not meet the client needs and, when the recommendations did not consider the context of use and additional requests, had to be sent for MCO approval. They also brought up several factors that could have contributed to the inadequate assessment. First, the lack of AT knowledge and training in therapists who perform the assessment led to inappropriate technology selection. Second, the assessors used a home modification assessment form for AT assessment. Instead of following a structured protocol with questions, they had a freeform field in the form to document the justifications and recommendations of AT products. Third, there was no device trial as part of the assessment and recommendation, which sometimes led to multiple purchase requests to the MCO in order to identify the right product for the client.

***Inadequate Training and Education.*** While the services provided by Group 1 include some basic education and training, they do not feel it is adequate and often receive troubleshooting requests from their clients. They do not have time to provide additional support within the approved service hours unless the client makes another request to the CHC-MCO. As AT is handled similarly as home modifications within the CHC-MCO, which typically do not require much client training, the training needs for AT are significantly underestimated. While Group 1 has independent living specialists in their organization who could potentially provide additional training, they are not part of the AT service delivery for the CHC-MCO.

***No Follow-Up.*** While Group 1 mentioned that the follow-up for home modification services is usually performed by the therapist who performs the assessment, there is no follow-up from the referral therapist or the CHC-MCO for the AT services. It was also mentioned that some clients are reluctant to sign off on the post-delivery paper for their AT devices because they are still not sure at the time if they can fully use the devices for their needs. This is very different from home modification services where clients usually know if things work right after installation.

***Lack of Efficiency.*** Group 1 mentioned that *“There is no way to predict the time for this service delivery process because of the variables to the environment and to the consumers and their specific needs*.” In addition to physical installations for some MSHT products, all MSHTs need to be paired and set up with smartphones or smart speakers so they can work cohesively together. Sometimes Group 1 had to continue providing the services even though it took longer than the approved time units, and sometimes they would ask clients to submit additional requests to the CHC-MCO before they provided additional support. They also mentioned that the inefficiency is in part related to “*the fact that they (therapists) do not assess appropriately at the beginning and they are not trying out multiple devices or really examine the full environment. If they were to have an appropriate assessment, we would deliver and set up the devices more efficiently.”*

Group 2 included two professionals who represent a nonprofit statewide organization that serves individuals with disabilities and another CHC-MCO, respectively. Group 2 was recruited, as the two organizations have partnered to plan a pilot MSHT service delivery program. At the time of the interview, they have not identified other professionals that will assist with the pilot program. According to the professional who represents the CHC-MCO, “*there is (currently) not a uniform established process (for AT including MSHT service delivery), and very minimal information is required from the AT provider who performs the assessment using their own process or tool*.” We extracted the following key points from Group 2.

#### Group 2

***Low Awareness of MSHT as ATDs.*** “*Today unless we have a participant who already has an awareness of the technology or device that they would take advantage of, they are not really aware of the AT service offering as part of their benefit package unless the service coordinator talks to them about it during the person-centered service planning process*.” However, *“The base knowledge on MSHT among participants in the CHC program, service coordinators, and state oversight is very limited.”* While Group 2 acknowledged the challenge, they also would like to address it in two ways in their pilot by “*not only informing people with disabilities about the power of MSHT and having them request it, but also informing service coordinators how there might be a technology solution to a goal*.”

***Bundled Services are Not Effective.*** “*So much is bundled together as kind of one cost. So, it is easy to short shrift a service if the assessment takes x amount of time, and ordering the devices, then having them installed, so the setup and training often get kind of short shrift*.” Group 2 would like to address this challenge by allowing individual services to be billable in their pilot, which will help ensure that the MSHTs are set up and customized to the unique needs of the participant and the participant receives adequate training.

***Education and Training are Needed for a Variety of Stakeholders.*** Group 2 recognized that a wide range of stakeholders including participants, family caregivers or direct support workers, service coordinators, clinical LTSS review team, their network of home modification teams and brokers, and home health agencies, should be educated and trained on MSHTs and how they work and support independent living.

***Funding for Internet Could Be a Barrier****.* “*There is not one funding stream for all things needed for MSHT.”* While CHC participants are eligible to receive AT, including MSHT and associated services, Internet is not part of it. Given the financial constraints, the monthly Internet cost could be a barrier to these individuals, especially when cloud-based technology such as voice assistance and remote support are needed.

#### Group 3

Group 3 included three professionals from the local VA including the supervisor for the VA wheelchair clinic, an occupational therapist, and a speech and language pathologist (SLP). As they receive increasing MSHT requests in their wheelchair clinic, they recently have begun offering MSHT services upon client requests. They do not have a set list of products provided, but they would cover any AT, including MSHT products, if there are identified needs.

***Barriers to MSHT Assessment****.* *“Knowing what questions I should ask and how much details I would need to know”* is helpful for making technology recommendations. *“There are no situations that are the same. They are all different.”* The diverse conditions among their clients have made the technology selection and recommendation difficult. For seating and mobility, *“I have the support of the suppliers if I need it, which I do not have for smart home tech. I also have access to demo equipment to use. There are a lot of things on the seating side that I do not have with the smart home stuff.”* There are many brands/models of MSHT, and with the many choices, it is challenging to select the specific device brands and features that meet the client goals.

***Barriers to Other Services Beyond Assessment.*** While VA would fund services such as installation (through contracted vendors), setup, customization, training and follow-up with MSHT, Group 3 experienced a variety of challenges. Most vendors in the VA system are contracted for other products than MSHT. It is difficult to find contractors who are familiar with MSHT and can work together with the therapist to assist with installation, setup, and customization. Time was also mentioned as a factor. Although all these services for MSHT are billable services in the VA, *“I do not have dedicated time to troubleshoot these things, and therapists are being monitored for productivity.*”

#### Group 4

Group 4 included three professionals from a university-based outpatient clinic. The clinic provides a variety of AT services including seating and mobility, augmentative and alternative communication (AAC), audiology, adaptive driving, and computer access. The director of the clinic who also provides the seating and mobility services, the rehabilitation engineer who provides computer access services, and the SLP who provides AAC services, joined the interview. The clinic currently does not formally provide MSHT services, but handles MSHT requests as part of a co-treatment with other services upon client requests. Site 4 works with multiple funding sources. In addition to CHC, Office of Vocational Rehabilitation (OVR) also covers some MSHT products and services. We extracted the following key points from Group 4.

***Client-Centered Service Delivery.*** Despite their current limited scope of MSHT delivery in the clinic, Group 4 intends to deliver MSHT in a similar process as traditional ATDs. “*We always look at our clients first and we do not start with our favorite device or what we would typically recommend.”* They formulated a small set of questions related to MSHT such as Internet/WiFi access and smartphone use, and a list of tasks that an AAC device could assist with, including controlling the environmental through MSHT.

***Lack of Training on MSHT in Therapists.*** Group 4 commented on little to no training for entry-level therapists on MSHT. According to the SLP in Group 4 who also teaches an AAC course, she only has time to cover functional communication, and hardly gets to cover alternative access methods, and has no time for peripheral features, such as smart home functions. The rehabilitation engineer in Group 4 had only one class as part of a course that dealt with MSHT. They also highlighted the difficulty of keeping pace with technological advancements in MSHT.

***Gaps for Other MSHT Services Beyond Assessment.*** After assessment, MSHT will need to be installed and/or set up and training should be provided. “*This type of technology is not a one-time drop or ship situation. It does require maintenance and follow up*.” Currently, it is not clear who would perform these subsequent services for MSHT. The SLP in Group 4 commented that “*Billing/reimbursement does not cover therapist time to conduct this (MSHT) part of the assessment*.” The seating and mobility area usually has wheelchair suppliers for in-home fitting, training, maintenance, and follow-up services, while the AAC field often relies on AAC specialists from the manufacturers to set up the AAC devices to integrate with existing products a user has in the home. However, MSHT does not have a similar group of professionals who would provide such services without additional cost. *“The current fee-for-service model for AT delivery does not support follow-up or training or anything else for durable medical equipment.”* Thus, this fee-for-service model will not work for MSHT, and a different payment model would be needed.

### Discussion

In this study, we conducted an exploratory qualitative case study to understand how MSHT is being delivered as ATDs in different settings. We expect that the findings from each interview will be used to guide the development and implementation of a MSHT service delivery process. While many findings from this study echoed what we have learned from our previous interview study with 15 practitioners on delivering MSHT (Ding et al., 2021b), this study also revealed additional challenges at the system level.

All four groups we interviewed are providing MSHTs as ATDs to some extent. They also intend to follow an AT service delivery process including the assessment, installation/setup, customization, training, and follow-up. While the populations they serve and the funding environments are different across the settings, the four groups face some common challenges across the three strategic drivers for AT, including personnel, provision, and policy identified by the WHO (MacLachlan & Scherer, 2018). Research has shown that a key element to assure that people with disabilities obtain the most appropriate technology solutions that meet their needs and actually benefit from the solution, is not only the quality of AT itself, but also a quality service delivery process (Federici & Borsci, 2016; Scherer 2002).

#### Personnel

Across all settings, there seemed to be a lack of practitioners with sufficient knowledge and skills to conduct MSHT assessments and make appropriate technology recommendations to the clients. This observation aligns with the recent report from UK on smart homes for independent living, which pointed out that health and social care staff are generally not trained to support the long-term use of MSHT (Gilbert 2022). This is also not surprising given that there has been documented lack of training in practitioners regarding traditional ATD and ATS (Arthanat et al., 2017; Jans & Scherer, 2006; Kanny & Anson, 1998). As MSHTs are new and evolve fast, they are typically not covered in the curricula of any health professions. Even with the curricula for rehabilitation technologists or rehabilitation engineers, MSHTs may only be introduced in one class of a semester-long course. Another major problem with AT training/education is that the instructors are commonly not expert or experienced in ATD and ATS (Jans & Scherer, 2006; Kanny & Anson, 1998). In the case of MSHT, such experts may be difficult to find. The rapid evolvement of MSHT also leads to a wide variety of MSHT choices in models and brands, and ever-increasing features in these products, which makes the technology selection difficult. For traditional AT, such as seating and mobility or AAC, the practitioners get to work with manufacturer representatives and/or suppliers who are well-versed about the technology when determining the appropriate technology for the clients. However, it is not feasible to expect manufacturer representatives and/or suppliers of MSHT to work alongside the practitioners. In terms of assessment, MSHTs are similar to the traditional AT but different from home modifications, in that the assessment is not just about the technology, and many factors need to be considered, including the access methods, mounting/charging of the access device, technology integration, environment compatibility, and user technology experience. With these factors, along with the complex and diverse nature of MSHT, it is crucial to find a match between the MSHT and people with disabilities who will be using them through a comprehensive and structured assessment process.

#### Provision

All four groups encountered challenges in MSHT provision. After MSHTs are identified for the clients, they need to be installed/set up and customized, and users need to be trained and followed-up with. Some challenges in provision resulted from inappropriate assessment, while in other cases, it is not yet clear who should be providing installation/set up, customization, training, and follow-up. In seating and mobility, such services are provided by wheelchair suppliers who are trained to provide the services in a client’s home. One group suggested that these wheelchair suppliers could be also tapped and trained to provide MSHT services, as they typically work with people who would need MSHT, and thus would understand their functional abilities and needs. However, this approach will only benefit a subgroup of potential MSHT users and will not be applicable to those who do not use wheelchairs for mobility. Another suggestion is to turn to mainstream technology providers, such as BestBuy Geek Squad services. Wallock and Cerny et al. (2021) worked with Geek Squad services when providing MSHT to their clients with ALS. It is most important if there are clear reimbursement policies to cover the entire provision services in addition to the devices.

#### Policy

The four provider groups in this study represent different funding environments. For people who are eligible for Medicaid Home and Community-based Services (HCBS) such as those served by Group 1 and Group 2, veterans with service-related disabilities such as those serviced by Group 3, and OVR clients served by Group 4, MSHT and associated services may be covered. However, the bundled service model may not be ideal to ensure that adequate time is allocated to support customization and training. These services could be especially important for those with low digital literacy. It is also worth noting that we do not know if other states also include MSHT into the AT service supported by their state Medicaid HCBS waivers. For individuals outside the HCBS, OVR, and veteran groups, there are currently no funding sources that can support the MSHT (including devices and services).

In addition to the AT strategic drivers discussed above, the recent report from UK on smart homes for independent living indicated that low levels of awareness represent one of the biggest barriers to the adoption of MSHT (Gilbert, 2022). This study also found that people with disabilities, especially those from a financially and functionally disadvantaged group, lack the awareness of the MSHT in supporting their independence, autonomy, and participation. Additionally, it is important to educate other stakeholders, such as service coordinators, on how the MSHT could be used as ATDs to support people with disabilities so they can be the brokers who introduce MSHT to their clients with disabilities.

### Outcomes and Benefits

This exploratory case study presented the current practice of MSHT service delivery in four provider sites. Knowing the challenges they face in delivering the MSHTs as ATDs to their target groups with disabilities, will help develop and implement a new service delivery process for each site as well as develop tools, resources, and educational materials to facilitate the implementation. In order for the MSHTs to be used as ATDs to effectively support people with disabilities, a comprehensive assessment is a critical step that could lead to appropriate and complete technology recommendations, making the subsequent provision process more efficient and effective, potentially saving healthcare costs and improving client experience and outcomes. It is also critical to ensure that adequate time is allocated for setting up the MSHTs so they are customized to individual client needs and abilities, and for training so people can take full advantage of the MSHT to support their independence, autonomy, and participation.

### Limitations and Future Work

This study is a qualitative case study with a small sample of four sites, which limits its reliability and external validity. However, given the limited research in the area of using MSHTs as ATDs and in earlier work on home automation technology and environmental control units for people with disabilities, it is important to conduct exploratory research to generate pilot data to establish the need for larger studies. This study also neglected to draw on the home modification field which has developed assessment tools and service delivery processes. As this study was to collect the baseline at each site to help inform the development of a new process for the site, we did not perform a thematic analysis to extract common themes. It also should be noted that the sample of participants in each site did not include representatives from each AT strategic driver (i.e., product, personnel, provision, and policy) of the GATE model (Federici & Borsci, 2016). This means the perspectives collected in this study may not align with those from individuals in specific strategic driver areas. In order to gather a more comprehensive understanding of the topic, future studies could consider targeting other groups such as policy experts, payers, and manufacturers of MSHTs and traditional ATD. In addition, future work could address the implementation barriers identified in this study by developing tools, resources, and educational materials to support efficient and effective MSHT service delivery.

### Conclusions

The study provided insights into the current practices of MSHT service delivery by provider groups in different settings. The results from this study could help guide other practitioners who intend to deliver MSHT services and inform the development of new tools and resources to support the MSHT service delivery. More research is needed to develop and evaluate viable service delivery models for MSHT that could be used as ATD for people with disabilities, and develop and evaluate tools that could facilitate the implementation of MSHT service provision.

### Declarations

This content is solely the responsibility of the author(s) and does not necessarily represent the official views of ATIA. This study was funded by the United States’ National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) under Grant 90REGE0016. The content is solely the responsibility of the authors and does not represent the official views of the NIDILRR. No non-financial disclosures were reported by the author(s) of this paper. The authors report no conflicts of interest.

### Acknowledgements

The authors would like to thank all practitioners who participated in the study for sharing their perspectives on delivering MSHT as AT.

### References

Arledge, S., Armstrong, W., Babinec, M., Dicianno, B., Digiovine, C., Dyson-Hudson, T., Pederson, J. Piriano, J., Plummer, T., Rosen, L., Schmeler, M., Shea, M., & Stogner, J. (2011). *RESNA wheelchair service provision guide*. Retrieved 2022, October 27, from <https://www.resna.org/Portals/0/Documents/Position%20Papers/RESNAWheelchairServiceProvisionGuide.pdf>

Arthanat, S., Elsaesser, L. J., and Bauer, S. M. (2017). A survey of assistive technology service providers in the United States. *Disability & Rehabilitation: Assistive Technology, 12*(8), 789–800. <https://doi.org/10.1080/17483107.2016.1265015>

Assistive Technology Act of 2004, Pub. L. No. 108-364 (2004). <https://www.govinfo.gov/app/details/PLAW-108publ364>

Bridge, C., Zmudzki, F., Huang, T., Owen, C., & Faulkner, D. (2021). *Impacts of new and emerging assistive technologies for ageing and disabled housing*. AHURI Final Report No. 372, Australian Housing and Urban Research Institute Limited, Melbourne. Retrieved 2022, October 27, from: <https://www.ahuri.edu.au/sites/default/files/documents/2021-12/AHURI-Final-Report-372-Impacts-of-new-and-emerging-assistive-technologies-for-ageing-and-disabled-housing.pdf>

Corso, C. L. (2021). *The impact of smart home technology on independence for individuals who use augmentative and alternative communication* [Dissertation, The College of Health Sciences and Professions of Ohio University]. <https://www.google.com/search?client=safari&rls=en&q=The+impact+of+smart+home+technology+on+independence+for+individuals+who+use+augmentative+and+alternative+communication&ie=UTF-8&oe=UTF-8>

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology,* *11*, 100. <https://doi.org/10.1186/1471-2288-11-100>

Ding, D., Morris, L., & Fairman, A. (2021a, February 1–4). *Development of ASSIST checklist for use of smart home technology as assistive technology.* Annual Conference of Assistive Technology Industry Association (AITA), virtual. <https://www.pathlms.com/atia/courses/22523>

Ding, D., Morris, L., Messina, K., & Fairman, A. (2021b). Providing mainstream smart home technology as assistive technology for persons with disabilities: A qualitative study with professionals. *Disability and Rehabilitation: Assistive Technology*. <https://doi.org/10.1080/17483107.2021.1998673>

Elsaesser, L. J., & Bauer, S. M. (2011). Provision of assistive technology services method (ATSM) according to evidence-based information and knowledge management. *Disability and Rehabilitation: Assistive Technology*, *6*(5), 386–401. <https://doi.org/10.3109/17483107.2011.557763>

Etingen, B., Martinez, R. N., Vallette, M. A., Dendinger, R., Bidassie, B., Miskevics, S., & Weaver, F. M. (2017). Patient perceptions of environmental control units: Experiences of veterans with spinal cord injuries and disorders receiving inpatient VA healthcare. *Disability and Rehabilitation: Assistive Technology*, *13*(4), 325–332. <https://doi.org/10.1080/17483107.2017.1312574>

Federici, S., & Borsci, S. (2016). Providing assistive technology in Italy: The perceived delivery process quality as affecting abandonment. *Disability and Rehabilitation: Assistive Technology*, *11*(1), 22–31. <https://doi.org/10.3109/17483107.2014.930191>

Forchuk, C., Serrato, J., Lizotte, D., Mann, R., Taylor, G., & Husni, S. (2022). Developing a smart home technology innovation for people with physical and mental health problems: considerations and recommendations. *Journal of Medical Internet Research MHealth and UHealth*, *10*(4), e25116. <https://mhealth.jmir.org/2022/4/e25116>

Gilbert, C. (2022). Smarter homes for independent living: Putting people in control of their lives. [cited Oct 27, 2022]. Available from: <https://policyconnect.org.uk/research/smarter-homes-independent-living/fulltext>

Jamwal, R., Jarman, H. K., Roseingrave, E., Douglas, J. & Winkler, D. (2020). Smart home and communication technology for people with disability: A scoping review. *Disability and Rehabilitation: Assistive Technology*, *17*(6), 624–644. <https://doi.org/10.1080/17483107.2020.1818138>

Jans, L. H., & Scherer, M. J. (2006). Assistive technology training: Diverse audiences and multidisciplinary content. *Disability and Rehabilitation: Assistive Technology*, *1*(1–2), 69–77. <https://doi.org/10.1080/09638280500167290>

Kanny, E. M., & Anson, D. K. (1998). Current trends in assistive technology education in entry-level occupational therapy curricula. *American Journal of Occupational Therapy*, *52*(7), 586–591. [https://doi.org/10.5014/ajot.52.7.586](https://research.aota.org/ajot/article-abstract/52/7/586/4314/Current-Trends-in-Assistive-Technology-Education?redirectedFrom=fulltext)

Kelley, G. L., & Roberts, D. (2021). Smart home technology used for health care and its potential tax benefits. *Journal of Financial Service Professionals*, *75*(3), 35–43.

MacLachlan, M., & Scherer, M. J. (2018). Systems thinking for assistive technology: a commentary on the GREAT summit. *Disability and Rehabilitation: Assistive Technology*, *13*(5), 492–496. <https://doi.org/10.1080/17483107.2018.1472306>

Myburg, M., Allan, E., Nalder, E., Schuurs, S., & Amsters, D. (2015). Environmental control systems – the experiences of people with spinal cord injury and the implications for prescribers. *Disability and Rehabilitation: Assistive Technology*, *12*(2), 128–136. <https://doi.org/10.3109/17483107.2015.10997>

Scherer, M. J. (2002). Assistive technology: Matching device and consumer for successful rehabilitation. *American Psychological Association.* <https://doi.org/10.1037/10420-000>

Stanek, O. (2019). *A smarter home, a better life: A report on smart home technology and neurological conditions.* <https://www.researchgate.net/publication/331825395_A_smarter_home_a_better_life_A_report_on_Smart_Home_Technology_and_Neurological_Conditions>

Tomita, M. R., Mann, W. C., Stanton, K., Tomita, A. D., & Sundar, V. (2007). Use of currently available smart home technology by frail elders. *Topics in Geriatric Rehabilitation*, *23*(1), 24–34. <https://doi.org/10.1097/00013614-200701000-00005>

Wallock, K. E., & Cerny, S. L. (2021). Benefits of smart home technology for individuals living with amyotrophic lateral sclerosis. *Assistive Technology Outcomes & Benefits (ATOB)*, *15*(1), 132–138.

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 57-75

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# Reflections on the Design, Development, and Implementation of a Braille Mobile App

## **Cheryl Kamei-Hannan, Ph.D.**

## Division of Special Education and Counseling California State University, Los Angeles

***Corresponding Author***

Cheryl Kamei-Hannan

Charter College of Education

5151 State University Drive

Los Angeles, CA 90032

Email: ckameih@calstatela.edu

Phone: (323) 343-4400

### Abstract

*Reading and Writing Adventure Time!* was developed to support braille literacy skills of first- through twelfth-grade readers. The purpose of this article is to present reflections on the three phases of design, development, and implementation. Usable design and participatory design were instrumental throughout the project. Teacher and student involvement led to high ratings on key indicators relevant to braille literacy. During implementation, 35 of 44 teacher participants rated the reading portion of the app and 32 of 48 participants rated the writing portion of the app. Results showed ratings at or above 3.5 of 4 on most items for both the reading and writing portions of the app. Professional development and technical support were provided throughout implementation. Data showed that 184.5 hours of support were given in the first year of implementation to the 44 participants and 96.2 hours in the second year to the 48 participants. The type and amount of technical support showed that teachers needed the most assistance when beginning to use the technology.

***Keywords*:** braille, assistive technology, screen readers, visual impairment, blindness

### Reflections on the Design, Development, and Implementation of a Braille Mobile App

*Reading and Writing Adventure Time!* is an iPadOS app designed to address braille literacy skills of students who are visually impaired. It has a futuristic theme with cartoon characters who guide students through a series of assessments and evidence-based activities. Specifically developed to function with a refreshable braille display and access software (screen magnification or speech), it was created in response to the prioritized need for implementation of accessible educational tools. The project was funded by the Office of Special Education Programs (OSEP) Stepping Up Technology Grant (H327S120007).

The purpose of this article is to document the process used in creating the app. This process involved three distinct phases: design, development, and implementation. At the core of each phase, the project relied on two paradigms presented by the International Organization for Standardization (2018): the *usable design* (UD) and *participatory design* (PD). UD parameters adopted by project leaders were defined based on a review of literature, unique features of the Unified English Braille code (a unique set of braille characters that represent whole words, parts of words, format, and punctuation), the use of peripheral devices (refreshable braille display), and needs of the target population (non-visual, braille readers, and screen reading access). PD ensured relevance and ease of use. Feedback from teachers, family members, and braille readers was incorporated throughout the project. In addition to the UD and PD paradigms, the project responded to literature from the fields of access technology and visual impairment. This article presents the project’s response to guiding literature and the process used during each phase (design, development, and implementation). Phases 2 and 3 included participant feedback. Research methods for these phases are described separately within the corresponding sections. This study was reviewed and approved by the Institutional Review Board California State University, Los Angeles.

### Target Audience and Relevance

The target audience for this article is software developers and educators wishing to design and develop educational software that is relevant and useful for specialized populations, such as braille readers. Because this app was primarily designed with a specific user in mind, the software programmers and educators were able to target unique aspects of braille literacy and accessibility. These considerations may be adopted by technology developers to promote best practices in braille access.

### Review of Literature and the Project’s Response to Research

#### Technology Development

Core to the project’s conceptualization was the existing body of literature. At the time, a great deal of research had been dedicated towards understanding effective models for technology development and its implementation in 21st century schools. In regard to hardware and software development, recommendations were that technology be universally accessible and include flexible approaches customizable for individual needs, including multiple means of representation, action and expression, and engagement, otherwise known as Universal Design for Learning (UDL; Center for Applied Special Technology [CAST], 2022; Rose & Gravel, 2010). It was believed that software designed with UDL in mind would be readily accessible, without the need for additional accommodations or peripheral devices (Edyburn, 2010). As the project progressed, the literature base also evolved. The 2017 report of the National Education Technology Plan (US Department of Education, 2017) recommended educators (a) develop and implement technology that provides equitable access, (b) promote use of universally designed technology, and (c) create an inclusive and shared vision for all users.

Despite efforts to integrate UDL in instructional and software design, UDL principles were sometimes thought of as unrealistic (Kamei-Hannan et al., 2017). Often, *access* was available to students with disabilities, but not *equal* in terms of the time, resources, effort, or skills needed to perform tasks, as compared to students without disabilities (Kamei-Hannan et al.). For example, access for non-visual users required excess cognitive demand such as the memorization of several commands and multiple steps. In comparison, sighted individuals used vision and touch to navigate a device. Furthermore, many technologies were not designed at inception to be fully accessible (Center on Online Learning and Students with Disabilities, 2017). In some cases, it was recognized that students with disabilities would require assistive technology to access information.

This project responded to the literature by: (a) incorporating principles of UDL and ensuring accessibility in the development of *Reading and Writing Adventure Time!* (b) involving braille readers to test ease of use and accessibility, (c) using data from participants to guide revisions and software upgrades, and (d) updating *Reading and Writing Adventure Time!* in adherence with UDL principles and to maintain pace with the continuous advancements of technology.

#### Educational Content

Musti-Rao et al. (2015) suggested that educational technology tools have a student-centered design that is explicit (addresses specific targeted skills), intensive (allows for ample practice opportunities), and systematic (builds in difficulty based on student performance). Seven key steps of their approach included: (a) identify target skills for each student, (b) address the skills using evidence-based strategies, (c) use suitable technology for developing the skills, (d) develop a protocol for using the technology, (e) train students to effectively use technology, (f) measure treatment integrity, and (g) monitor students’ progress on the skills. This approach mirrors aspects of the problem-solving method posited by Fuchs and Fuchs (2006), in which data are used to determine appropriate evidence-based interventions and subsequent decisions are based on additional student progress monitoring data.

Following these design suggestions, app developers of *Reading and Writing Adventure Time!* included baseline, formative, and summative assessment measures as part of its blueprint. Baseline was assessed through a placement test, in which students’ results were used to identify their reading level. Then, following a problem-solving model (Fuchs & Fuchs, 2006), students completed activities that had built-in progress monitoring assessments. Teachers were encouraged to monitor student data and provide instruction as needed to address any areas of weakness. Additionally, components within the app were tied to the Common Core State Standards (CCSS; National Governors Association Center for Best Practices and the Council of Chief State School Officers, 2010).

Assessments and activities within the app were based on well-known literacy practices. Data from fluency measures and miscue analysis were recognized as beneficial (Hudson et al., 2005; Johns & Lenski, 2010; National Reading Panel, 2000). In the writing assessment, oral dictation and proofreading were assessed. The oral dictation was further broken into spelling, language, and grammar skills. Repeated-Reading was one of the few interventions supported by evidence in the field of visual impairment and blindness (Pattillo et al., 2004), and a *Repeated Reading* activity was created. The repeated reading activity included a component where students could record themselves reading and listen to a playback to help them identify reading errors.

The importance of motivation was much discussed in the project’s initial blueprint, and the Core Leadership Team further stressed it as a consideration. The activities developed for this app were designed to be motivating, including the use of novel mainstream technology (Kelly, 2009). Added features included professionally designed graphic images for visual appeal, a variety of sounds, and hired actors and actresses who recorded their voices for various features within the app.

#### Implementation

Regarding implementation, the existing literature identified several barriers and potential strategies for success. To begin, the literature documented a lack of access to appropriate technology devices and teachers reported a lack of expertise needed to support their students’ learning needs (Kelly, 2009). Additional barriers to successful implementation included a lack of access of educational technology tools, supportive administrative leadership, and a school culture that embraced a digital environment (Pittman & Gaines, 2015; USDOE, 2017; Walker & Shepard, 2011). Many schools did not have policies or practices in place that supported schoolwide initiatives to adopt new technology (Smith & Stahl, 2016; Wisdom et al., 2007). In fact, they occasionally restricted access to particular devices or educational materials (Wisdom et al., 2007). Barriers such as information technology (IT) policies, spam filters, and firewalls were causes of restrictions on using digital tools. Strategies for successful implementation included establishing consistent and systematic technology support structures (Biancarosa & Griffiths, 2012; Hall et al., 2015; Smith & Stahl, 2016). The project addressed these gaps by: (a) providing iPads and refreshable braille displays to teachers, (b) providing support to teachers to effectively integrate assistive technology into the school systems, including navigating internal IT structures within school districts, (c) creating a professional learning community to support participants during implementation, and (d) developing an infra-structure that facilitated problem solving, trouble-shooting, and ongoing technical support.

#### Professional Development

Once technology was distributed to students and the infrastructure was in place to support its use, the literature pointed to a need for professional development to sustain technology use (Reid et al., 2013). Simply providing technology to teachers did not guarantee its use (Grunwald & Associates, 2010). Researchers further asserted that computers do not teach, they are tools by which instruction may be delivered (Musti-Rao et al, 2015). Etscheidt (2016) noted that students may be issued technology but not be trained on how to use it, and teachers often lack needed training to use specific devices. Researchers suggested that because teachers lacked skills in using the given technology, they may be ill-prepared to provide students with adequate training (Nelson et al., 2016). Lack of appropriate technology training during teacher preparation was noted as a barrier to technology use in classrooms (Hasselbring & Glaser, 2000; Smith & Kelley, 2007; USDOE, 2017). The gap in teachers’ knowledge was purported to lead to inadequate services and non-use of technology, particularly assistive technology used by students with disabilities (Zhou et al., 2011).

Research involving students who read braille showed that learning to use braille devices is complex and challenging for both teachers and students (Kamei-Hannan et al., 2020). Thus, many braille technology tools were underused by teachers or ineffectively implemented. Teachers needed ample professional development opportunities and resources to maintain their skills and stay abreast of advancements in technology (Kamei-Hannan et al., 2012). Research in implementing educational technology indicated that ongoing supports and coaching were most effective. Yet as reported in the National Education Technology Plan (US Department of Education, 2017), this intensive level of just-in-time support was rarely provided. Coaching was not only shown to be costly (Pittman & Gaines, 2015) but also time consuming (Wisdom et al., 2007). A potential solution supported coaching through telepractice as an effective practice in the field of visual impairment and blindness. Telepractice was used to support students who lived in distant communities and rural settings (Dewald & Smyth, 2014).

Best practices in technology implementation pointed to professional development, including consistent and systematic support for teachers (Biancarosa & Griffiths, 2012; Hall et al., 2015; Smith & Stahl, 2016). With a premise that technology should be a tool that increases opportunities to learn and is most effective when used with adult interaction (caregiver, peer, or educator-led interactions), the following strategies were used during implementation of this project: (a) engaging teachers in professional development including side-by-side coaching, and (b) providing ongoing technical support as needed.

### Phase 1: Design

The goal of phase 1 was to develop a fully functioning beta version of the *Reading and Writing Adventure Time!* app, including populating the app with sample content. This phase also built the internal leadership structure and technical framework that was used throughout the project. The result of phase 1 was a beta version of the app that was tested during phase 2.

#### A Team-Based Approach

***Figure 1: Organizational Chart***

Organizational chart

Figure depicting four teams, the Core Leadership Team, Technical Development and Maintenance Team, Content and Research Team, and Recruitment, Retention, and Implementation Oversight.

From the onset, a team-based approach was used (see figure 1). Phase 1 involved the development of a *Core Leadership Team* and supporting members. The Core Leadership Team divided their expertise into three smaller working teams: (a) Content and Research; (b) Technical Development and Maintenance; and (c) Recruitment, Retention, and Implementation Oversight. Each of these teams had specific roles, aligned with their expertise. The Core Leadership Team coordinated each team’s efforts and acted as a liaison between computer programmers who needed to troubleshoot technical aspects of app design but were not familiar with braille and the content experts who were education and braille experts. This structure was retained throughout the duration of the project. Also, instrumental to phase 1 were teachers, students, and family members, including braille readers, who developed content and tested various builds of the app. Their initial feedback shaped the beta version of the app. In sum, a total of 30 individuals participated in content development and the technical design of the app.

#### Framework for Technical Design

A network of foundational, back-end technology tools was created to support the app. These tools were not seen by the user, but were essential for the app’s basic functionality (see figure 2).

***Figure 2: Technical Framework***

Technical Framework

Figure shows the Automated Web-Based Validation process inputting into the app, data going out to the Data Chasse, and flowing out to the Results Database. In addition, the website inputs content into the Data Chasse which is pulled into the app.

First, a **website** was developed that allowed *content writers* to input passages and questions into a **data chasse**, whichhoused the content. This input website was an essential component of the design stage, because we had as many as 30 individuals simultaneously entering and editing app content. Second, to meet the distinct needs of individual students within the 1st–12th grade continuum, an enormous amount of content had to be written for the assessment and activities. To increase downloading speed and decrease the potential for the app to be overloaded, the data chasse was built to deliver content *on demand* to the app. To determine the most appropriate content for an individual, each student completed a *placement test*. Results from the placement test allowed teachers to select the most appropriate level for the students (e.g., literacy material created for beginning 1st grade, middle of 1st grade, beginning 2nd grade, middle of 2nd grade, etc.). Once the student’s reading level was assigned, the app selectively retrieved the designated content from the data chasse and downloaded it to the iPadOS device using a Wi-Fi connection.

Key participants were given unique identification numbers through an **automated web-based validation process.** To receive their identification numbers, teachers completed an online web-based demographic survey. This system kept the data confidential. Only the website administrators had access to the data linking identification numbers to the teachers. A similar process was used to allow teachers to add multiple students to their roster, and each student also was given a unique identification number. Lastly, a **results database** was created to collect student performance data across multiple skills from the assessments and activities. The deidentified data could be exported for student outcome analysis. Data regarding the app’s efficacy and impact on student achievement are available (see D’Andrea, et al., 2021; Kamei-Hannan, et al., 2020; and McCarthy, et al. 2022).

#### Technical Design Challenges

The first challenge encountered in the technical design was related to how content should be created in order to display accurate braille and test readers’ understanding of the braille code rules (e.g., when one contraction should be used in place of another contraction). Issues with iPadOS operating system and limitations of the mainstream platform restricted specific elements needed in portraying braille characters accurately. For example, because the device had a built-in braille translator, reverse translation would autocorrect braille contractions (e.g., incorrectly used contractions such as “er” in the word “mother” would automatically be corrected by the translator).

***Figure 3: ASCII Example of a Test Item Regarding Braille Rules***

|  |
| --- |
| An example of a multiple choice question in the writing portion of the app illustrates the need for displaying incorrect braille:  Question: Which of the following words is written correctly?  simbraille font is used to spell the word  (a) f-i-n-g-e-r  (b) f-ing-er (c) f-in-g-er (d) f-ing-er  This same question is rewritten below using parenthesis to highlight which braille characters are contractions.  Question: Which of the following words is written correctly?   1. finger 2. f(ing)(er) 3. f(in)g(er) 4. f(ing)er |

A work-around for this was to write content in American Standard Code for Information Interchange (ASCII) which is a set of characters used to encode text data to display in contracted braille code using standard keyboard characters, each assigned to represent a particular configuration of dots within a braille cell (e.g., an ! is coded as the braille symbol “dots 2, 3, 4, 6” or the contraction for “the”). This would allow purposeful errors to be retained. See figure 3 for an example of how braille may look in a test question. In this example, the word is spelled the same in each response. The iPadOSs braille translation software (when set to contracted braille) would correct these responses and display each of them with correct braille symbols. Therefore, by using ASCII, the app retained the incorrect usages of contractions and the respondent had to identify the correct version of the word “finger” from the choices (a) finger (b) f(ing)(er) (c) f(in)g(er) (d) f(ing)er.

Accessibility and UDL were critical to the design of the app. However, because the app was created primarily for braille users and tested knowledge using the braille code, accessibility had to consider the ability to present braille accurately using various media [e.g., print font, simulated braille font, tactile braille, audio playback, and screen reader access using VoiceOver)]. App developers and content writers had to navigate differences between what was *seen* on the visual screen, *read tactually* on a braille display, and *heard* in audio playback or with VoiceOver. Sometimes what was seen differed from what was heard and what was felt on the braille display. For example, the “Begin” button was read aloud by VoiceOver in ASCII as “2g9,” but it was displayed correctly on the braille display and visually in simulated braille font 2g9. App developers and content writers had to make choices about displaying things in sim-braille or print font, whether to have VoiceOver read it, and whether to put it in ASCII. To reduce confusion between the how VoiceOver read the text and how it was displayed in ASCII code, the programmers forced VoiceOver to be silenced unless manually adjusted. To assist with the determination of which format to use, the project leadership team informally surveyed over 50 teachers of students with visual impairments. Unanimously, they all wanted *sim-braille font* to show correctly on the visual display. These teachers felt it was more important that students could independently read accurate braille than have it display correctly in print for the teacher. Teachers of students with visual impairments also felt that braille proficiency was a requisite skill for their job, and they should be able to read the sim braille font.

During phase 1, it was discovered that some characters in the iPadOS's translation program did not display as desired. For example, the braille symbol for Dot 4,5,6 rendered a backspace during input (used for activities that involved writing in braille). Therefore, content for the writing dictation activity was written to eliminate the use of words that contained a 4,5,6 symbol (e.g., passages could not contain the words *cannot*, *had*, *many*, *spirit*, *world*, or *their*). While this solution worked for the project, it may be an unrealistic and temporary fix that does not generalize to other contexts. Similarly, output (used for activities that involved reading on a braille display) of a dot 4,5,6 symbol was displayed with a dot 7. Although this is not the correct display of the braille symbol, authors decided to retain the use of the symbol in the writing multiple choice activity with a note to users indicating that the 4,5,6 symbol is rendered dot 4,5,6,7 throughout the activity.

#### Design Features

The app had to run smoothly and have procedural fidelity features built in so that there was control over how a user accessed and implemented its use. Users repeatedly tested the app to ensure that the user experience was seamless and fully accessible. Programmers also used tables for easy navigation, and they forced VoiceOver to land on the starting element for each page. For example, when navigating a long list of passages, it made sense to land on the next passage on the list after completing a passage, rather than always landing at the top of the page. Operationally, this meant for instance, that if you just finished passage #4, then when you returned to the list of passages you would land on passage 5 with VoiceOver, instead of having to scroll through all 4 completed passages before finding the passage that was next. This was especially helpful in the activities where there were over 100 items on the list. In another example, programmers forced the users to land within an edit field to allow the user to begin typing immediately. Lastly, programmers installed a feature to silence VoiceOver during reading comprehension activities, so passages were not read aloud.

### Phase 2: Participatory Development

Once a fully designed beta version of *Reading and Writing Adventure Time!* was created, the project entered into a phase 2 which involved beta testing the app. Six participants were recruited to provide an external review of the app, and their feedback was used in further development of the app using an iterative process.

#### Methods

Qualitative methods were used to evaluate the app in repeated cycles of design, develop, test, and revise. Participant feedback guided each cycle of revisions. The main research questions for beta testing were:

1. Is the app user friendly, accessible, and of high quality?
2. Is the content relevant for the population, accurate, and of high quality?

##### Participants

Participants were teachers of students with visual impairments who taught in local districts near to the researchers. Interested teachers had to be certified teachers of students with visual impairments who self-identified as proficient in braille and who had a student who read braille at a minimum of 1st grade level, as determined by the child’s learning media assessment. Users had to be familiar with iPadOS technology and its interface with refreshable braille displays in order to advise technical development in using the devices to their full capacity and to problem-solve technical glitches. Potential teachers of students with visual impairments also were interviewed and asked if they were comfortable with basic iPad and VoiceOver skills. If a teacher indicated that they were not familiar with a skill, researchers provided needed assistance. Interested teachers of students with visual impairments were asked to commit to completing at least 8 activities and providing feedback throughout phase 2 of the project. Additional readiness criteria included: (a) access to a braille display and iPad, (b) wireless internet capability, (c) high-speed internet access, and (d) access to outside materials and support for firewall restrictions. Braille displays and iPads were distributed to participants needing equipment.

##### Data Collection and Analysis

Surveys and interviews were used to gather information about the quality, usefulness, and relevance of the app. Participants provided feedback regarding the design of the app, and the Core Leadership Team responded to comments with app revisions. Continuous feedback was gathered until a minimal level of satisfaction, set at a mean score of 3.5 or higher on a 4-point Likert scale, was obtained by the participants (see Table 1).

Additionally, an item-by-item analysis of content was conducted. Teacher/student dyads and the leadership team were asked to respond to the surveys with specific questions related to the quality of items within various activities and question types presented in the app. The survey included 10 open-ended questions regarding the accuracy of the braille translation, the flow of the app, cultural bias, accuracy of the question (e.g., grammar, spelling, correct responses identified), and appropriateness of the content.

***Table 1: Development Survey***

***(n = 6)***

| **Rating** | **1**  **(not at all)** | **2**  **(somewhat)** | **3**  **(mostly)** | **4**  **(completely)** |
| --- | --- | --- | --- | --- |
|  | **Quality** | | | |
| The app interface was easy to use. | 0% (0) | 0% (0) | 60% (3) | 40% (2) |
| Within each step in setting up a student profile, it was clear what I was to do next. | 0% (0) | 0% (0) | 40% (2) | 60% (3) |
| The training materials and other in-app resources were easy to find. | 0% (0) | 0% (0) |  | 100% (5) |
|  | **Usefulness** | | | |
| The in-app training materials and resources were useful. | 0% (0) | 20% (1) | 60% (3) | 20% (1) |
| The app is designed to accommodate students with a range of technology skills. | 0% (0) | 0% (0) | 60% (3) | 40% (3) |
|  | **Relevance** | | | |
| The app activities appear to complement classroom activities in reading and writing. | 0% (0) | 0% (0) | 20% (1) | 80% (4) |

#### Results and Data Driven Development

The six participating teachers provided some important feedback regarding the beta version of the app. Findings from the item-by-item analysis were analyzed qualitatively and coded for similar themes. These comments were divided into three categories: (a) editorial errors, (b) technical errors, and (c) content issues. They were then distributed to appropriate teams to address. An editorial team fixed typographical and braille errors. The technical team reviewed and addressed the errors related to the app design and function. The content team addressed editorial errors in the reading and writing materials. Content issues included things like addressing cultural bias, identifying constructs that were misaligned to specific CCSS, redundant answers, and rewriting content that was deemed inappropriate.

In regard to content, data showed that a copyediting phase needed to take place, and certified braille transcribers needed to be involved. Some of the errors were driven by the iPadOS translation tables, such as when the chosen symbol was incompatible with the translation tables (e.g., brackets caused the braille display to show dots 7 and 8, versus curly brackets were displayed correctly). As a result of discovering these incompatibilities, a group of certified braille transcribers was hired to proofread and edit the content.

In addition, during the item-by-item analysis, teachers indicated that they did not see the relevance of the CCSS. This was surprising to the researchers. A website needed to be developed that linked the CCSS to braille literacy that supported teachers using this app. Participants also did not agree that the students who are visually impaired should be accountable for all of the CCSS selected. Specifically, teachers did not think that the standard requiring students to search for words and interpret the meaning of those words within the passage’s context should be applied to students reading braille. They felt that searching for the word was a skill for sighted individuals. Also, they felt that the ability to define alternate meanings of words that appeared in the passages and ability to explain how formatting of text provides meaning were not skills they felt should be tested. Again, this was surprising to the researchers. It provided evidence that researchers needed to offer professional development about literacy and the explicit connections between CCSS and achievement.

Another major outcome that fed into the revision of the app had to do with one specific activity: Braille Hunt. Although participants loved the concept behind this activity, the technology presented some functional challenges. This activity required the student to locate a single braille cell within a line of text and enter a line break after the character. The concept of a line break for many students was foreign, because a braille display only shows one line of text. Therefore, having a line break was not visible on the braille display. This “sighted” concept proved challenging and made the activity very difficult. Additionally, the activity required students to have 100% accuracy, another challenging task. The activity was modified to enter a symbol (such as \*) instead of a line space and activities were created that were shorter, thus increasing the likelihood of having 100% accuracy.

Overall, at the end of phase 2, five of the six teachers rated they rated the app with a mean score of 3.7 for *quality*, 3.6 for *usefulness*, and 3.8 for *relevance to braille literacy*, based on a 4-point Likert scale. The sixth teacher did not rate the app because she did not feel she had enough time to explore it at the time the rating scale was delivered. Anecdotal comments from all six teachers were used to revise the app.

### Phase 3: Implementation

The purpose of phase 3 was to implement the *Reading and Writing Adventure Time!* App with a large group of teachers and students. Data during this phase showed participants’ ratings on the quality, usefulness, and relevance of the app. Additional data regarding the implementation practices (e.g., types of support, quality and duration of support) used during phase 3 are documented in this section.

#### Method

Qualitative and quantitative methods were used to evaluate the following guiding research questions:

1. What were the participants’ overall rating and feedback during implementation?
2. What types and how many hours of support were needed during implementation?

##### Participants

Following the development stage, researchers entered into an implementation and pilot testing phase. Researchers cast a widespread recruitment net and considered participation from any qualified participant who had expressed interest in the project. Teachers had to be certified teachers of students with visual impairments who self-reported braille proficiency and who had a student who used braille as the primary reading medium at or within one grade level, as determined by learning media assessment. The teachers had to be willing to explore the technology and commit to using the app at least twice a week for 40 minutes each session for 16 weeks. Required technology included Wi-Fi access. Furthermore, given the low incidence population of braille-reading students, researchers felt it was imperative to include any teacher who met minimum inclusion criteria, regardless of their familiarity with the technology. At the beginning of the study, teachers used a checklist to self-assess their familiarity with iPad technology. Self-guided instructional videos were created to support them in learning any skills with which they were not familiar. Researchers also worked with teachers who needed additional support, until a minimum level of 90% of skills on the checklist was obtained.

##### Intervention

Implementation took place over the course of two years. During year one the focus was on the reading portion of the app, and in year two the focus was on the writing portion. At this point in the project, the app was divided into two separate apps, *Reading Adventure Time!* and *Writing Adventure Time!* Researchers encouraged all participants to proceed with the full duration of the 16-week study. Because participants began using the app at different times throughout the year, implementation took place over the course of a full year for each portion of the app. This was important because of the difficulty in recruiting a large enough sample size to obtain statistical power for efficacy of the app on student achievement (see Kamei-Hannan, et al., 2020), and because of the intense amount of support that was given to each teacher/student dyad.

##### Data Collection

Several types of data were collected throughout phase 3. However, this article focuses on data pertinent to the app’s design, development, and implementation, particularly participants’ feedback during implementation and the supports provided during phase 3. Researcher-developed surveys were used to collect participant feedback. The surveys were brief, and included questions that asked participants to rate indicators of quality, usefulness, and relevance of the app to braille literacy using a 4-point Likert rating scale. All teachers were asked to complete the survey after their initial training and completion of a minimum of eight activities. Data regarding implementation supports were collected by the Core Leadership Team, each of whom kept a log that included the amount of time spent providing technical support and the type of support that was provided. Attendance logs for professional development webinars also were used to document participation.

##### Implementation Tools

To support the implementation of the app, a variety of training tools, resources, and materials were created, including videos on basic iPadOS/VoiceOver skills, creating student rosters within the app, using the app, and conducting a miscue analysis. Additionally, a blog-site to explain the CCSS and its connection to the app was created. Training sessions were archived and made available to participants. Within the app, several supporting documents were linked at strategic points for just-in-time access. These links included documents with detailed instructions for the activities and assessment, a description of types of miscues, and explanation of the student score reports.

### Results

In the end, a total of 47 teachers met recruitment criteria and participated in the implementation of *Reading Adventure Time!,* 44 of whom are represented in these results. Three teachers who were initially recruited did not participate after training, and their data is not included in this study. In addition, 48 teachers in the *Writing Adventure Time!* participated in implementation of *Writing Adventure Time!* Demographics of the teachers represented a geographical range throughout the United States and Canada. All teachers were licensed teachers of students with visual impairments, who had a range of teaching experiences from 1–15+ years and ages ranging from 20–60 years old.

#### Teacher Ratings of the App

Thirty-five of the 44 teacher participants rated the reading portion of the app in year one and 32 of the 48 participants rated the writing portion of the app in year two. Results from the reading implementation showed that participant ratings of each question hovered around a mean score of 3.5 or higher.

***Table 2: Implementation Pilot Study and Teacher Ratings of the App***

***(n = 35 of 44 participants)***

| **Question** | **Mean** | **\*SD** | **1**  **Strongly disagree** | **2**  **Disagree** | **3**  **Agree** | **4**  **Strongly agree** |
| --- | --- | --- | --- | --- | --- | --- |
| The directions for each contest and activity were clear and easy to follow. | 3.50 | 0.66 | 6% (2) | 0% (0) | 46% (16) | 49% (17) |
| The items in the contests and activities were well chosen for their purpose. | 3.37 | 0.69 | 3% (1) | 3% (1) | 49% (17) | 46% (16) |
| The scores gathered from the contests and activities will be useful for teachers to improve literacy instruction. | 3.43 | 0.70 | 3% (1) | 3% (1) | 43% (15) | 51% (18) |
| The app covers important skills for improving braille literacy | 3.49 | 0.66 | 3% (1) | 0% (0) | 43% (15) | 53% (19) |
| The app will motivate students to improve their literacy skills. | 3.60 | 0.65 | 3% (1) | 0% (0) | 31% (11) | 66% (23) |
| Overall, the app is of high quality. | 3.49 | 0.66 | 3% (1) | 0% (0) | 43% (15) | 53% (19) |

*\* SD = standard deviation*

Table 2 shows results of the survey. Results from the writing implementation showed participant ratings at or above 3.5 on most quality indicators, with the exception of the question regarding navigation (see Table 3). Participants struggled to navigate the writing app in comparison to the reading portion of the app. It is likely that the difference reflected difficulty with navigating simulated braille font presented in the writing portion of the app, compared with print font which was used in the reading portion of the app.

***Table 3: Quality Ratings of* Writing Adventure Time!**

***(n = 32 of 48 participants)***

| **Question** | **page12image16297232page12image10050080Mean** | **\*SD** | **0 No Response** | **page12image9983728page12image142660161 Strongly disagree** | **2 Disagree** | **page12image12113536page12image163739843 Agree** | **4 Strongly agree** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Overall were you able to navigate through each activity in the app using a braille display with ease? | 3.09 | 0.82 | 0 | 2 | 3 | 17 | 10 |
| The directions throughout the app were easy to follow. | 3.41 | 0.67 | 0 | 0 | 3 | 13 | 16 |
| Within each step of the app, it was clear what to do next. | 3.41 | 0.76 | 0 | 2 | 1 | 12 | 17 |
| The items within each activity logically progress in difficulty. | 3.53 | 0.92 | 1 | 0 | 3 | 5 | 23 |
| Overall, the app is high quality. | 3.69 | 0.54 | 0 | 0 | 1 | 8 | 23 |
| The scores gathered from the app are useful for teachers to improve literacy instruction. | 3.56 | 0.84 | 1 | 0 | 1 | 8 | 22 |
| The feedback provided by the app will be helpful for students to improve their own literacy skills. | 3.53 | 0.84 | 1 | 0 | 1 | 9 | 21 |
| The feedback provided on the score page for the app was easy to interpret. | 3.66 | page13image57692480.55 | 0 | 0 | 1 | 9 | 22 |
| This app covers important skills for improving braille literacy. | page13image99639683.78 | 0.42 | 0 | 0 | 0 | 7 | 25 |
| Overall, the items in the app are well chosen for their intended purpose. | 3.69 | 0.78 | 1 | 0 | 0 | 6 | 25 |
| Overall, I believe that the app will help students improve their literacy skills. | 3.72 | 0.58 | 0 | 0 | 2 | 5 | 25 |
| Overall, I believe that the app is a motivating instructional tool for students. | 3.69 | 0.59 | 0 | 0 | 2 | 7 | 23 |

*\* SD = standard deviation*

#### Implementation Supports

Several layers of support and training were given to participants throughout the pilot studies. First, upon initial contact, all participants were given a one- to two-hour, one-on-one training on how to download the app to the iPad, use basic VoiceOver commands, and pair their braille display to the iPad. This initial contact accounted for a significant portion of our training. After the initial contact, teachers were given a readiness checklist on which they had to score 90% before being able to log into the app. Teachers scoring below 90% were given video tutorials to learn technology skills prior to the start of intervention. Second, all teachers participated in a three-hour small group webinar training on how to use the app. Third, all teachers were invited to a bi-monthly *Power Hour* webinar which established a learning community, in which researchers had topical discussions and presentations. During these sessions, participants were able to voice suggestions, concerns, and triumphs. Finally, a number of individual phone calls were made throughout the duration of the study, during which participants were able to troubleshoot technical issues. Tables 4 & 5 document the total number of technical support hours provided.

Implementation supports provided during evaluation of the writing portion of the app followed a similar format. One added component to the initial training focused on braille display settings and inputting/editing braille during writing tasks.

Noteworthy of the implementation process was the number of hours spent in initial training. Researchers were surprised that teachers were not familiar or confident with braille displays prior to the start of the study. Many teachers had never used one before, and those who did use a braille display were not familiar with using it on an iPad. Therefore, the amount of time spent in initial setup was quite extensive. During the implementation of the writing portion of the app, researchers increased the amount of contact with teachers by reaching out to them on a monthly basis to provide one-on-one support. Researchers suggest that future implementation must allocate extensive time for initial and ongoing support for teachers, especially when it comes to specialized assistive technology for braille readers such as using braille displays and VoiceOver. Additional information regarding the teachers’ perceptions of their technology skill growth while participating in the project can be found in Kamei-Hannan et al., 2020.

***Table 4: Number of Minutes Spent Providing Training and Technical Support During Year One –* Reading Adventure Time!**

***(n = 44)***

| **Support Type** | **Average minutes per contact** | **Number of teachers needing this support** | **Total number of contacts** | **Total minutes per type of contact** |
| --- | --- | --- | --- | --- |
| Initial contact | 90 | 44 | 44 | 4,960 |
| Webinar training | 180 | 44 | 15 | 2,700 |
| \*Power hour | 60 | 27 | 10 | 600 |
| Refresher training | 60 | 16 | 2 | 120 |
| Wi-fi connectivity | 20 | 21 | 23 | 460 |
| VoiceOver | 15 | 28 | 31 | 465 |
| General iPad settings | 10 | 21 | 21 | 210 |
| Pairing | 30 | 34 | 31 | 930 |
| Miscue analysis | 10 | 30 | 16 | 160 |
| Refreshable Braille display settings | 20 | 14 | 11 | 220 |
| ID/password issues | 5 | 30 | 18 | 90 |
| Miscellaneous | 10 | 17 | 18 | 180 |
| ***TOTALS*** |  |  | ***240*** | ***11,095***  ***(184.9 hours)*** |

*\* Power hour = monthly interactive and topical webinars developed to support a community of practice for users engaged in using the app.*

***Table 5: Number of Minutes Spent Providing Training and Technical Support During Year Two –* Writing Adventure Time!**

***(n = 48)***

| **Support Type** | **Average minutes per contact** | **Number of teachers needing this support** | **Total number of contacts** | **Total minutes per type of contact** |
| --- | --- | --- | --- | --- |
| Initial training | 90 | 48 | 15 | 1,350 |
| Refresher training | 60 | 20 | 3 | 180 |
| Power hour | 60 | 37 | 14 | 840 |
| Wi-fi connectivity | 20 | 23 | 26 | 520 |
| VoiceOver | 20 | 15 | 17 | 340 |
| General iPad settings | 10 | 24 | 27 | 270 |
| Pairing | 20 | 16 | 23 | 460 |
| Miscue analysis | 12 | 23 | 36 | 432 |
| Refreshable Braille display settings | 20 | 8 | 15 | 300 |
| ID/Password | 10 | 40 | 44 | 440 |
| Miscellaneous | 10 | 42 | 64 | 640 |
| ***TOTAL*** |  |  |  | ***5,772***  ***(96.2 hours)*** |

### Limitations

As with any research, this study had limitations. First, the design methods presented here reflect a process that took place several years ago. Therefore, guiding literature has evolved and development results of today may differ than what was considered state-of-the-art at the time of conceptualization of the *Reading and Writing Adventure Time!* app. Furthermore, data presented regarding the participant ratings represent a small sample. Nonetheless, due to the low incidence nature of braille literacy, large sample sizes are often unattainable, and similar educational research studies on braille literacy have similar sample sizes. Given that a national, widespread recruitment effort took place and that the sample size still remained relatively small, the implication for this low-incidence population is that readiness cannot be restrictive. Researchers in this study chose to accept all participants who inquired and had consent/assents. If researchers had restricted participant criteria, they would not have acquired the needed sample size.

### Outcomes and Benefits

The ultimate outcome of this project was the design, development, and implementation of the *Reading Adventure Time!* and *Writing Adventure Time!* Success of the project was dependent on several factors. The team-based approach to design that involved software programmers, educational experts, content experts, teachers of students with visual impairments, and students who were braille readers, was critical. Maintaining a sense of purpose throughout design and development was also important. In this case, design focused on usability and non-visual navigation as well as the tactile display of braille characters. Throughout the project, peripheral refreshable braille displays were used to test braille access. Several iterations of feedback were important throughout development.

Reflecting upon the design, development, and implementation process set forth in this project, we discovered the emergence of several key points. The most notable finding was the need for initial training on how to use a braille display. The majority of participants were sighted individuals, and unlike technology developed for sighted individuals, braille technology requires heavy reliance on auditory and braille proficiency. In the absence of visual navigation (features such as tapping the screen) teachers relied on listening to speech output and reading the refreshable braille display, which presented the teachers with a challenging learning curve.

In regard to scalability, sustainability, and commercialization, products created for braille users are highly specialized. Sometimes, the low incidence nature of the population limits potential commercialization because of the lack of profit that can be gained from the product. Similarly, sustainability plans must consider broad needs of a population to increase a product’s reach within the population and the technology’s staying power. Statewide or national agency support could assist with adoption of products created for low incidence populations. However, a lack of funding in combination with very few affordable technology options often limit adoption of highly specialized technology.

Finally, given the emphasis of this project being on braille literacy, it is important to point out that learning to read in braille requires many of the same reading and writing skills as those required of sighted readers. However, the unique aspects of the braille code, particularly in regard to the use of contractions and knowledge of the rules governing their use, warrants the development of additional educational supports that emphasize braille. *Reading and Writing Adventure Time!* is a tool that may be used to support braille literacy development for students who are visually impaired, as well as their teachers.

### Declarations

This content is solely the responsibility of the author(s) and does not necessarily represent the official views of ATIA. This study was funded by the Office of Special Education Programs, Stepping Up Technology Grant (H327S120007). No non-financial disclosures were reported by the author(s) of this paper.

### References

Biancarosa, G., & Griffiths, G. G. (2012). Technology tools to support reading in the digital age. *The Future of Children, 22*(2), 139–160. <https://doi.org/10.1353/foc.2012.0014>

Center for Applied Special Technology (2022). *About Universal Design for Learning*. Retrieved August 1, 2022 at <http://www.cast.org/our-work/about-udl.html>

Center on Online Learning and Students with Disabilities (2017). *Universal Design for Learning (UDL) scan tool.* Retrieved July 1, 2018 at: <http://centerononlinelearning.org/resources/udl-scan-tool/>

D’Andrea, F., McCarthy, T., Kamei-Hannan, C., & Holbrook, M. C. (2021). Investigating comprehension measures of the *Reading Adventure Time!* for improving reading skills. *British Journal of Visual Impairment.* <https://doi.org/10.1177/02646196211034648>

Dewald, H. P, & Smyth, C. (2014). Feasibility of orientation and mobility services for young children with vision impairment using teleintervention. *International Journal of Orientation & Mobility, 6*(1), 83–92. <https://doi.org/10.21307/ijom-2013-009>

Edyburn, D. L. (2010). Would you recognize Universal Design for Learning if you saw it? Ten propositions for new directions for the second decade of UDL. *Learning Disability Quarterly, 33*(1), 33–41. <https://doi.org/10.1177/073194871003300103>

Etscheidt, S. L. (2016). Assistive technology for students with disabilities: A legal analysis of issues. *Journal of Special Education Technology*, *31*(4), 183–194. <https://doi.org/10.1177/0162643416673912>

Fuchs, D., & Fuchs, L. S. (2006). Introduction to response to intervention: What, why, and how valid is it? *Reading Research Quarterly, 41*(1), 93–99. <https://doi.org/10.1598/RRQ.41.1.4>

Grunwald & Associates. (2010). *Educators, technology, and 21st century skills: Dispelling five myths*. Retrieved January 26, 2023 at <https://grunwald.com/pdfs/Educators_Technology_21stCentury-Skills_GRUNWALD-WALDEN_Report.pdf>

Hall, T. E., Cohen, N., Vue, G., & Ganley, P. (2015). Addressing learning disabilities with UDL and technology: Strategic reader. *Learning Disability Quarterly*, *38*(2), 72–83. <https://doi.org/10.1177/0731948714544375>

Hasselbring, T. S., & Glaser, C. H. (2000). Use of computer technology to help students with special needs. *The Future of Children, 10*(2), 102–122. <https://doi.org/10.2307/1602691>

Hudson, R., Lane, H., & Pullen, P. (2005). Reading fluency assessment and instruction: What, why, and how? The Reading Teacher, *58*(8), 702-714. <https://doi.org/10.1598/RT.58.8.1>

Johns, J. L., & Lenski, S. D. (2010). Improving reading: Interventions, strategies, and resources (5th ed.). Kendall Hall Publishing Company.

Kamei-Hannan, C., Brostek Lee, D., & Presley, I. (2017). Assistive technology. In C. Holbrook, T. Wright, & C. Kamei-Hannan (Eds.), *Foundations of education: Instructional strategies for teaching children and youths with visual impairments* (3rd ed., Vol. II, Chap. 19). American Foundation for the Blind Press.

Kamei-Hannan, C., Howe, J., Herrera, R., & Erin, J. N. (2012). Perceptions of teachers of students who are visually impaired regarding assistive technology: A follow-up study to a university course. *Journal of Visual Impairment & Blindness, 106*(10), 666–678*.* <https://doi.org/10.1177/0145482X1210601011>

Kamei-Hannan, C., McCarthy, T., D’Andrea, F., & Holbrook, M. C. (2020). Investigating the efficacy of *Reading Adventure Time!* for improving reading skills. *Journal of Visual Impairment and Blindness*, *114*(2)*,* 88–100*.* <https://doi.org/10.1177/0145482X20913128>

Kelly, S. M. (2009). Use of assistive technology by students with visual impairments: Findings from a national survey. *Journal of Visual Impairment &* *Blindness*, *103*(8), 470–480. <https://doi.org/10.1177/0145482X0910300805>

McCarthy, T., D’Andrea, F., Kamei-Hannan, C., & Holbrook, M. C. (2022). Speed and accuracy measures of school-age readers with visual impairments using a refreshable braille display. *Journal of Special Education Technology*. <https://doi.org/10.1177/01626434221131775>

Musti-Rao, S., Cartledge, G., Bennett, J. G., & Council, M. (2015). Literacy instruction using technology with primary-age culturally and linguistically diverse learners**.** *Intervention in School and Clinic, 50*(4), 195–202. <https://doi.org/10.1177/1053451214546404>

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards*. Washington, DC: Authors.

National Reading Panel. (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction*. National Institute of Child Health andHuman Development.

Nelson, N. J., Fien, H., Doabler, C. T., & Clarke, B. (2016). Considerations for realizing the promise of educational gaming technology. *TEACHING Exceptional Children*, *48*(6), 293–300. <https://doi.org/10.1177/0040059916650639>

Pattillo, S. T., Heller, K. W., & Smith, M. (2004). The impact of a modified repeated-reading strategy paired with optical character recognition on the reading rates of students with visual impairments. *Journal of Visual Impairment & Blindness, 98*(1), 28–46. <https://doi.org/10.1177/0145482X0409800104>

Pittman, T., & Gaines, T. (2015). Technology integration in third, fourth and fifth grade classrooms in a Florida school district. *Educational Technology Research and Development*, *63*(4), 539–554. <https://doi.org/10.1007/s11423-015-9391-8>

Reid, G., Strnadova, I., & Cumming, T. (2013). Expanding horizons for students with dyslexia in the 21st century: Universal design and mobile technology. *Journal of Research in Special Educational Needs, 13*(3),175–181*.* <https://doi.org/10.1111/1471-3802.12013>

Rose, D., & Gravel, J. (2010). *Technology and learning: Meeting special student’s needs.* National Center on Universal Design for Learning.

Smith, D. W., & Kelley, P. (2007). A survey of assistive technology and teacher preparation programs for individuals with visual impairments. *Journal of Visual Impairment & Blindness*, *101*(7), 429–433. <https://doi.org/10.1177/0145482X0710100705>

Smith, S. J., & Stahl, W. (2016). Determining the accessibility of K–12 digital materials: Tools for educators. *Journal of Special Education Leadership*, *29*(2), 89–100. <https://files.eric.ed.gov/fulltext/EJ1118558.pdf>

U.S. Department of Education. (2017). *Reimagining the role of technology in education: 2017 national technology plan update*. Retrieved January 26, 2023 at <https://tech.ed.gov/netp/>

Walker, L. R., & Shepard, M. (2011). Phenomenological investigation of elementary school teachers who successfully integrated instructional technology into the curriculum. *Journal of Educational Research and Practice*, *1*(1), 23–35. <https://files.eric.ed.gov/fulltext/EJ1118470.pdf>

Wisdom, J. P., White, N., Goldsmith, K., Bielavitz, S., Rees, A., & Davis, C. (2007). Systems limitations hamper integration of accessible information technology in northwest U.S. K–12 schools. *Educational Technology & Society*, *10*(3), 222–232. <https://www.jstor.org/stable/jeductechsoci.10.3.222>

Zhou, L., Parker, A. T., Smith, D., W., & Griffin-Shirley, N. (2011). Assistive technology for students with visual impairments: Challenges and needs in teachers’ preparation programs. *Journal of Visual Impairment & Blindness 105*(4), 197–210. <https://doi.org/10.1177/0145482X1110500402>

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 76-95

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# What Users of AT Wish Developers Knew About Their Literary Experiences

## **Ben Satterfield, Ed.D.**

## Center for Inclusive Design and Innovation Georgia Institute of Technology

***Corresponding Author***

Dr. Ben Satterfield

Center for Inclusive Design and Innovation

Georgia Institute of Technology

512 Means Street

Suite 250

Atlanta, GA 30318

Email: [rsatterfield8@gatech.edu](mailto:rsatterfield8@gatech.edu)

Phone: (404) 618-3414

### Abstract

This developmental study included seven high school students with high-incidence disabilities and who use assistive technology (AT) to help them address their challenges with reading and comprehension. The methodology involved a “Think Aloud” approach (Ericsson & Simon, 1980). Participants were interviewed individually. Each participant was asked to perform a reading task using their preferred AT. As they performed this task, they were encouraged to talk about what they were doing and experiencing. These interviews were recorded, transcribed, and analyzed. The results were collected and used to create two personas for use by software developers and publishers in the field of AT.

***Keywords***: assistive technology, high-incidence disabilities, personas, reading, think aloud

### What Users of AT Wish Developers Knew About Their Literacy Experiences

There are differences in the experience of reading using assistive technology (AT) compared with that of reading print text from paper (Singer & Alexander, 2017). Many individuals with disabilities use AT tools as supports for reading. They rely on these tools as a means of enhancing their comprehension. Without these tools, many struggle with reading and with writing (Murray, 2002). AT products, such as text readers, have been developed to help these individuals derive greater understanding from what they read. These products have enjoyed widespread, but not universal, acceptance. While there is a general sense that these AT tools are beneficial, the research to support such a conclusion is neither deep nor robust (Edyburn, 2013; Larson, 2015).

This study was funded by a small development grant. One of the purposes of the grant was to investigate ways to engage people with disabilities in the design process. Our center embraces the idea that the inclusion of people with disabilities in the design process should be a foundational element of inclusive design. This project sought to explore how the reading experiences of individual users of AT might help shape the future design of AT products that supported literacy. As such, this study is appropriate for inclusion in this AT Outcomes and Benefits Journal volume on *Best Practices for Design and Development of AT Products*.

### Target and Relevance

The primary target audience for this paper includes those who develop reading support products for individuals with disabilities. Designers, programmers, project managers, and product marketing leaders involved with reading products will find the insights derived from the participants in this study instructive and enlightening. Understanding how AT users apply these products to the reading process should lead to the development of more efficient and effective products.

A second target audience would be those who instruct and support individuals with disabilities. This would include classroom teachers, therapists, and parents of students with disabilities. The insights these participants have provided will be illuminating as to how these students approach the reading task. With insights from these personas (defined later in the article), those who support struggling readers will be in a better position to assist these students. While these personas and their accounts of the reading process may not be universally applicable, the method of collecting information about an individual’s unique challenges and approach to reading may prove useful.

### Literature Review

#### Who Uses AT for Reading?

Many people read using AT today. Individuals with print disabilities, that is, anyone who is challenged by print text due to a visual, perceptual, or physical disability, is a candidate to use AT when reading (NCLD, 2010). This includes Individuals who are blind or have visual impairments, people with physical challenges such as cerebral palsy, or those with cognitive issues such as dementia or brain injury, or perceptual challenges to reading, including dyslexia (Vision Australia, 2020). Many individuals with visual impairments use specially designed screen reading tools (such as JAWS) which provide access to screen commands and settings as well as content of screens, books, and documents. In this study we looked specifically at students with high-incidence disabilities: individuals with learning disabilities (LD), attention-deficit hyperactivity disorder (ADHD), high end autism spectrum disorder (ASD), Emotional-Behavior Disorders (EBD) and some individuals with Mild Intellectual Disability (MID; Murray & Pianta, 2007). This group often uses reading pens (C-Pen), text reading software (Read & Write, Snap & Read, and Kurzweil 3000), as well as digitally recorded books (Audible.com, Learning Ally) to enhance their comprehension.

#### Does Reading with AT Help?

The last decade has seen a growing number of studies conducted on the efficacy of reading support for students with high-incidence disabilities using AT. Many of these studies focus on the effectiveness of text-to-speech technology. Text-to-speech refers to the use of synthesized speech technology to read documents aloud for students (Stetter, 2018). The meta-analysis of these studies (Wood et al., 2018) examined the impact of text-to-speech technology on reading. They found that while these studies generally lack rigor and consistency, there was evidence that the use of text-to-speech reading support did yield gains in reading comprehension for students with disabilities. Other recent studies found that text-to-speech reading support yielded improved reading comprehension and student classroom performance (Dawson et al., 2019; Park et al., 2017; Stodden et al., 2012; Young et al., 2019). While the investigation of the effectiveness of text-to-speech continues, students are using these tools in classrooms to support their reading, if for no other reason than as a means of independent access to their curriculum (Wood et al., 2018).

#### What are the Differences Between Reading in Electronic and Print Text Environments?

Individuals who read books primarily use visual decoding to read and comprehend what they read. They may read aloud to themselves. Typically, they hold the book or document in their hands or place it on a desk or table before them. They may use a finger or a ruler to keep their place as they read. They read the printed page as it is presented and have no options to adjust the font, text size, text color, or background color (unless they use a reading filter). Their reading speed is dictated by their own reading fluency. For navigation within a book or document, they turn pages manually. They may dog-ear a page or use a physical bookmark to mark their place.

***Table 1: Comparison of Reading in Print Text and Digital Environments***

| **Print Text environment** | **Digital environment** |
| --- | --- |
| Single modality: visual decoding | Dual modality: visual decoding and auditory support |
| Reading – holding the book, document | Reading and using technology  Requires a customized method of using available tools |
| WISIWIG\* | Adjustments to text size, font, text color, background color |
| WISIWIG\* | Adjustments to reading speed, voice intelligibility, volume |
| Open book, find page (Bookmarks/dog-ear pages) | Locating and opening assigned documents |
| Dictionary look up – in a separate book or dictionary tool. | May have access to a definition look-up tool or use an online dictionary/thesaurus |
| Annotation – manually write in columns (if book is owned) manual notes made. | May have electronic tools with which to add notes/ annotate passages they read. |

In a digital reading environment, with the help of AT, the reader has auditory support to complement their visual decoding skills. When they read, they will employ a computer, laptop, tablet, or smartphone. There are many variables to address, including personalized adjustments to text size, font, text color, background color, reading speed, voice, and volume. Navigation of reading with AT can be a challenging process as the task of locating and opening assigned documents must be done within the file structure of the network or device in use. Looking words up may be quicker and less distracting as some reading tools include dictionary features and online access to dictionaries and thesauruses when Wi-Fi permits. Annotation can be different in an AT supported reading environment as some products have features available with which to add notes and annotate passages.

#### Obstacles and Challenges for Digital Readers who use AT

There are a number of obstacles and challenges facing users of AT when reading. The first has to do with the reading voices. When readers make use of digitally recorded programs such as Audible and Learning Ally, they are accessing a digital recording of the book as read by a real person. The recordings of these voices are often perceived by readers as more lifelike and easier to understand. Digitally recorded books come only in the selected actor’s voice (no options to change voices) and do not present the text supported with highlighted reading (Larson, 2015).

When it comes to reading an assignment or a document for which no digital recording is available, students rely upon Text-To-Speech (TTS) tools. TTS reads the text within the document according to prevailing rules of pronunciation. TTS voices generally read everything (page numbers, punctuation, navigation info, running headers, etc.) and often mispronounce words. Students often complain that the TTS voices do not sound human enough (Taylor, 2009).

In order to read a document using TTS, the document must be made available in some accessible form. Documents that are in Microsoft Word (.DOC), Google Docs, or Adobe’s Portable Document Format (.PDF) are generally accessible and can be read by most TTS tools. When an assignment is still in print text form, it remains inaccessible until it is scanned (usually using optical character recognition (OCR) tools, like those in a printer-scanner). The output of the scanning process is often a PDF document. However, unless a scanned document has been reviewed for scanning errors and zone-edited to ensure the proper reading sequence for any charts or images within the text, there are likely to be the kinds of distractions and mispronunciations that students complain about (Taylor, 2009). Some documents are locked or encrypted and thus are not accessible and not readable by most TTS tools.

Reading off the internet is unpredictable and sometimes difficult. Internet presentation tools (like Adobe *Flash*) present text to the screen, but not in a text format that TTS tools can recognize. Often, this requires a special (different) reading tool. Many publishers of TTS products include features or provide companion products to read text in these cases.

#### Conceptual Framework for this Study

This study looked at the process of reading as it is experienced by individuals with high-incidence disabilities using AT tools. In order to capture authentic and meaningful information about this process we adopted the *Think Aloud Method.* Since the output of this study was intended for publishers of the TTS software tools, we elected to employ *Personas* as a means to convey the nature of the reading experience and the challenges faced by students who use the tools they produce.

#### The Think Aloud Method

Ericsson and Simon (1980) have asserted that oral accounts can provide valuable insight into the cognitive processes behind behavior. In order to understand the thinking and processing that is involved in complex behavior, we must get beyond mere recollection of the steps involved, as they often omit important elements and are more concerned with the products of the cognitive processes involved rather than the thinking itself (Someren et al., 1994).

In order to capture these cognitive processes accurately, the Think Aloud method was developed (Ericsson & Simon, 1980). This approach involves having the subject share their thoughts aloud as they carry out a particular task (Eccles & Arsal, 2017). The conceptual framework here asserts that the statements the subject provides during a Think Aloud session are a dependable expression of some, if not most, of the thinking involved in the task being done. This process is useful in identifying deep insights into a subject’s approach to an activity or their steps in solving a problem. A distinction should be made between the Think Aloud process, which seeks to identify distinct thoughts and their sequence in the moment of activity, and the “talk-aloud” process, which is often used to elicit reflective accounts of an activity some time after the event itself (Cowan, 2019).

We selected the Think Aloud method for this project because it provided a means to get insight to the specific steps that individuals with disabilities who used AT go through in the reading process. The use of concurrent verbalization (sharing one’s thoughts aloud while performing a task) has been used effectively to enhance the usability of computer software \*Roberts & Fels, 2006). Other methods often invite “reactive” explanations of the task under observation in which the individual inserts descriptive comments and after-the-fact explanations of the process based on their memory and perspective (Ericsson & Simon, 1998). A structured Think Aloud session asks the individual to verbalize their thinking “in the moment” and invites less embellishment upon the process under study.

#### Personas

Personas are a composite representation of a group of individuals’ abilities, perspectives, preferences, and behaviors. They have become an accepted tool for use in the design of technology products. Personas are an effective, user-centered way for developers to conceptualize and understand the needs and perspectives of consumers when designing products (Miaskiewicz & Kozar, 2011).

Cooper (2004) asserted that without input from users, the design process can easily get off course. He suggests that employing personas presents designers with a more concrete image of the customers and their needs and preferences. Use of personas should lead to a better fit of product to user.

Miaskiewicz and Kozar (2011) employed a Delphi Method to empanel experts in personas to identify the five areas in which personas most impacted product design. They found that use of personas helped 1) focus upon actual customers and their goals, 2) orient design toward the correct problems, 3) give priority to the key constituency, 4) unseat incorrect assumptions about users and customers, 5) avoid design which leans on personal experience or reasoning. So and Joo (2017) have demonstrated in a study of business school graduate students how the use of personas can stimulate creativity and novel design ideas. These specific impacts on design attracted us to the idea of using personas as an output for this study.

#### Personas and AT

Personas have not been widely used in the AT market in relation to design and development of products (Subrahmahiyan et al., 2018). The few studies and examples of persona use with regard to design of AT are reviewed here.

In 2004, the Wireless Rehabilitation Engineering Research Center (RERC) developed a survey of user needs (SUN). With this, they surveyed 1200 individuals with disabilities regarding their needs as wireless device customers. From this data, they employed a Grounded Theory technique (Glaser & Straus, 1999) to fashion a compilation of strengths and weaknesses, tasks, and viewpoints of individuals with visual impairments and people who are deaf or hard of hearing with regard to wireless device use (Mueller 2004; Mueller et al., 2005). These data were shared with wireless communication manufacturers to help them make their systems more accessible to users with disabilities.

The Pew Research Center (Horrigan, 2007) released survey results that presented descriptions of a hierarchy of users of technology. Included in these descriptions was the sense of ownership, how each interacted with their technology, and how each saw the technology influencing their lives for users at each level. Over a decade later and though technology itself has changed, these personas and their levels of mastery of technology may still be identified.

Subrahmaniyan et al. (2018) engaged in two studies to explore the value of personas in the design and development of Augmentative and Alternative Communication (AAC) devices. These personas were presented to manufacturers in the Assistive Technology (AT) industry to assist them in improving their designs. More recently, Silva and Tiexeira (2019) developed a series of personas to depict individuals on the Autism Spectrum in order to aid researchers in conceptualizing the multidisciplinary needs of individuals with autism. Hallewell et al. (2020) demonstrated the efficacy and the need for continued user-center depictions of individuals who are aging and who have a disability.

### Method

#### Research Questions

The research questions we addressed in this study were: (1) How do students with high-incidence disabilities experience reading in a digital context? (2) How could these experiences help shape the product design plans of manufacturers and publishers of assistive technology (AT)? This study was funded by a small faculty development grant with the goal of generating concepts and models for larger study. One key element of the grant was to explore ways to include people with disabilities in the design process. Because of the time required to interview the participants, transcribe their interviews, and analyze their comments, it was decided to limit the size and scope of this study. By focusing upon a limited set of students with similar learning challenges and AT use, we hoped to produce a small number of personas in sufficient detail to demonstrate the usefulness of this approach.

#### Sample

We looked for high school and college-age students with high-incidence disabilities (learning disabilities, ADHD, etc.) who use assistive technology to read. Seven students who attended a local private school took part in this study. The group was comprised of three girls and four boys ranging in age from 14 to 18.

The original project plan called for seven to 10 participants with high-incidence disabilities in the study who attended high school or college and who used AT to support their literacy experiences. This range of sample size was chosen because of the limited size and scope of the project and the time anticipated as necessary to code and analyze the statements and develop the personas. We met and worked with seven students from a local high school. Our plans to meet and work with additional students from a local university were interrupted by the COVID-19 pandemic. When the university students were sent home and face-to-face instruction was suspended, the decision was made to cease data collection and recruitment of additional participants. Because the goal of working with seven students had been reached, it was decided to curtail data collection rather than develop a new protocol for working with additional participants.

Approval from the Institutional Review Board at the Institute was sought and received. With the help of faculty and administration at the local school, informed consent was obtained from parents. The researcher explained the research project and described the rights and protections to each student individually. Assent was provided by the participating students prior to the start of each session.

#### Data Collection

The technique used for data collection was the Think Aloud method (Ericsson & Simon, 1980). Each of the participants met face-to-face with the researcher for about an hour. They were asked to read a short passage using their personal AT tool. As they did so, they were encouraged to talk about what they were doing and thinking. The goal was to understand how they approached the process of reading.

After introductions and an explanation about the research project, we introduced this method to them in a warm-up exercise immediately before beginning the Think Aloud session. The warm-up involved doing a set of simple addition and subtraction problems. These involved basic math facts and the processes of carrying and borrowing, so the participants could practice talking about their actions. Positive feedback and encouragement were provided.

A digital recorder was turned on when the participant was ready to begin to read and tell us about their process. The researcher initially withheld any clarifying questions in favor of encouraging the participant to think aloud with phrases such as, “please keep talking,” and “please continue.” When the individual appeared to run out of things to talk about, the researcher asked clarifying questions about what they had said. The digital recorder captured the Think Aloud comments and the interaction with the researcher.

### Results

The recordings of each session were transcribed by a single audio description specialist who is on staff at the Institute. The statements were transferred to a Microsoft Excel document for analysis (Amozurrutia & Servós, 2011). All coding and analysis were done by the author. A series of zones were laid out (generally in separate tabs), including a narrative zone to array the comments directly from the transcripts, a zone for the identification, weighing, and sorting of variables, and a zone for coding the variables. This made the arrangement and sorting of statements fairly straightforward. The variables identified most often from the participants’ Think Aloud comments included: reading control, voices, highlighting, fonts, notes and annotation, dictionary, and navigation (see Table 2).

***Table 2: Most Common Variables Identified from “Think Aloud” Transcripts***

| **No.** | **Description** | **Number of Occurrences** | **Number of Participants** |
| --- | --- | --- | --- |
| 1 | Reading Control | 365 | 7 |
| 2 | Voices | 233 | 7 |
| 3 | Highlighting | 124 | 7 |
| 4 | Fonts | 88 | 7 |
| 5 | Notes & annotation | 81 | 6 |
| 6 | Dictionary | 80 | 7 |
| 7 | Navigation | 74 | 4 |
| 8 | Speech to Text (writing) | 66 | 6 |
| 9 | Platform (PC, laptop, tablet, phone) | 45 | 4 |
| 10 | Editing | 31 | 4 |
| 11 | Spelling | 23 | 4 |

An analysis of the statements was done to establish the major categories addressed by the participants. In this process, we adapted elements associated with Grounded Theory (Glaser & Strauss, 1999). Rather than approach the participants’ statements with a rigid conceptual framework for categories, it was decided to adopt a heuristic strategy that developed the categories from the participant statements. In essence we took a bottom-up approach to developing the categories for analysis. Later we applied weighted frequencies in order to help make qualitative inferences around persona types.

The categories that emerged from the analysis of participant statements included: bookmarking, color (font and background), comprehension strategies, use of dictionary, digital voices, filters, fonts and font sizes, highlighting, masking, navigation, note-taking and annotation, reading platform, reading control, reading speed, translation, and voice (synthesized). Also, some comments spilled over into writing: editing, grammar checking, speech-to-text, spelling, word prediction.

With such a small sample, our analysis sought out commonalities among the Think Aloud statements. Our goal was to see if there was enough similarity in these individuals’ approaches to reading with AT that we might find that aspects of their statements clustered around two or three sets of preferences and approaches.

### Discussion

Several items emerged from our analysis of the Think Alouds that were common to most, if not all, participants. All participants in this study were using the same tools. However, they described different strategies or ways in which they use these tools. As each student described how they use their AT to read, they revealed individualized tricks and shortcuts that they use personally. It was evident that their teachers have helped these students develop strategies to employ AT in a way that works for them. Over time, students have internalized (taken ownership of) the strategies that worked for them. Each has used their tools long enough to establish a level of comfort using them, but most have not explored the tools fully. We found that there were several features that individual students had not yet discovered or had apparently yet to implement.

The students all began the reading process having to make some preliminary decisions and judgements about the task before them before they could actually begin reading. They had to determine the nature of the document: was it a Word document, a PDF file, or in Google Docs format? Once the document was opened, the preferred reading tool was selected (ScreenShot reader Chrome extension, Read & Write for Windows, Read & Write for Google Chrome extension, etc.). Then adjustments to the font, font size, line spacing, font color, and background color would need to be addressed. Finally, students attended to the reading voice, reading speed, and auto-read settings (continuous reading, read one paragraph at a time, read one sentence at a time). Fortunately, the reading settings in their tools have often been set through previous reading experience, and rarely have to be changed. Still, when some students encountered dense text, reading speed was an adjustment they leveraged to help their comprehension.

Getting lost, or losing their place while reading, was on the minds of all of the participants. In spite of electronic bookmarks and highlighted reading supports, students were following as they read with their finger, the mouse, or a paper clip, so that they would not lose touch with the reading. Beyond this, the chunking or the pacing of the reading was an issue for almost all of our participants. Saying that they needed to stop periodically to process what had been read, many preferred to use the Screenshot reader tool because it gave them the most control over how much they were reading at one time.

For most of the participants, processing what was being read involved forming a mental picture in their imagination out of what was being read. Some took longer than others to do this. Some reported needing to “insert” the emotional aspects into their understanding, or to consider (or look for) implications that might not be obvious. It was a moment for all students to assess their understanding. Some admitted that they might need to stop and summarize (at least in their heads) what they had heard. Others suggested that they would go back and reread if they felt that their understanding was incomplete.

It was not uncommon for our participants to encounter unfamiliar words. Most preferred to keep reading and hoped that the broader context of their understanding would help fill in the meaning for them. When they stopped next, it appeared that they would assess whether the word was so central to their understanding of the passage that they would have to look it up. If so, they often used a Google search to look up the word. Often there was a dictionary feature in their reading software tool, although many students did not remember it was there.

Many students confessed to ongoing difficulty with the synthetic text-to-speech voices that they used to read daily assignments. They preferred the digital human recorded voices that were often available when they read books (Audible Books and Learning Ally). The participants were unanimous in saying that the human voices were easier to understand. Many noted the more natural inflection in these voices. However, these voices are only available with specific books and are not available to read daily assignments or to proofread written work. The synthetic voices were reported to make errors in pronunciation (especially with fractions and words with unusual spellings). At other times these voices read page numbers and running headers within documents. These were distracting to our participants and at times caused them to stop and process before resetting the reading cursor and moving on.

Portability was important to all of the participants. They liked to have AT tools available to read on their cellphones and mentioned the convenience of always having a cellphone with them. However, most mentioned that they only did leisure reading on their cellphones. They did all their schoolwork on their laptops. They said that having these separate platforms helped them make a distinction between reading for school and reading for fun. While several said that reading on separate devices was helpful, some students described their laptops as “clunky” or “bulky” and suggested they preferred not to use them to read.

These findings were recast into two basic personas. While there were several universal characteristics, the student comments tended to cluster around one of two perspectives. These personas are presented in the Appendix.

The major distinction found was that reading challenges appeared to be centered around either difficulty maintaining focus or difficulty with decoding. To be sure, all students had some of both of these issues going on, but some of the students built their compensatory strategy around maintaining focus. Others were concerned with adapting the mechanics of reading to maximize their comprehension. This was generally reflected in their level of interest in reading outside of school. As the personas we developed reveal, Ellie does not like to read print text. When she does self-selected reading, she prefers animated books. Even though he reads slowly, Aaron likes to read, at least about his favorite topics. He is concerned with his mind wandering and getting distracted.

#### Observations and Limitations in this Research

There were several observations which bear further reflection and consideration in future research. One question was whether all these participating students had mastered the AT they use. Not all appeared to have fully internalized their AT and personally customized strategies for use. Most appeared to know what works for them, and at least to some degree, how to use AT to get to their desired outcome. It would be interesting to examine how the process of mastery of AT factors into these personas.

Much credit for the independence and academic progress of the participants goes to the school whose teachers have invested in these students and in the materials they are reading. Many students credited their teachers with helping them figure out how to use their AT to make the reading process work for them. It appeared that the materials students were reading had been edited so that they were accessible. Students did not encounter spurious items and misreads while reading the passages for us. This was part of the support provided by a private school serving students who struggled with literacy. Future research should examine to what degree such support exists in public school settings.

All of the students in our sample appeared to have executive function challenges. They all seemed to have difficulty describing what they were doing when they read for us. We wondered whether their difficulty thinking aloud about how they read was because this was something that they had not thought about before? Or was this still an emerging process and too new for them to have words to describe it clearly? Would we have found college-level students better at explaining their approach to reading with AT? These are questions to address in future research.

The challenges these students had in talking aloud about their reading put some pressure on the researcher to “tease out” some of what was taking place. Effort was made to suggest as little as possible and to rely on observation to supplement the participants’ Think Aloud comments. But it may have been inevitable that some assistance was needed to help students articulate what they were trying to say. Clearly this invites the danger of “putting words in their mouths.” Therefore, care should be taken to avoid researcher interference. Future research should prepare interviewers with more tools and strategies with which to support the authentic Think Aloud protocol.

#### Considerations for Future Research

One additional consideration for future research would be the close contact that was involved in this development study. In the context of the issues related to COVID-19, any future study may need to consider what would be involved in conducting effective Think Aloud interviews at a distance.

The fact that so many participants found TTS voices difficult to understand is intriguing. It would be interesting to use tools such as those used for sentiment analysis (Kulkarni et al., 2021) to explore the features of prosody, pitch, and other voice features that comprise recorded (digitized) human speech that are absent from the TTS voices available today. If that proves to be significant, solutions to improve the effectiveness of current TTS voices may follow. As sentiment prediction (Li et al., 2019; Luo et al., 2019) continues to become more sophisticated, perhaps a way to address the most common sentiment features missing in TTS voices may be found.

### Outcomes and Benefits

Outcomes and benefits of this study include a demonstration of the use of the “Think Aloud” method as a way for product designers and engineers to obtain input from future users of the products they create. This method shows promise as a means of engaging AT users in the development process but needs further study to demonstrate how and when this method can be used effectively. The personas included with this manuscript suggest a platform for collecting and presenting information about students with disabilities who struggle with reading. They provide examples of specific challenges faced by these individuals and the approaches they take to work around these difficulties. Taking these into account in future product design will lead to more effective products and enhanced sales in the future. Specifically, the Think Aloud model presented here suggests a means to obtain feedback from students about their approaches to the reading challenges they face. Developers may find this to be a productive approach to including input from individuals with disabilities in the early stages of their design processes.

Other outcomes and benefits involve insights related to the struggles of students who use AT, that will raise the understanding of parents, teachers, and therapists who nurture and work with students with disabilities. Reading continues to be central to learning as students progress through the K–12 educational system. Understanding the challenges these students are navigating as they use AT to assist their reading will help educators provide more meaningful support and assistance. From this, teachers and therapists who support reading may develop more effective and more targeted supports that help students read and comprehend more effectively.

### Declarations

This content is solely the responsibility of the author and does not necessarily represent the official views of ATIA. The author disclosed financial relationships with Georgia Tools for Life, the Center for Inclusive Design and Innovation, and the College of Design at the Georgia Institute of Technology. The author’s research has been funded by The College of Design at the Georgia Institute of Technology. Dr. Satterfield disclosed two non-financial relationships. He is a member of the Editorial Board of the Assistive Technology Outcomes and Benefits and a member of the Assistive Technology Industry Association Research Committee.

### References

Amozurrutia, J. A., & Servós, C. M. (2011). Excel spreadsheet as a tool for social narrative analysis. *Quality & Quantity*, *45*(4), 953–967. <https://doi.org/10.1007/s11135-010-9406-9>

Clarke, R. (1994). The digital persona and its application to data surveillance. *The Information Society*, *10*(2), 77–92. <https://doi.org/10.1080/01972243.1994.9960160>

Cooper, A. (2004). *The inmates are running the asylum.* SAMS Publishing.

Cowan, J. (2019). The potential of cognitive think-aloud protocols for educational action-research. *Active Learning in Higher Education*, *20*(3), 219–232. <https://doi.org/10.1177/1469787417735614>

Dawson, K., Antonenko, P., Lane, H., & Zhu, J. (2019). Assistive technologies to support students with dyslexia. *Teaching Exceptional Children*, *51*(3), 226–239. <https://doi.org/10.1177/0040059918794027>

Eccles, D. W., & Arsal, G. (2017). The think aloud method: What is it and how do I use it? *Qualitative Research in Sport, Exercise and Health*, *9*(4), 514–531. <https://doi.org/10.1080/2159676X.2017.1331501>

Edyburn, D. L. (2013). Critical issues in advancing the special education technology evidence base. *Exceptional Children*, *80*(1), 7–24. <https://doi.org/10.1177/001440291308000107>

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, *87*(3), 215. <http://dx.doi.org/10.1037/0033-295X.87.3.215>

Ericsson, K. A., & Simon, H. A. (1998). How to study thinking in everyday life: Contrasting think-aloud protocols with descriptions and explanations of thinking. *Mind, Culture, and Activity*, *5*(3), 178–186. <https://doi.org/10.1207/s15327884mca0503_3>

Glaser, B. G., & Strauss, A. L. (1999). *The discovery of grounded theory: Strategies for qualitative research*. Routledge. <https://doi.org/10.4324/9780203793206>

Hallewell Haslwanter, J. D., Neureiter, K., & Garschall, M. (2020). User-centered design in AAL. *Universal Access in the Information Society*, *19*(1), 57–67. <https://doi.org/10.1007/s10209-018-0626-4>

Horrigan, J. (2007). *A typology of information and communication technology users.* Pew Research Center.

Kulkarni, S., Barbado, L., Hosier, J., Zhou, Y., Rajagopalan, S., & Gurbani, V. K. (2021, October). Project Vāc: Can a text-to-speech engine generate human sentiments? In *2021 International Conference on Speech Technology and Human-Computer Dialogue (SpeD)* (pp. 103–108). IEEE. <https://doi.org/10.1109/SpeD53181.2021.9587366>

Langdon, P., Lazar, J., Heylighen, A., & Dong, H. (Eds.). (2016). *Designing around people*. Springer. <https://doi.org/10.1007/978-3-319-29498-8>

Larson, L. C. (2015). E‐books and audiobooks: Extending the digital reading experience. *The Reading Teacher*, *69*(2), 169–177. <https://doi.org/10.1002/trtr.1371>

Li, B., Dimitriadis, D., & Stolcke, A. (2019, May). Acoustic and lexical sentiment analysis for customer service calls. In *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)* (pp. 5876–5880). IEEE**.** <https://doi.org/10.1109/ICASSP.2019.8683679>

Luo, Z., Xu, H., & Chen, F. (2019, January). Audio sentiment analysis by heterogeneous signal features learned from utterance-based parallel neural network. In *AffCon@ AAAI*.

Miaskiewicz, T., & Kozar, K. A. (2011). Personas and user-centered design: How can personas benefit product design processes?. *Design Studies*, *32*(5), 417–430. <https://doi.org/10.1016/j.destud.2011.03.003>

Mueller, J. (2004). Getting personal with universal. *Innovation*, *23*(1), 21–25.

Mueller, J., Jones, M., Broderick, L., & Haberman, V. (2005). Assessment of user needs in wireless technologies. *Assistive Technology*, *17*(1), 57–71. <https://doi.org/10.1080/10400435.2005.10132096>

Murray, C. (2002). Supportive teacher-student relationships: Promoting the social and emotional health of early adolescents with high incidence disabilities. *Childhood Education*, *78*(5), 285–290. <https://doi.org/10.1080/00094056.2002.10522743>

Murray, C., & Pianta, R. C. (2007). The importance of teacher-student relationships for adolescents with high incidence disabilities. *Theory Into Practice*, *46*(2), 105–112. <https://doi.org/10.1080/00405840701232943>

Karger, J. (2010). Accessible instructional materials: Ensuring access for students with learning disabilities. *National Center for Learning Disabilities*.

Park, H. J., Takahashi, K., Roberts, K. D., & Delise, D. (2017). Effects of text-to-speech software use on the reading proficiency of high school struggling readers. *Assistive Technology*, *29*(3), 146–152. <https://doi.org/10.1080/10400435.2016.1171808>

Roberts, V. L., & Fels, D. I. (2006). Methods for inclusion: Employing think aloud protocols in software usability studies with individuals who are deaf. *International Journal of Human-Computer Studies*, *64*(6), 489–501. <https://doi.org/10.1016/j.ijhcs.2005.11.001>

Silva, S., & Teixeira, A. (2019). Design and development for individuals with ASD: Fostering multidisciplinary approaches through personas. *Journal of Autism and Developmental Disorders*, *49*(5), 2156–2172. <https://doi.org/10.1007/s10803-019-03898-1>

Singer, L. M., & Alexander, P. A. (2017). Reading on paper and digitally: What the past decades of empirical research reveal. *Review of Educational Research*, *87*(6), 1007–1041. <https://doi.org/10.3102/0034654317722961>

So, C., & Joo, J. (2017). Does a persona improve creativity? *The Design Journal*, *20*(4), 459–475. <https://doi.org/10.1080/14606925.2017.1319672>

Stetter, M. E. (2018). The use of technology to assist school-aged students with high incidence special needs in reading. *Education Sciences*, *8*(2), 61. <https://doi.org/10.3390/educsci8020061>

Stodden, R. A., Roberts, K. D., Takahashi, K., Park, H. J., & Stodden, N. J. (2012). Use of text-to-speech software to improve reading skills of high school struggling readers. *Procedia Computer Science*, *14*, 359–362. <https://doi.org/10.1016/j.procs.2012.10.041>

Subrahmaniyan, N., Higginbotham, D. J., & Bisantz, A. M. (2018). Using personas to support augmentative alternative communication device design: A validation and evaluation study. *International Journal of Human–Computer Interaction*, *34*(1), 84–97. <https://doi.org/10.1080/10447318.2017.1330802>

Taylor, P. (2009). *Text-to-speech synthesis*. Cambridge University Press.

Van Someren, M., Barnard, Y. F., & Sandberg, J. (1994). The think aloud method: A practical approach to modelling cognitive. *London: AcademicPress*, *11*. 29-41. Retrieved January 25, 2023 from: <https://hdl.handle.net/11245/1.103289>

Vision Australia (2020). *What is print disability?* Retrieved June 18, 2020, from [https://www.visionaustralia.org/services/print-accessibility/what-is-print-disability#](https://www.visionaustralia.org/services/print-accessibility/what-is-print-disability# )

Wood, S. G., Moxley, J. H., Tighe, E. L., & Wagner, R. K. (2018). Does use of text-to-speech and related read-aloud tools improve reading comprehension for students with reading disabilities? A meta-analysis. *Journal of Learning Disabilities*, *51*(1), 73–84. <https://doi.org/10.1177/0022219416688170>

Young, M. C., Courtad, C. A., Douglas, K. H., & Chung, Y. C. (2019). The effects of text-to-speech on reading outcomes for secondary students with learning disabilities. *Journal of Special Education Technology*, *34*(2), 80–91. <https://doi.org/10.1177/0162643418786047>

### Appendix: Personas

#### Persona 1

##### Name

Ellie

##### Picture



##### Bio profile

Ellie is 16 years old and in the 10th grade at her high school. She says school is hard. She struggles to get good grades (she is comfortable with a B in most classes but sometimes settles for a C).

She knows she is smart. She has a good vocabulary, but sometimes struggles to complete throughs in extemporaneous conversation.

She spends more time on assignments that most of her friends, but she knows she can keep up with her peers in class if she works at it and can use her tools. Her assistive technology has been a great help.

She like to read animated books (Anime). She does not need any AT to read these as the illustrations provide her added context. Because she is engaged, she reads effectively. She is an aspiring artist and likes to create her own illustrated stories.

She likes to dress casually and comfortably. She doesn’t spend a lot of time getting ready for school.

She plays on the high school soccer team where she is a valued member of the team. She prides herself on her assertive play, and views some of her teammates as among her closest friends.

##### Personal information

Ellie can, at times, become distracted. She says her minds runs out ahead of her a lot. She loses her place often when she reads. If she is reading unaided, she frequently skips lines. Often, she tracks the words as she reads them with her finger or (if on the computer) with her mouse. Reading is difficult for her. She often is successful at recognizing the words she reads but does not immediately grasp what they are saying.

She says she cannot read and process well what she is reading at the same time. She requires a few seconds (usually at the end of a paragraph) to think through what she has read. If reading continues without this step, she gets lost and confused.

“I can’t really process that well while I’m reading, so that’s one of the reasons why I need to go slower—then I can understand what I’m actually reading and try and paint a picture in my head.”

She like black print on white background. She says other colors are a distraction. “Colored text or background just changes the way I see it. Black and white are the easiest for me.”

Highlighted reading with text-to-speech is very helpful to her, even though it is not perfect.

She loses her place when she gets interrupted. She forgets to put an electronic bookmark where she stopped. When this happens, she usually starts over from the beginning.

After listening to the reading for a moment, she adjusts the speed. “I try to keep it on a low speed.”

She has the TTS voice “Ava” set as her default in Read & Write. She has the reading speed set at 50. “Ava sounds better to me than any others. I stick with how things have been set up. I don’t change these very often. But when I read one of my online textbooks (which has a different voice), I usually have to slow things down.”

##### Setting

She has been asked to read a passage from a recent assignment.

She uses her laptop. She says she prefers Microsoft Word. She says it is pretty flexible, but she is often presented with assignments in PDF file or Google Docs formats.

She has these reading tools available:

* Read & Write for Windows
* Read & Write for Google (available in Google Classroom/Docs)
* Screenshot reader (Chrome extension)

She uses all three, but she says the Screenshot reader gives her the most control over how much she is reading at one time.

We have asked her to tell us what she is doing and what she is thinking as she reads the passage.

##### Sequence of events

When she gets the document downloaded, there are several steps that she must go through:

* After opening the document, she identifies the platform (PDF, Google Docs, MS Word, other, etc.) “It just depends on the paper. I don't—I mean unless if it's not a PDF then I won't have to use Read & Write Gold PDF form. There’s different… I just prefer not using PDFs because it's a lot harder sometimes, because you have to download it like, to the desktop. And then also, you have to click “*Save*” a lot more and make sure it won't delete your work (like when I am answering questions). In Google Docs, it saves everything—which I prefer.”
* Based upon that, she decides on the optimal reading tool.
* Then she looks at the content and the structure of the document.
* If the font is too small, she increases the size. If the text is too dense, she tries double-spacing to make it more readable.
* She uses the Screenshot reader to select a limited passage to be read. (She confides that it is important to her to be able to limit the amount of text she is trying to comprehend at one time). “One of the reasons why I like Screenshot reader is because I’ll screenshot like one section, and then it will read it to me. And as I'm hearing it, I can like paint a picture of what's going on in my head. And then it stops, and then I screenshot another one. And by the time I've done that, I've already processed the last one.”
* She follows the words that are highlighted on the screen with her mouse as they are read audibly. Her reading speed is set to a slow pace. “I try to keep it on a low speed.” She is using the Ava voice.
* When she encounters a word she does not understand, she lets the reading continue; she says she hopes that the context will help her “back into” the meaning. If the meaning remains obscure, she uses a thesaurus (via Google).
* When the reading and highlighting stop, she says she puts the story together in her head, imagining it like it was a movie.
* She uses the Screenshot reader to highlight another paragraph. The highlighted reading begins again. She stops and says, “I read like a robot.” She elaborates about her difficulty discerning emotion. She observes that the digital text-to-speech voice she is listening to does not express any emotion. She says that is the way she reads when she reads aloud as well. “I'm so busy trying to get the words like out or even in my brain that I don't put emphasis on them.” She says she has to stop and think about what emotions the character is feeling. She says she has to picture this in her head.
* When the highlight goes away, she forgets where she left off and gets confused where to pick up reading again. She goes back and starts from the beginning. “When the highlighting goes away, I lose my place.”
* She gets frustrated when the voice reads extraneous things like punctuation and quotation marks, page numbers and running header, or when the voice mispronounces a word. She gets stuck on figuring that out as the reading continues.

##### What I wish developers knew

“All the voices have trouble with like… pronouncing some words or even like quotation marks. They pronounce those as something… I don't even know what. But that's not the most irritating thing. It’s like in the middle of reading something it'll say a random-like thing, like a random word, or a page number and then go back like to a text—that's my biggest thing.”

#### Persona 2

##### Name

Aaron

##### Picture



##### Bio profile

Aaron is 17 years old and in the 11th grade. He sees himself as a good student, but his classroom performance is erratic. He knows he has a scattered focus and is working to increase his attention span. His parents and teachers tell him that he shows great potential. Aaron is interested in history (military and political especially) and in geography (he is particularly attracted to maps). When he reads, he likes to read about these topics. He uses his cellphone for personal reading, but not for school; as he likes to be on social media and to play games, he knows that would distract him from schoolwork.

Aaron sometimes underestimates how long an assignment will take. Too often he finds himself under pressure to complete his work. He reads unaided with adequate understanding but very slowly. He says his mind wanders often and he finds that he skips lines without realizing it. AT as a support for reading has been helpful to increase his focus, but Aaron finds authority reading alone is not sufficiently engaging. He has decided he needs both auditory support and text in order to maximize his comprehension.

##### Personal information

Aaron confesses that his mind wanders when he reads. He follows the words he reads unaided with his finger. In the digital environment, he follows words with the mouse as he reads. Sometimes with Screenshot reader he will let his eyes follow the highlighting because he usually keeps the passage short. He has occasionally used a masking tool to help him focus on just the line he is reading. That especially helps him keep his place when reading print text.

Aaron can read unaided, using visual decoding, but he says that having audio support really helps with speed, focus, and comprehension. He says he can listen to words read to him, but his understanding is only partial. He says his mind wanders without having the text present. He needs both to remain engaged, and to fully comprehend.

He separates the two, so he won’t get distracted by other things to do on his phone. Sometimes he reads white text on black background on his phone, to give the text “some extra pop” and because “everything is smaller on my phone.” He uses his computer when reading for school. He doesn't read books for fun or personal interest on his computer. When reading for pleasure on his phone he uses Audible (and sometimes uses Learning Ally or VoiceStream reader). He reads a lot of books and finds that many are available through Audible. “From my phone, I'll have a chapter book or just a regular book. And when I'm on vacation or when I'm on the couch, I'll read an actual book on my phone versus on my computer.”

He would rather read on his phone as opposed to his laptop, which he describes as “clunky” (even though his laptop is a new slimline model). He prefers the phone for its portability and because of the convenience of always having it with him. He also has an iPad. He says it has the same software as is on his phone.

He used to make use of a Kindle for reading at home, but he found that he did not like that changes it made to the font affected the pagination. This created problems for him when he was required to report how many pages he had read for school. Aaron says he gets lost a lot when he reads on his computer. He relies heavily on the bookmark feature in his reading tool.

##### Setting

Aaron has been asked to read a passage from his literature textbook, which is available to him as a PDF, saved in his classroom electronic “assignments” folder on the school file share system. He can access this through Google Drive on his laptop.

Besides the books he is assigned to read, his assignments come mostly in PDF and Google Docs formats. Aaron has these reading tools available:

* Read & Write for Windows
* Read & Write for Google (available in Google Classroom/Docs)
* Screenshot reader (Chrome extension)

He uses all three, but he says that the Screenshot reader is easy for him to use.

I have asked him to tell us about what he is doing, what he is thinking as he reads the passage.

Sequence of events

Aaron downloads the reading assignment onto his laptop. When Aaron opens the assignment, there are several steps that he says he must go through:

After opening the document, he identifies the kind of document it is (PDF, Google Docs, MS Word, other, etc.). Based upon this, he decides the best reading tool to use.

Then he looks at the content and the structure of the document. If the font is too small, he increases the size. Aaron prefers the Times New Roman font (he uses it regularly because it is part of the MLA standard used at school), but he can use most fonts. (“As long as the font is not like calligraphy or cursive or anything crazy, I can use it.”)

He uses the Screenshot reader to select a limited passage to be read. He likes being able to click and drag the Screenshot reader out to surround a specific amount of text. The software highlights each word as it is read. Aaron’s eyes follow the highlighted word. Aaron volunteers that he sometimes uses his finger or a paperclip when he reads unaided.

Aaron stops after one sentence and relates that he listens to see if the speed at which the voice is reading is too fast for him. In this case, it is not. He is using settings for the voice and reading speed that have been arranged previously. He suggests that sometimes the subject matter in the passage is hard for him to follow, so he might have to slow the reading speed down a little. He resumes reading. He volunteers that he frequently has to slow the reading down when he starts an Audible book.

When the reading stops, Aaron says he is reviewing the details in the story. He relates that he regularly summarizes what is taking place in his mind. He says that this step helps him with understanding and helps him anticipate what might come next. If the passage is too detailed, or if there are several characters introduced at one time, he will write down notes on a piece of paper.

Aaron says that he normally wears headphones to read (he is not using them in our session). He suggests that in the classroom there are always background noises that distract him. With the headphones, he can hear the reading voice better, and he gets distracted less often.

Sometimes he stops the reading because the voice does not pause long enough at the end of a sentence. He says that sometimes he feels like he has to stop and “breathe.” If he allows the software to keep reading before he has had a chance to process what he has just read, he says he will have gaps in his understanding, which he says leads to confusion later.

When he encounters a word he does not understand, he lets the reading continue. He says he uses the context to help him “get” the meaning. Sometimes he stops and does a “copy/paste” of the new word into an online thesaurus so that he gets the correct definition. (If he is in class, he confesses that he will often just ask the teacher.) With the definition in mind, he resumes reading.

Toward the end of a passage he has just read with the Screenshot reader, Aaron appears to have lost his place. He laments that the highlight went away and thathe is confused as to where he was. He appears to guess where to restart and actually goes back to a paragraph he had read earlier and reads it again.

Aaron says the voice he is using, Ava (synthesized text-to-speech), is OK. However, he wishes Ava sounded more “realistic.” He says that sometimes this voice doesn’t pronounce words accurately, and it throws him off. Aaron is especially frustrated with the way Ava pronounces fractions and math equations. He says that the Audible voices (digital recordings by a live reader) are easier for him to listen to. However, Aaron says he does not always like the reader’s voice there, either. He has occasionally stopped listening to a book because he could not get comfortable with the reader’s voice. He wishes he could choose readers of Audible books like he can choose voices in his Read & Write program.

##### What I wish developers knew

“It would be great to be able to just click on a word to see the definition.”

“I wish that the highlighted reading would keep your place when you stop reading. When I read on Audible, I wish I had the text included to read along, instead of having to go find the actual book in print.”

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 96-109

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from the Field

# Participatory Design Approach to Creating an Accessible Nurse-Call/Hospital Room Control System for Individuals with Severe Physical Impairments

## **Susan K. Fager, Ph.D., CCC-SLP, Judith M. Burnfield, Ph.D., PT, and Tabatha Sorenson, OTR/L, OTD**

## Institute for Rehabilitation Science and Engineering Madonna Rehabilitation Hospitals Lincoln, Nebraska

***Corresponding Author***

Susan K. Fager

Director, Communication Center

Institute for Rehabilitation Science and Engineering

Madonna Rehabilitation Hospitals

5401 South Street

Lincoln, NE 68506

Email: [sfager@madonna.org](mailto:sfager@madonna.org)

Phone: (402) 413-4506

### Abstract

Nurse-call and hospital room control technology are critical for the safety and well-being of patients recovering from serious injuries and illnesses, yet many with physical impairments that limit manual dexterity are not able to use traditional systems. To address the unmet need for an integrated and intuitive device that enables individuals with limited manual dexterity to control their hospital room features and communicate with nurses, this research and development project employed a participatory design approach that integrated stakeholder feedback from key constituents (e.g., patients with manual dexterity and mobility limitations, caregivers, clinicians, and infectious disease prevention representatives) with rehabilitation research and engineering expertise to guide design decisions during conception, and iterative testing and refinement of a prototype technology. Eight patient participants with spinal cord injury undergoing acute rehabilitation evaluated the final version of the device (AC20 by Curbell Medical). The participants averaged using the AC20 15.6 times per day to call the nurse, 12.5 times per day to turn hospital lights on/off, 4.5 times per day to turn the TV on/off, 66.2 times per day for TV channel controls, and 19.3 times per day for TV volume controls. Perceived workload (NASA-Task Load Index) using the AC20 fell within the relatively low workload range for all domains with overall average workload being rated at 2.9 for all participants. On the Psychosocial Impact of Assistive Devices (PIADS), all participant scores fell within the positive range across all subcategories of competence, adaptability, and self-esteem. Semi-structured interviews revealed positive comments and perceptions of their experiences using the device while undergoing acute rehabilitation. This paper describes the technology development, transfer and ongoing evaluation process employed to create a novel device that enables individuals with limited manual dexterity greater hospital room autonomy and communication capacity with healthcare team members.

***Keywords*:** assistive technology, nurse-call, alternative access, severe physical impairment

### Participatory Design Approach to Creating an Accessible Nurse-Call/Hospital Control System for Individuals with Severe Physical Impairments

*Andy suffered a high level (cervical) spinal order injury (SCI) after a car accident and woke up orally intubated in a hospital Intensive Care Unit (ICU), unable to move and unable to communicate due to the intubation. In this state, he was unable to signal to the nurses when he needed help or when he was in pain and had to rely on trying to communicate with them when they were in the hospital room attending to his medical needs.*

Andy’s initial ICU experience in this case illustration is not uncommon, echoing a theme that many of our patients have shared. Individuals who lack manual dexterity due to conditions such as spinal cord injuries or brain stem strokes often find it difficult to access and control traditional nurse-call remotes. Zubow and Hurtig (2013) found that 14% of inpatients (an average of 66 patients per day) were unable to access the nurse-call system using their hands in a study of patient-provider communication needs of all patients receiving care at a medical center across a seven-day period. This reality is concerning, as it has been documented that medical setting errors (adverse events) are three times more likely to occur for patients who are unable to communicate and signal for help (Bartlett et al., 2008; Stransky et al., 2018). For hospitalized patients, the ability to contact a nurse has been identified as one of the most fundamental means of communication and as a method to reduce costly adverse events by allowing exchange of information regarding urgent needs related to pain, pulmonary issues, adverse drug reactions, stress, and fall prevention (Hurtig et al., 2018).

*Eventually, the breathing tube in Andy’s mouth was removed, and he was able to talk to the nurses. However, due to his physical limitations, he was unable to do simple things like control the nurse-call, turn on/off the lights, or control his TV in his hospital room. He would often have to yell to gain attention of nursing staff or wait to have the TV channel changed until a nurse or family member was available to do so. Andy remained in this state of helplessness until he transitioned to acute rehabilitation. In that environment, over time, he was introduced to a myriad of assistive devices to be able to control his call light, room lights, and TV. However, he found that multiple devices were required to perform different tasks (e.g., sip-and-puff call light with specialized mounting equipment, switch-adapted TV remote controlled with another switch and specialized mounting equipment), the technology was often fragile and easily breakable, and it was difficult for nursing and care staff to set up and operate.*

After a devastating injury like Andy’s, access to controlling one’s environment is not only critical for safety and care, but also impacts an individual’s quality of life as they begin to learn to navigate life in a different way (Hurtig et al., 2018; Zubow & Hurtig, 2013). Assistive technology can provide the tools to regain independence and instill hope as patients recover. However, Andy’s experiences demonstrate the need for changes and improvements in nurse-call and room control technology in healthcare settings to be able to best support patients’ and care providers’ needs and to set the stage for successful use of assistive technology, which will often be a lifelong need for those whose injuries result in severe physical impairments.

### Personal Statement

Housed within a large, freestanding rehabilitation hospital, our multidisciplinary team of clinical rehabilitation researchers brings extensive experience in developing and clinically applying assistive technologies for individuals with severe physical impairments resulting from conditions such as SCI, severe stroke, severe traumatic brain injury (TBI), Guillaine Barré syndrome, and amyotrophic lateral sclerosis (ALS). We work closely with patients, families, and healthcare providers to design and implement solutions to increase independence and improve quality of life. Our research approach embraces participatory design principles, with key stakeholders involved in the conception, testing, design iterations, and finalization of technology solutions (Meiland et al., 2014; Oude Weernicnk et al, 2017 Spinuzzi, 2005; Wilkinson & De Angeli, 2014). This project illustrates our process from conception to implementation.

### Target Audience and Relevance

Healthcare providers (e.g., nurses, physicians, physical therapists, speech-language pathologists, occupational therapists, respiratory therapists, psychologists, neuropsychologists, and recreational therapists) and administrators working in a wide range of medical settings (e.g., ICU, acute care, long term acute care, rehabilitation, and skilled nursing) often serve the needs of patients who have sustained severe injuries that limit their speech production capabilities and manual dexterity (e.g., SCI, severe TBI, stroke, cerebral palsy, ALS). The resulting physical challenges combined with technology limitations hinder communication between patients and healthcare team members regarding key medical needs. Additionally, many patients are unable control their hospital room environments independently, resulting in a loss of autonomy. This participatory design project describes the research and development process used to create an alternative nurse-call and hospital room control system for use by patients and healthcare professionals to maximize patients’ capacity to communicate their needs and control their environments independently.

### Project Development and Implementation

#### Participatory Design

Our project employed a participatory design approach to develop an adaptive nurse-call system for medical environments. Participatory design involves end-users (e.g., patients, clinicians, and caregivers) providing input and feedback throughout key development phases from early conceptualization, iterative design modifications, and product finalization. Participatory design methods are essential in the development of assistive technologies to ensure that the specific needs of end-users are met (Meiland et al., 2014; Oude Weernicnk et al., 2017 Wilkinson & De Angeli, 2014). Our process, adapted from various models of participatory design, included 1) identifying a specific need through interviews with end-users to understand the challenges and opportunities that existed, 2) iterative testing and refinement of a prototype to rapidly make changes to meet the needs of end-users in a hospital setting, and 3) finalization of the project leading to technology transfer to a manufacturer. Our project also included collecting data on the use of the finalized product to understand the real-life impact of the technology on patients requiring an adaptive nurse-call system.

Our core development team included a rehabilitation engineer, researchers with clinical backgrounds in physical therapy and speech-language pathology, and a clinical occupational therapist. This team had a history of assistive technology research and development. Additionally, the patients, families, and care staff who engaged in trials of the technology and provided ongoing feedback during the development process were an integral part of the team.

#### Identifying a Need

This project was first conceptualized from an interview the first two authors of the paper conducted (Fager & Burnfield, 2014). Ten individuals who participated in inpatient rehabilitation and/or a close family member completed a semi-structured interview to describe their experiences using assistive technology in that setting. Results highlighted the ongoing challenges associated with the reliability and fragility of assistive technology options as well as the high level of expertise often required to set up and maintain this kind of equipment. Some of the concerns expressed in the study (Fager & Burnfield, 2014) related to nurse-call technology included the following:

* *Challenges related to combining nurse-call with environmental control features (e.g. TV).*
  + Patient perspective: “It was also tied into turning the TV channels. I’m doing the sip and it was awful sensitive to turning on the call light at the same time. So, there were a few times where the call light got engaged and the nurses came in” (p.3).
* *Challenges related to knowing when the nurse-call was activated.*
  + Caregiver perspective: “Because at first, when he had this injury, he had panic attacks because of someone not coming in there. Not knowing how long it had been since he had activated or whatever……Anything visually to be able to help him see would be beneficial” (p. 3).
* *Challenges related to positioning.*
  + Patient perspective: “It moved around, which in the middle of the night, if the nurses are trying to, trying to do their treatment or whatever, they would almost always, well, bump into it a little bit, and that little bit made all the difference in the world” (p.3).

These results were consistent with the clinical experiences of our research team and clinical staff reports. At the time of the study, numerous pieces of equipment were often required to allow a patient to control their nurse-call system, TV, lights, and to complete other environmental control options such as opening window shades. Assistive technology was often seen as minimally compatible with other equipment in a medical environment (i.e., ventilators, IV poles, suction equipment) due to size and number of devices required. Additionally, devices often broke or were easily misplaced. The number of care providers a patient could encounter throughout all shifts through a multi-week hospital stay was large, and training all care providers on the setup and maintenance of every piece of specialized equipment was often challenging.

As a result of the Fager and Burnfield (2014) study, our team investigated a wide range of commercially available/affordable off-the-shelf options, including devices such as the Amazon Alexa and other smart home devices, in an attempt to streamline and simplify setup and maintenance for care staff. However, using mainstream technology presented ongoing challenges including lack of alternative access, other than voice, to devices such as smart TVs and the Amazon Alexa or Google Home; challenges at the time associated with HIPAA and security in the implementation of devices such as the Amazon Alexa or Google Home in medical settings; inconsistent infrared (IR) access to different TVs; and incompatibility with alternative IR control devices such as smartphones. In summary, a range of alternative access options that many of our patients required due to the combined loss of manual dexterity and the loss of interpretable speech, rapidly changing mainstream technology, and lack of security standards for medical settings, made the application of off-the-shelf solutions, at the time of the conception of the project, impractical.

#### Prototype Development

Given the critical need for an accessible nurse-call and hospital room control system, challenges experienced using multiple pieces of assistive technology to meet these needs, limitations of mainstream technology, and the specific feedback on the challenges our patients experienced in the Fager and Burnfield (2014) study, our research team focused on developing a system to meet our patients’ needs. Over a 2-year timeframe, we iteratively developed a prototype device that integrated directly with the Rauland 5 nurse-call system that was utilized in our rehabilitation hospital. The Rauland 5 is used in hospitals across the U.S. This nurse-call system also included lights, TV control, and basic communication capabilities (e.g., pain, water, need to toilet) and these features were integrated into the prototype control device (Figure 1).

***Figure 1: The First Hope system being used by a patient with a button switch.***

The First Hope system being used by a patient with a button switch.

A therapist stands beside him, smiling. 

Our prototype was named First Hope, inspired by a desire to help patients envision new ways of being able to control their environments and communicate their needs. The device allowed patients to control all handheld nurse-call pillow speaker features through switch-activated scanning. Capability switches that used a 1/8-inch plug could be used with the First Hope system. Upon admission to our facility, the occupational therapist would evaluate the patient for the most appropriate capability switch (e.g., sip-and-puff, button, light touch) based on their physical, cognitive, and visual capabilities. Patients would then control the First Hope system with their personalized switch access method to call the nurse, communicate basic needs (pain, water, toilet), turn on/off hospital room lights, and control the TV.

Our clinical-research technology development team collected ongoing feedback on the use of the First Hope system from our patients, families, and care staff and used these data to guide a series of iterative design refinements to be quickly responsive to needs as they arose. For example, a light was added to each unit so patients received visual feedback when they successfully activated the call-light. This modification addressed an unmet need with existing commercial technology, in that the call-light indicators were often located on the wall behind the hospital bed, out of view of the patient (Fager & Burnfield, 2014). When access to a nurse-call was challenging due to physical deficits, the visual indication of a successful activation often gave patients peace of mind. Physical buttons were added to the First Hope device to ensure that a caregiver had direct access to hospital room lighting, especially important in case of an emergency during overnight hours. Specifically, respiratory therapists requested direct access to lighting controls without the need to scroll to select and activate. Exterior buttons were placed to facilitate education provided by the occupational therapist, allowing them to demonstrate the concept of operation, which would have been difficult to do for sip-and-puff switch users. Scanning speed for individuals who needed more time to make selections could be adjusted manually by an engineer. Three-dimensional (3D) printed labels were integrated into the system’s exterior casing to assist caregivers in easily identifying the purpose of each exterior button.

Our final prototype enabled patients who were unable to access a traditional nurse-call pillow speaker due to manual dexterity challenges to use the First Hope system to call the nurse, turn on/off the lights, and control the TV in their hospital rooms within our facility. Feedback from patients, family members, and care staff was very positive. One patient, who had used the First Hope system during a hospitalization, contacted the clinical-research team to reserve a unit on the way back to the hospital for bedrest after wound surgery. He saw the device as a highly valuable tool that he was able to successfully use to support his independence while hospitalized.

To ease adoption of the device across shifts (day, evening, night) and units, we also developed educational materials, including a set of instruction cards to help clinical staff easily operate the system. The manual included basic information related to the function of each switch, purpose of the ports, mounting suggestions across varying situations (e.g., wheelchair, bed), as well as troubleshooting considerations. This latter aspect was considered an invaluable resource as it allowed clinicians to rapidly identify likely underlying causes of a malfunction (e.g., cord detachment contributing to display screen turning off) versus having to wait for a research team member to resolve a basic issue. This simple and intuitive guide was developed in collaboration with clinical team members. The resulting instruction cards were plasticized and attached to each system to facilitate ease of access for team members. The last card included the specific means for contacting the research team should the suggested actions not solve the system malfunction. The team monitored an incoming shared email account to not only activate a quick response, but also to identify reoccurring challenges that could be addressed either by further design modifications or instruction card refinements. By the final iteration, the team identified that a 20-minute training program for core staff on nursing units and the instruction cards provided sufficient education to enable clinicians to operate the device intuitively and easily. Subsequent training focused on training new and less familiar care providers (e.g., agency staff) on how to operate the device using the final prototype educational materials.

#### Technology Transfer and Product Finalization

Once the prototype achieved a stable design (i.e., the team was no longer receiving actionable suggestions for modifications), focus shifted to the technology transfer and product finalization. Given substantial demand for the final prototype First Hope system by Madonna Rehabilitation Hospital’s patients and clinicians, as well as interest expressed by external visitors, our team concentrated on identifying a commercial partner to advance the technology to market. Four criteria served as the basis for identifying an ideal commercial partner for the First Hope: 1) shared values on importance of advancing affordable, intuitive, and durable technology; 2) strong reputation and expertise in manufacturing regulatory compliant healthcare technology for hospital room applications; 3) international (preferred) or national presence in the market; and 4) an existing marketing and distribution network.

Following an internet search and discussion with internal and external clinical leaders, information technology specialists, and local manufacturing and small business start-up colleagues, Curbell Medical Products, Inc. (Orchard Park, NY) was identified as a potential partner. Curbell Medical is a leading medical device manufacturer with more than 60 years of healthcare experience including a focus on nurse-call accessory technology. Its flagship pillow speaker products were being used in approximately 80 percent of hospital rooms across the U.S., reflecting expertise and knowledge related to the technology.

Outreach from the Madonna research and development team to the Curbell engineering team was initially made via an established Madonna business connection. Preliminary discussions were held to gauge interest and compatibility. Then a Non-Disclosure Agreement was executed and the product was presented to Curbell’s engineering and marketing teams by Madonna’s research and development team. Subsequently, one of the co-authors (JMB) traveled to Curbell Medical and met with their engineering, marketing, legal, and organizational leadership teams to discuss the product and to learn greater details related to their resources, capabilities and vision.

***Figure 2: Schematic of the individual components of the Assistive Control Adaptor (AC20).***

Schematic of the individual components of the Assistive Controller Adaptor by Curbell Medical

The components depicted in the image include the existing nurse call system, the base module and AC adaptor, the display module, ear buds or headphones, and breath-actuated nurse call device (selected by the hospital specifically for the patient).  

*Picture courtesy of Curbell Medical*

Following a period of due diligence, a Product Assignment Agreement was executed between the organizations enabling Curbell to commercialize the technology. Curbell then focused on translating the First Hope concept into a medical-grade device with a modern, intuitive design and interface that met full regulatory compliance (Figure 2). During iterative design refinements, the Curbell and Madonna teams worked closely to consider possible benefits as well as potential negative impacts of design changes to the device’s function and ease of use across patient populations and medical environments. Patients, clinicians from multiple disciplines, and administrators were consulted to provide input into design considerations. The refined design included not only cosmetic and durability improvements, but also a number of functional enhancements, including easy access to nurse-call regardless of what screen the device was on, adjustments to menu scroll speeds, control of smart TV and interactive systems, and the capacity to dim the display at night, select from various color combinations, and present prompts in English as well as other languages (Figure 3).

***Figure 3: Close up of user interface of Assistive Control Adaptor (AC20). The control options are outlined or highlighted as they are automatically scanned. The user then makes a control option selection by activating a switch.***



*Picture courtesy of Curbell Medical*

Following achievement of full regulatory compliance including UL 1069, the AC20 Assistive Control Adaptor is now available for use in rehabilitation facilities, hospitals, long-term care settings and skilled nursing facilities across the globe.

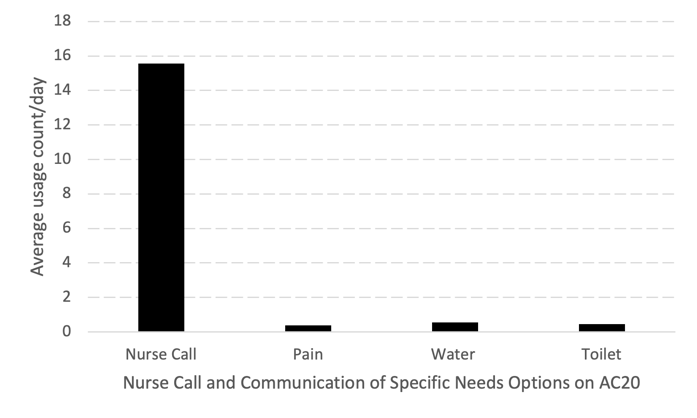
***Figure 4: Assistive Control Adaptor (AC20) by Curbell Medical being used by a patient with a sip-and-puff switch.***

****

#### AC20 Patient Experience

With the AC20 now being implemented throughout our inpatient rehabilitation hospital, the research team sought to further understand the impact of the technology on our patients’ experiences through a research study approved through Madonna Rehabilitation Hospital’s Institutional Review Board. Following informed consent, participants were recruited from our inpatient rehabilitation hospital. Our research team collected usage data from patients using the AC20, perception data through the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) and the Psychosocial Impact of Assistive Devices (PIADS; Day & Jutai, 1996), as well as semi-structured interviews. Case study data from three individuals with SCI using the AC20 was described in a paper by Fager et al. (2022) and illustrated the application of the technology to meet different patient needs in a rehabilitation environment. The following includes a summary of the preliminary group data the team has collected thus far from eight individuals with SCI undergoing acute rehabilitation.

***Figure 5: Average usage count per day across 8 pateints using the Assistive Control Adaptor (AC20) to call the nurse and communicate specific pain, water, and toilet needs.***



Patients used a range of AC20 features. Specifically, the patients used the AC20 to call the nurse an average of 15.6 times per day (Figure 5). Some selected specific communication messages including pain (average of 0.4 times per day), water (average of 0.6 times per day), and toilet (average of 0.5 times per day; Figure 5). Patients used the AC20 an average of 12.5 times per day to turn hospital room lights on/off, 4.5 times per day to turn the TV on/off, 66.2 times per day for channel controls (channel up/down and channel surfing features), and 19.3 times per day for volume controls (volume up/down and mute; Figure 6).

***Figure 6: Average usage count per/day across 8 patients using the Assistive Control Adaptor (AC20) to perform environmental controls of turning lights on/off, controlling TV channel options (channel up/down and channel surfing) and TV volume controls (volume up/down/mute).***

Bar chart for average usage count per/day across 8 patients using the Assistive Control Adaptor (AC20) to perform environmental controls of turning lights on/off (12.5), turning TV on/off (4.5) controlling TV channel options (channel up/down and channel surfing) (66.2) and TV volume controls (volume up/down/mute) (19.3).

NASA-TLX scores are rated as relatively low (0–6), medium (7–13), and high (14–20) across six domains (mental demand, physical demand, temporal demand, performance, effort, and frustration). Average scores of the eight patients fell within the relatively low workload range across all domains with overall average workload being rated as 2.9 (Table1). The PIADS rates perceptions of self within the subcategories of competence, adaptability, and self-esteem with possible ratings ranging from -3 to 3. Average scores of the eight participants fell within the positive range across all subcategories with an average overall rating of 0.6 (Table 1).

***Table 1: Average Scores across 8 Patients on the NASA-TLX and PIADS***

|  |  | **Average Patient Scores** |
| --- | --- | --- |
| **Psychosocial Impact of Assistive Devices (PIADS) Scale** | Competence | 0.71 |
| Adaptability | 0.48 |
| Self-Esteem | 0.56 |
| ***Average PIADS*** | ***0.58*** |
| **NASA Task Load Index** | Mental Demand | 2.00 |
| Physical Demand | 2.00 |
| Temporal Demand | 2.75 |
| Performance | 3.00 |
| Effort | 03.38 |
| Frustration | 4.38 |
| ***Average Workload*** | ***2.92*** |

Semi-structured interviews (Appendix A) focused on describing patients’ perceptions of the AC20 device during their hospital stays. Preliminary analysis of the interview questions and comments revealed that patients had positive experiences using the AC20. While many of the patients had limited memory of their hospitalizations when they did not have access to the AC20, a few patients were able to recall what their experiences were like. One described the experiences while in the acute care hospital when he did not have access to the AC20 or any other assistive technology for nurse-call access:

*…you just had to wait for the nurse to walk by and hopefully know what their name was. Or say whatever. And there was one night where like I said help but that [was] all I could [do], you know I got their attention.*

Another patient described how he tried to manage a regular remote call system when in the acute care hospital*, “It’s hard to push on those buttons….It’s like gel buttons even then that’s hard to press those. I was actually using my elbows because my hands weren’t….it’s hard to press which ones you want.”* Another patient described how he felt once he had nurse-call access with the AC20, *“So what I had before was completely inconvenient…was useless. Changed my life having this… absolutely did….to lean over and then press… that would call somebody.”*

Future research plans are underway to collect feedback from the nursing staff who interact with these patients and the technology to better understand of the impact on workflow and to assess if improvements could be made to further enhance the use of this technology in the medical environment.

### Outcomes and Benefits

This project illustrates the benefit of closely aligning research and development efforts with the needs, challenges, and experiences of key stakeholders. Our research team has sought to understand and design solutions for challenges experienced by our patients, their families, and care providers. The products are driven by a goal of overcoming an unmet patient/clinical need. The resulting prototype First Hope system contributed to greater functional independence, communication capacity, and control for patients with limited manual dexterity and speaking capacity cared for in our facility. Providing a method to achieve independence early in recovery was an important driving force behind the development of this technology. The prototype First Hope system and finalized AC20 device provided this early independence and served as a training tool for those requiring alternative access to environmental control. While many alternative access methods for environmental control are readily available for home and community settings (e.g, Amazon Alexa, Google Home), access to these systems/technologies often came later in recovery. Developing technology to introduce independence early in recovery is critical not only to the safety and well-being of individuals undergoing medical care, but also to helping them envision a future where technology can play an important role as they recover and learn to live in a new way. The subsequent commercial version of the technology is now being used to address similar needs for patients cared for across a broader array of facilities including rehabilitation, acute care hospitals and skilled nursing facilities.

Through this research and development project, our team learned the importance of early and ongoing end-user feedback. The impact of the technology on the day-to-day life of the end-user cannot be fully understood without the direct feedback from that individual. This became apparent to our research team through the numerous iterations made to the prototype First Hope system. While our first study (Fager & Burnfield, 2014) provided a foundation upon which we began our journey, the ongoing evaluation and feedback was critical to developing a device that truly met the needs of the end-user. Building close, ongoing relationships with key stakeholders is a critical aspect to product development in assistive technology and should be a primary goal for developers.

### Conclusion

Thorough evaluation and integration of end-user feedback at all phases of research and development is critical to successful assistive technology development and implementation. This project illustrates a process that many clinicians, developers, and researchers can follow to develop technology to meet the needs of individuals who require assistive technology to maximize their independence.

### Acknowledgements

We would like to thank the patients, family members, and care providers for their ongoing partnership with our research team in the development of assistive technologies to improve the lives of individuals with physical impairments. We would like to thank Dr. Chase Pfeifer, former Rehabilitation Engineer at Madonna Rehabilitation Hospitals, for his collaboration and work on the early development of the First Hope prototype device. The authors also wish to thank Aaron Beulow, Seraphina Provenzano, Isabella Carnazzo, and Madison Henry, physical therapy student research interns at Madonna Rehabilitation Hospitals, for their assistance in data collection with patients using the AC20.

### Declarations

The content is solely the responsibility of the authors and does not necessarily represent the official views of ATIA. The First Hope prototype was developed in part through a grant from the Department of Health and Human Services, Health Resources and Services Administration (Award No. 1 R1CRH20680-01-00; Project Director: Judith M. Burnfield, PhD, PT). However, the contents do not necessarily represent the policy of the Department of Health and Human Services, and endorsement by the federal government should not be assumed. J. M. Burnfield, S. Fager, and T. Sorenson co-invented the First Hope technology in collaboration with T. W. Buster and C. M. Pfeifer. A product assignment agreement was completed with Curbell Medical Products, Inc. to commercialize the technology. Sales of the technology have resulted in royalty distribution to Madonna Rehabilitation Hospitals and to the members of the team that invented the First Hope technology. No non-financial disclosures were reported by the authors of this paper.

### References

Bartlett, G., Blais, R., Tamblyn, R., Clermont, R. J., & MacGibbon, B. (2008). Impact of patient communication problems on the risk of preventable adverse events in acute care settings. *Canadian Medical Association Journal, 178*(12), 1555–1562. <https://doi.org/10.1503/cmaj.070690>

Day, H., & Jutai, J. (1996). Measuring the psychosocial impact of assistive devices: The PIADS\*. *Canadian Journal of Rehabilitation, 9*(2), 159–168. ISSN: 0828-0827.

Fager, S. K., & Burnfield, J. M. (2014). Patients’ experiences with technology during inpatient rehabilitation: Opportunities to support independence and therapeutic engagement. *Disability and Rehabilitation: Assistive Technology, 9*(2), 121–127. <https://doi.org/10.3109/17483107.2013.787124>

Fager, S., Burnfield, J. M., Sorenson, T., Buelow, A., Provenzano, S., & Carnazzo, I. (2022, July 15). *Offering first hope for individuals undergoing inpatient SCI rehabilitation: evaluation of a novel assistive technology for promoting hospital room independence* [Paper Presentation]*.* Rehabilitation Engineering Society of North America virtual conference.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati, (Eds.). *Human mental workload*. North Holland Press.

Hurtig, R. R., Alper, R. M., & Berkowitz, B. (2018). The cost of not addressing the communication barriers faced by hospitalized patients. *Perspectives of the ASHA special interest groups, 3*(12), 99–112. <https://doi.org/10.1044/persp3.SIG12.99>

Meiland, F. J., Hattink, B. J., Overmars-Marx, T., de Boer, M. E., Jedlitschka, A., Ebben, P. W., Stalpers-Croeze, I. I., Flick, S., van der Leeuw, J., Karkowski, I. P., & Dröes, R. M. (2014). Participation of end users in the design of assistive technology for people with mild to severe cognitive problems: The European Rosetta project. *International Psychogeriatrics, 26*(5), 769–779. <https://doi.org/10.1017/S1041610214000088>

Oude Weernink, C. E., Sweegers, L., Relou, L., van der Zijpp, T. J., & van Hoof, J. (2017). Lost and misplaced items and assistive devices in nursing homes: Identifying problems and technological opportunities through participatory design research. *Technology and Disability, 29*(3), 129–140. <https://doi.org/10.3233/TAD-170179>

Spinuzzi, C. (2005). The methodology of participatory design. *Technology Communication, 52*(2), 163–174. [https://www.ingentaconnect.com/content/stc/tc#](https://www.ingentaconnect.com/content/stc/tc)

Stransky, M., Jensen, K., & Morris, M. (2018). Adults with communication disabilities experience poorer health and healthcare outcomes compared to people without communication disabilities. *Journal of General Internal Medicine, 33*(12), 2147–2155. <https://doi.org/10.1007/s11606-018-4625-1>

Wilkinson, C. R., & De Angeli, A. (2014). Applying user centered and participatory design approaches to commercial product development. *Design Studies, 35*(6), 614–631. <https://doi.org/10.1016/j.destud.2014.06.001>

Zubow, L., & Hurtig, R. (2013). A demographic study of AAC/AT needs in hospitalized patients. *Perspectives of the ASHA Special Interest Groups, 22*(2), 79–90. <https://doi.org/10.1044/aac22.2.79>

### Appendix: Semi-Structured Interview Questions

1. How long have you been using the AC20?
2. What do you like about the AC20?
3. What things do you not like about the AC20 and how would you envision changing it?
4. What was it like accessing your call-light and controlling things in your environment (e.g., you TV and lights) before you had the AC20 (e.g., when you were in the acute care hospital or ICU)? Compare/contrast that time with how you are currently using the AC20 to do those things?
5. What else would you like to share with us about the AC20?

Assistive Technology Outcomes and Benefits

Volume 17, Spring 2023, pp. 110-124

Copyright ATIA 2023 ISSN 1938-7261

Available online: [www.atia.org/atob](http://www.atia.org/atob)

# Voices from Academia

# Design Considerations for Aphasia Rehabilitation Technologies: How Linguistic Factors and Computer Interaction Designs Alter User Behaviors during Autonomous Practice

## **Richard D. Steele, Ph.D.1, Michael de Riesthal, Ph.D.2,3, and Angel L. Ball, Ph.D.4**

## 1Lingraphica Princeton, New Jersey

## 2Department of Hearing and Speech Sciences Vanderbilt University Medical Center

## 3Pi Beta Phi Rehabilitation Institute Vanderbilt University Medical Center 4School of Education, Program in Speech-Language Pathology Nevada State College

***Corresponding Author***

Richard D. Steele

Lingraphica

103 Carnegie Center

Suite 104

Princeton, NJ 08540-6235

Email: [rsteele@lingraphica.com](mailto:rsteele@lingraphica.com)

Phone: (506) 534-3161

### Abstract

In this observational case study, we analyze how two factors—[i] human-computer interaction (HCI) designs, and [ii] linguistic properties of target word stimuli—affect observed behaviors of a person with aphasia and apraxia of speech using a therapeutic rehabilitation technology autonomously. The contrasting HCI designs display either a static image or an articulation video in response to user activation. The linguistic factors are syllabic constituent typicalities and word frequencies of the lexical stimuli. The data show that the linguistic factors interact with the HCI designs to influence user engagement patterns and word repetition success rates, discernibly and with a degree of predictability. These findings suggest mechanisms for incorporation into adaptive algorithms that can personalize stimulus selection and sequencing to boost engagement with, and effectiveness of, therapeutic apps being used autonomously by individuals with aphasia.

*Keywords*: aphasia with apraxia of speech, computer interaction design, word frequency, syllabic constituents, stimulated monosyllable repetition

### Design Considerations for Aphasia Rehabilitation Technologies: A Case Study Relating Computer Interaction Designs, Linguistic Properties of Practice Words, and Autonomous User Engagement and Success

Rehabilitation technologies for persons with disabilities are becoming more powerful, sophisticated, and integrated. As their domains of uses expand, developers and consumers of rehabilitation technologies must understand the implications of such changes for their work. Rehabilitation researchers and developers, for example, must effectively incorporate emerging technologies into new products and services that are attractive to, usable by, and empowering for all who use them. In today’s world, people may find apps for use via hit-or-miss internet searches and downloads. Consequently, successful rehabilitation offerings must attend to designs that deliver benefits to those without the advantages of ongoing support from rehabilitation clinicians. We illustrate here how observational research can help address such issues regarding persons with aphasia and co-occurring apraxia of speech (PWA/AOS).

This article draws on the authors’ years of collaborative work on rehabilitative technologies for persons with aphasia (PWA). Aphasia is an acquired communicative disorder in which a person’s natural speech, language, and communicative capabilities become neurologically impaired. Most aphasias are caused by left hemisphere strokes that damage language-critical areas of the brain. Aphasias are not “curable” because—among other things—lesions of the brain do not resolve over time. Nonetheless, given appropriate tools, guidance, and practice, PWA do make gains in their communicative performance, even years post-onset (Brookshire, 1997).

Interest in using computers for aphasia rehabilitation dates back over half a century, with progress accelerating as technologies matured (Katz, 2001). By the 1990s, clinical outcome studies appeared that documented the effectiveness of speech generating devices (SGD) in promoting widespread, communicatively important, and unexpectedly large therapeutic gains in PWA (Aftonomos et al., 1997; Aftonomos et al., 1999). Medicare took note of these developments, and, in 2001, changed longstanding policy by approving reimbursement for SGDs prescribed to PWA as durable medical equipment (CMS, 2014). Two subsequent decades brought the advent of handheld devices like smartphones and tablets, and the establishment of online stores for widespread app dissemination. Together, these have greatly expanded opportunities for developing new offerings, including smart apps for the rehabilitation of aphasia. However, the research required for effectively developing such products is ongoing. The current study aims to contribute by expanding insight into how contrasting HCI interface designs interact with linguistic properties of stimulus words to influence engagement decisions and success rates of a PWA/AOS practicing word repetition autonomously. Previous studies have focused on each of these factors independently, but not on their effects conjointly.

Investigators have long studied how linguistic variables, such as word frequency, syllable frequency, syllable structure, or articulatory complexity influence the ability of a PWA/AOS to produce a word successfully. Their findings show that, other things (e.g., word length, phonotactic complexity) being equal, words that are more frequent in the English language are generally easier to produce in repetition activities than less frequently occurring words (Biederman & Nickels, 2008; Goldrick & Rapp, 2007; Haley & Jacks, 2014; Jeffries et al., 2006; Martin et al., 1996; Nozari et al., 2010). In individuals without neurological damage, shorter latencies in production are linked with higher syllable frequency compared to lower syllable frequency (Cholin et al., 2011; Stenneken et al., 2007). In PWA, both with and without coexisting AOS, Aichert and Ziegler (2004) report greater production success with more frequent syllables. Such production success or failure is further influenced by consonant clusters’ locations adjacent to or across morphological boundaries. For individuals with AOS, there is also general agreement that greater articulatory complexity is associated with higher error rates. From the illustrative citations above, we recognize numerous interacting factors to consider from speech-language pathology and linguistics.

In this study, we limit our linguistic stimuli to monosyllabic words, resulting in syllable frequency equating to word frequency. We developed for these words an algorithmically calculable metric—syllable constituent typicality—explicitly to rank-order the inventories of phonological constituents (onsets, vocalic nuclei, offsets) for correlation calculations. We selected as the subject of this case study a PWA with severe apraxia of speech. These investigative constraints allowed us to focus, in practice, on influences of interactions between word frequencies and syllable constituent typicality values, for a PWA/AOS working on a computer-based rehabilitation app.

In this context, it becomes important to understand just how differing HCI designs evoke varying responses in PWA. In research done to date, the focus of such investigations has varied between internal responses solely (e.g., activation of neural networks), external responses solely (e.g., change in observable behaviors), and a combination of the two. As examples, Nishitani and Hari (2002) developed computer displays of speech-related visuomotor stimuli and documented activation of language areas of the cortex in brain scans. For these researchers, the focus of attention was users’ internal response. Elsewhere, Fridriksson et al. (2012) showed that synchronizing videos of speech articulation with audio recordings of the associated speech utterances stimulated cerebral activity and additionally enhanced the fluency in subjects who used computer displays to induce speech entrainment. Here, the researchers captured both the internal response (cortical activation) and the associated externally observable behaviors (improved fluency in volitional speech production). In a purely behavioral study, Ball et al. (2018) focused on analyzing patterns in externally observable, volitional activities. They showed that contrasting video display types coupled with speech output led to differing practice patterns and performance improvements in their PWA/AOS subjects.

Studies of the latter type, in considering observable behaviors, may usefully avail themselves of familiar assessment instruments that have been refined over decades. The best of these tools are standardized, psychometrically characterized, and of documented validity, reliability, and sensitivity to change (e.g., Frattali et al., 1995; Goodglass et al., 2001; Kertesz, 2007; Lomas et al., 1989; Porch, 1967). Such instruments are useful both in prospective, scientifically controlled studies that address efficacy (e.g., Steele et al., 1992), and in clinical outcome studies that probe real-world effectiveness (e.g., Steele et al., 2010). To a degree, the use of these tools may assist investigators in interpreting research results across study methodologies.

No less important than scores are the observational skills acquired by the researchers, who become practiced at observing and recording user behaviors during task performance. It is the combination of valid and reliable quantitative data with careful observational study methodologies that permit mixed-methods research such as the current study. The authors used such skills to process video recordings of a PWA/AOS during autonomous practice, generating time-ordered transcripts of categorized participant behaviors for statistical analysis (Ball et al., 2018). Behaviors identified included the participant’s accuracy of word production performance and the concomitant behavioral patterns associated with the participant’s interaction with the stimuli (e.g., number of practice attempts, timing of response, constituent production success rates, etc.). These were used in the following statistical analysis, which shows how user engagement decisions and word production success rates may be influenced not only by linguistic properties of the individual stimulus words, but simultaneously by key features of human-computer interaction designs.

### Target Audience and Relevance

Readers from a range of disciplines may find aspects of this work of interest and value. Computer scientists who specialize in the design of interfaces, or of human-computer interactions, may wish to investigate uses for video *vs.* drawing for stimulus presentation among other populations than studied here (e.g., pediatric users). Some clinical speech-language pathologists who treat persons with aphasia using only paper technologies could exploit data from typicality tables and responses to “drawing as stimulus” when working on improving word production therapeutically. Neurolinguists could use brain scans to investigate different cerebral network recruitment patterns associated with the observed performance behaviors in different stimulus conditions. That said, there are two groups of people who comprise the primary intended audience of this article, namely, aphasia researchers and clinicians interested in best practices for employing advanced rehabilitation technologies, and assistive technology developers who must produce and support effective products and services for use by the many stakeholders in communication rehabilitation. Benefits to these latter two groups are discussed in dedicated sections following the Discussion below.

### Method

#### Participant

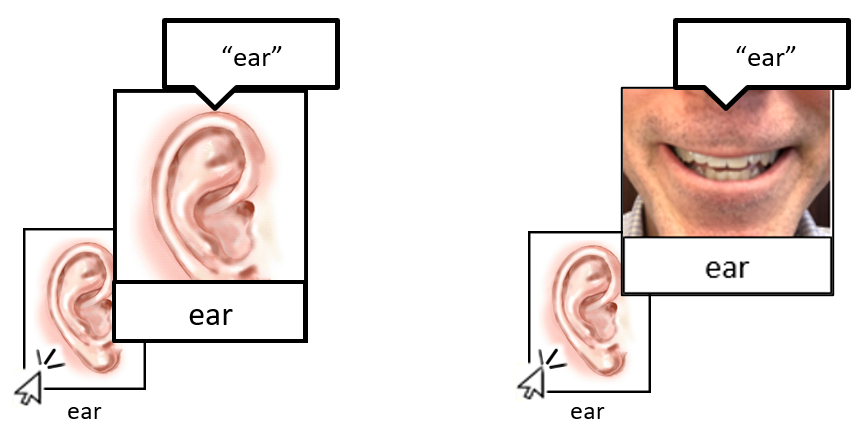
The participant is a 62-year-old white female diagnosed with aphasia and apraxia of speech (Ball et al., 2018). She had suffered an ischemic left hemisphere stroke four years earlier that produced a lesion that damaged the frontal, parietal, and temporal lobes. Premorbidly, she had been a neurotypical monolingual speaker of standard American English, with two years of college education. During practice activities, her right hemiparesis caused her to use her non-dominant left hand for technology operations. At time of testing, her hearing and visual scanning were within normal limits, and she wore reading glasses. Clinically, she presented with a moderate Broca’s aphasia and severe AOS, coupled with mild limb apraxia and oral apraxia, based on assessment results from the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007), the Apraxia Battery for Adults-Second Edition (ABA-2; Dabul, 2000) and the Philadelphia Naming Test short form (PNT30-A; Walker & Schwartz, 2012). Her WAB-R Aphasia Quotient (AQ) was 64.5, which placed her in the moderate category for aphasia severity. Her oral expressive language was non-fluent, characterized by halting, telegraphic utterances, and word-finding difficulty. Her Auditory Verbal Comprehension score was 7.85/10 on the WAB-R, with a relative strength in auditory word recognition, accompanied by difficulty in following sequential commands. Her Repetition performance of words/phrases of increasing length was 6.7/10. Naming baselines included 5.7/10 on the WAB-R composite Naming section and 11/30 confrontation naming on the PNT Short Form. The Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001) was administered to examine cognitive-linguistic function: her overall severity score was moderate. By specific modality areas, her ability was scored as severe for the intertwined language (and memory) tasks, moderate for executive functioning, and mild for attention and visuospatial skills.

#### Stimuli

Lexical targets in the initial research (Ball et al., 2018) comprised two phonologically comparable sets of words compiled from the Philadelphia Naming Test (Roach et al., 1996). Each set was constructed to contain 9 monosyllabic words (along with 11 polysyllabic stimuli, not treated here) and was associated with one of the two interface display conditions. During construction, the investigators attended in particular to phonological and syllabic equivalency with respect to constituent phonotactics (e.g., C-V-C, CC-V-C, etc.), as well as to associated segmental and cluster frequencies. During practice sessions, the computer interface displayed icons one at a time to the user, who could initiate—whenever desired—a multimodal response that was prompt, physiologically stimulating, and precisely repeatable. On initial presentation, an icon appeared as a small, framed selectable icon showing a graphic (drawing or photo) with text of the target word beneath. When clicked, the icon responded by suddenly doubling in dimensions about its own visual center of mass, then displayed either an enlarged version of the static drawing or a video of articulatory motions with synchronized audio as the stimulus word was spoken. After about three seconds of enlargement, the icon returned to its original smaller dimensions and visual appearance. The key features of these two interface user interaction designs are illustrated schematically in Figure 1.

***Figure 1:******Two Contrasting User Interaction Designs for Icons***

*“drawing as stimulus” “video as stimulus”*



Enlarge, then display Drawing+Audio Enlarge, then display Video+Audio

#### Procedure

The researchers analyzed participant data from recorded videos of simulated autonomous practice sessions for each of the two stimulus conditions: “drawing as stimulus” and “video as stimulus.” As the practice routine, the participant was instructed to: (1) click on the icon for the current target word; (2) focus attention on the multimodal stimuli delivered during the icon’s response; (3) internally process those stimuli in preparation for her own word-production attempt; and (4) say the target word as accurately as possible. The participant was at liberty to iterate this practice routine as often and as frequently as she liked, in preparation for a final unassisted production attempt, absent computer involvement. No cueing or feedback was provided to the participant by the researchers during practice sessions. Clarification of instructions and/or operational device assistance were available if requested. All practice productions and independent utterances were video recorded with synchronized audio for subsequent data analyses.

#### Data Analysis

The audiovisual recordings of the participant’s actions were analyzed using iterative, cyclical processes that moved in a bottom-up fashion to produce increasingly refined behavioral taxonomies for application to, and interpretation of, the user’s autonomous practice behaviors. The details of this mixed-method analytical approach are described in Ball et al. (2018). The end products of these iterative analytical passes were chronologically ordered practice logs, i.e., transcripts of user-initiated computer interactions, responsive user verbalizations, word-production successes or failures, and constituent-production successes or failures. Tallies of event sequences during a session could be generated for statistical analysis.

We analyzed the data from these practice logs to investigate three issues, generating results for each of the interface’s icon responses of Fig. 1 separately. The issues were: (A) the rank order correlations between *syllabic constituents’ typicality* vs. their *verbal production success rates*; (B) the relationship between *successful verbal production of the onset* of a stimulus word and *successful verbal production* of the entire word; and (C) the effects of *onset typicality* and *spoken word frequency,* considered together*,* on autonomous practice engagement patterns with, and successful verbal production of, target words during autonomous practice.

To investigate issue (A), we generated rank-ordered tables for the typicality of all constituents—namely, the consonantal *onsets* (these precede vocalic nuclei), the vocalic *nuclei*, and the consonantal *offsets* (these follow vocalic nuclei) of English monosyllabic words. Table 1 displays selected illustrative constituents of each type, along with their typicality percentages. Using production transcriptions, we also tallied up for each constituent position—onset / nucleus / offset—the total number of constituent production attempts and successful productions during autonomous practice. Dividing the number of successful productions by the total number of production attempts yielded, for each attested constituent, a success percentage value. These were used to rank-order those constituents by production success rates, and those rank orderings were juxtaposed with typicality rank orderings for the same constituents. Spearman’s *ρ* rank-order correlation coefficients were then calculated using SPSS (IBM Corp., 2020), with the probability level for rejection of the Null Hypothesis set at *p* < .05. This procedure was carried out in all three available positions, in each icon response condition, for all constituents attested in the stimulus word sample.

***Table 1: Illustrative Typicality Percentages for Constituents of English Monosyllables***

| **Onset** | **%-age** |  | **Nucleus** | **%-age** |  | **Offset** | **%-age** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| /ø/- | 5.0% |  | -/ɪ/- | 10.9% |  | -/ø/ | 8.1% |
| /b/- | 5.0% |  | -/e/- | 10.0% |  | -/t/ | 7.7% |
| … | … |  | -/æ/- | 9.7% |  | -/n/ | 6.7% |
| /t/- | 4.2% |  | -/ej/- | 9.4% |  | … | … |
| /f/- | 4.1% |  | -/ij/- | 8.7% |  | -/p/ | 3.8% |
| … | … |  | -/ʌ/- | 7.6% |  | -/s/ | 3.4% |
| /st/- | 2.5% |  | -/ow/- | 7.4% |  | -/st/ | 2.7% |
| /g/- | 2.1% |  | … | … |  | … | … |
| … | … |  | -/uw/- | 5.8% |  | -/ŋ/ | 1.8% |
| /str/- | 1.2% |  | -/ʊ/- | 5.0% |  | -/ŋk/ | 1.4% |
| … | … |  | … | … |  | … | … |
| /spl/- | 0.1% |  | -/ɔj/- | 1.0% |  | -/rst/ | 0.2% |

To investigate (B), we tallied up—in each stimulus condition of Figure 1 and for each consonantal onset among the stimulus words—the total number of successful verbal productions of the onset, and the number of successful stimulus word completions. Dividing the number of successful word productions by the number of successful onset productions yielded, for each icon responsecondition, the percentage likelihood that successful onset production marks successful target word production.

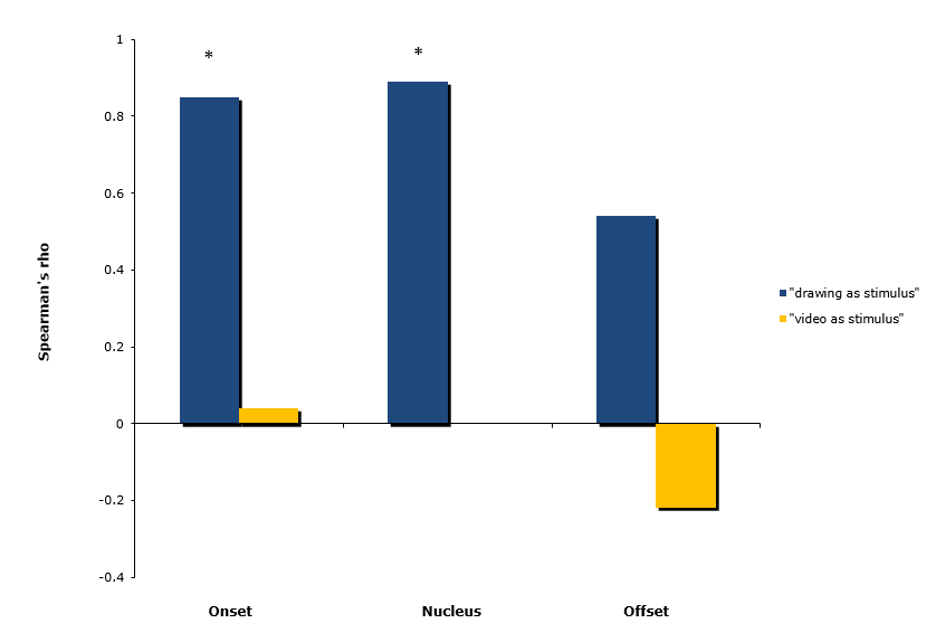
To investigate (C), we partitioned target words in our stimuli samples into two groups: those occurring with higher frequency vs. lower frequency in spoken English. Raw frequency values were drawn from the SUBTLEXus database, which was developed by analyzing transcripts of contemporary conversational American English (Brysbaert & New, 2009). We also partitioned the syllabic onsets into two groups: those of higher typicality vs. lower typicality among English monosyllables. These word-intrinsic partitioning criteria are orthogonal and permit every English monosyllable to be assigned unambiguously to one of four groups: (i) high onset typicality/high word frequency; (ii) high onset typicality/low word frequency; (iii) low onset typicality/high word frequency; and (iv) low onset typicality / low word frequency. We reviewed our practice logs to tally the total number of production attempts in each of the four groups, and the total number of successes, to explore the effects of intrinsic linguistic properties on patterns of engagement and of success, during autonomous practice.

### Results

#### Constituent Typicality – Production Success

For the three intrasyllabic positions, calculations of values of *Spearman’s ρ* between *syllabic constituents’* *typicality* vs. *frequency of production success* reveals clear dependencies on Figure 1 stimulus conditions. With “drawing as stimulus,” target word production success is significantly positively correlated with the syllabic constituent typicality for *onsets* and *nuclei*. In contrast, with “video as stimulus,” the corresponding correlational values are small in magnitude, variable in sign, and uniformly non-significant. Figure 2 displays the results graphically. Numerically, with “drawing as stimulus,” for *onsets* *ρ* = .85 (\**p =* .004), for *nuclei* *ρ* = .89 (\**p* = .04), and for *offsets* *ρ* = .54 (*p* = .17). With “video as stimulus,” for *onsets* *ρ* = .04 (*p =* .93), for *nuclei* *ρ* = 0 (*p* = 1), and for *offsets* *ρ* = –.22 (*p* = .63).

***Figure 2: ‘Typicality – Practice Success’ ρ Values for Syllabic Constituents, Positionally***



#### Onset Production Success – Word Production Success

Again, we observe differing effects of stimulus conditions on success patterns. With “drawing as stimulus,” target words in which the *onset* constituents were successfully produced were carried through to successful whole-word completion in only 55.6% of attempts. With “video as stimulus,” the comparable figure is 90.0%. Because onset constituents were not always produced correctly in either condition, overall successful completion rates of target words for sessions overall were correspondingly lower. Table 2 displays these results.

***Table 2: Effects of User-Initiated Stimulus Conditions on Word Production Success***

| **Successful word-production rates** | **“drawing as stimulus”** | **“video as stimulus”** |
| --- | --- | --- |
| - after onset is correctly produced | 55.6% | 90.0% |
| - in all attempts during practice | 25.9% | 41.9% |

*Note: Figure 1 illustrates the contrasting “drawing as stimulus” and “video as stimulus” user interaction designs.*

#### Effects of Combined Linguistic Properties of Targets on User Behaviors

Assignment of each target word to its proper quadrant in the 2-by-2 matrix of Table 3 permits tally and display within each quadrant of total number of stimuli, total production attempts for those items, mean number of attempts per item, and mean percentages of successful attempts. Visual inspection of the data in Table 3 establishes that these intrinsic properties of target words have influenced both user engagement patterns and success rates. Note especially the lower left quadrant (‘lower onset typicality’/‘higher word frequency’), where numbers of total attempts and of mean attempts per item clearly exceed the corresponding numbers in other quadrants, despite the average success rate being strikingly lower than in the other three quadrants. This pattern suggests enhanced subject motivation to master these particular words, manifesting as engagement perseverance in the face of challenge.

***Table 3: Effects of Combined Linguistic Properties on User Practice Behaviors***

|  |  |  |  |
| --- | --- | --- | --- |
| **High Onset Typicality and High Word Frequency**  ***e.g.,* ‘hand’, ‘dog’ (*n* = 6)** | | **High Onset Typicality and Low Word Frequency**  ***e.g.,* ‘harp’, ‘dice’ (*n* = 6)** | |
| Total Number of Attempts | 25 (14, 11) | Total Number of Attempts | 34 (25, 9) |
| Auton. Pract. Successes | 12 [48.0%] | Auton. Pract. Successes | 18 [52.9%] |
| Mean Pract. Attempts/Item | 4.2 {2-11} | Mean Pract. Attempts/Item | 5.7 {1-10} |
| **Low Onset Typicality and High Word Frequency**  ***e.g.,* ‘clock’, ‘tree’ (*n* = 4)** | | **Low Onset Typicality and Low Word Frequency**  ***e.g.,* ‘glove’, ‘broom’ (*n* = 2)** | |
| Total Number of Attempts | 58 (38, 20) | Total Number of Attempts | 11 (8, 3) |
| Auton. Pract. Successes | 6 [10.3%] | Auton. Pract. Successes | 4 [36.4%] |
| Mean Pract. Attempts/Item | 14.5 {8-20} | Mean Pract. Attempts/Item | 5.5 {3-8} |

### Discussion

The current research reports on influences of two independent factors—namely, [i] intrinsic linguistic properties of English words, and [ii] contrasting human-computer interaction designs—on the engagement behaviors and word production success rates of a PWA/AOS using a therapeutic technology autonomously for stimulated word repetition. The specific findings help sharpen our understanding of effects of each of these factors considered singly, while illustrating ways in which they can work together. Such results hold implications for several types of activities: how we think about the rehabilitation potential for PWA/AOS; how we select rehabilitative tools for them to use; and how we design those tools to deliver the desired benefits. As such, this work should be of interest to several groups including research aphasiologists, SLP clinicians, and technology developers. Below we first discuss implications of individual findings, then their significance for the groups.

#### Finding I – Constituent Typicality Influences

The data indicated a significant, positive correlation between production success rates of onsets and nuclei and their typicality rank order, in the “drawing as stimulus” condition. That is, onsets and nuclei that are more frequently occurring in English monosyllabic words are easier to produce than less frequently occurring syllable constituents. Within the typicality rank order, single segment onsets tend to be ranked as more typical than consonant clusters. Thus, the typicality rank appears to be a proxy for articulatory complexity. This finding is consistent with the observations of previous investigations (Aichert & Ziegler, 2004; Staiger & Ziegler, 2008) that for PWA/AOS, complex consonant clusters at the beginnings of words represent greater barriers to successful word production than single-segment onsets that are more common. Interestingly, the lack of a significant correlation between these variables in the “video as stimulus” condition suggests that the strength of this phenomenon is contingent upon stimulus input. That is, accuracy of performance is decoupled from typicality rank order when articulation videos were presented as stimuli. This finding is consistent with a study of speech entrainment (Fridriksson et al., 2012) that found greater fluency and articulation success when articulation videos were presented compared to auditory only stimuli. Thus, the use of articulation videos as stimuli may broaden the range of complexity of target words that may be selected for treatment. The finding offers a partial predictive surrogate metric (i.e.,typicality rank order) for success likelihood of onset production in this stimulus condition.

#### Finding II – Onset Production Success

Finding II characterizes another aspect of the differing onset production success rates in the two contrasting stimulus conditions, namely, their influences on whole-word production. The data show that, with “video as stimulus,” successful production of a target word’s onset is associated with successful completion of the entire wordin 90.0% of attempts; with “drawing as stimulus,” that rate is only 55.6%. This finding arguably indicates that the two stimulus conditions differently engage with disparate neural networks—sensory, cognitive, motoric—that must perform in integrated, synchronized choreography for successful word repetition. Among other things, articulation video displays may better tap into mimetic capabilities, given that they provide dynamic, synchronized, multimodal display clues to temporal factors such as timing and sequencing. These temporal factors are, in principle, precluded from display via static graphics. Aichert and Ziegler (2004) examined factors affecting successful syllable production by persons with AOS and concluded that “results demonstrate that apraxic patients have access to the syllabary, but that they fail to retrieve the syllable motor patterns correctly” (p.148). In the current study, the 90% success rate of word completion associated with correct onset production with videos suggests that, 9 times out of 10, this participant accessed not only thesyllabary, but also the motor patterns associated with production of all syllabic constituents, individually and in concatenation. It may be worth investigating how such phenomena are related to speech entrainment (Fridriksson et al., 2012), with which they appear to share important elements in common. Although entrainment was not a part of the current study’s instructions or training, the autonomy afforded our participant during practice did not preclude entrainment, and we did on occasion observe her spontaneously though non-systematically opting to entrain (i.e., produce the word in unison with the stimulus).

#### Finding III – Frequency + Typicality Together

Finding III expands our use of syllabic onset typicality by combining it with spoken word frequency (Brysbaert & New, 2009) in a multidimensional analytical framework. The 2-by-2 matrix of Table 3 allows target words to be assigned to quadrants according to each target word’s pairing of these orthogonal linguistic properties of syllables, and this permits easy visual inspection of stimulus practice patterns by quadrants. Most striking are the behaviors posted in the two lower quadrants of Table 3, that is, where onsets are of lower typicality. These onsets comprise mostly consonant clusters. Where those target words are of relatively higher frequency in spoken English, we observe heightened levels of engagement overall, with both more attempts *in toto* and more attempts per target word, despite production challenges that are reflected in lower practice success rates. Arguably, such behaviors result from deliberate user choices to focus on relatively high-frequency words whose production is experienced as challenging; their mastery comes only through intensive practice and perseverance. Previous researchers have looked at how word production success in PWA/AOS is influenced by word frequency (Jefferies et al., 2006; Martin et al., 1996; Nozari et al., 2010). Other researchers have investigated the influence of the articulatory challenge of consonant clusters at the start of the target words on production initiation and production success (Aichert & Ziegler, 2004; Cholin et al., 2011; Laganaro, 2008; Staiger & Ziegler, 2008; Stenneken et al., 2007). Such prior investigations have not convincingly demonstrated the primacy of either factor when considered in isolation. In this context, the findings from the current study suggest analytical value in considering these factors in combination rather than singly. Additional focused research should help clarify how this combined analytical framework may be best exploited.

### Outcomes and Benefits

#### For Aphasia Researchers and Clinicians

Observational studies such as this one complement randomized controlled studies in aphasiology research, producing findings of different types that help shape future research. Observational studies do not establish treatment efficacy like randomized, controlled trials; nor do they probe intervention effectiveness, as do clinical outcome studies. When done well, however, they are advantageously positioned to flag and characterize unanticipated behavioral phenomena worthy of attention. For example, previous studies examining the clinical effectiveness of an SGD in delivering language therapy to PWA have focused on the use of technology broadly to present a variety of stimulus types (Aftonomos et al., 1997; Aftonomos et al., 1999). While these outcome studies demonstrated the benefits of including advanced technologies in aphasia therapy, they did not compare differences in response accuracy across stimulus types. The current study provides this level of comparison and generates hypotheses that may be explored in future research.

Ball et al. (2018) helped clarify how PWA engage with apps when working autonomously, choosing their own goals, and pursuing them in their own ways. Specifically, we showed that PWA did not adhere to instructions provided by SLP clinicians in a stimulated word-repetition task during autonomous practice, but rather that they engaged in a wide range of stimulation and practice behaviors, seemingly exploring the available experience space for various types of leverage that might increase success. The current analysis reveals patterns of behavioral decisions during autonomous practice that emerge for visual inspection when the associated data are spatially organized by syllable onset typicality and stimulus word frequency, considered conjointly. Engagement complexity arises because behavioral patterns during autonomous practice are not driven by individual factors operating in isolation, but by multiple factors that dynamically, complexly, and adaptively interact with one another.

#### For Assistive Technology Designers

For various reasons both clinical and economic, assistive technologies for persons with aphasia remain relatively immature. Yet there are significant opportunities still available for research, development, and commercialization of more technologically sophisticated products and services. The research presented here makes its contributions to the inventory of interaction designs, linguistic materials, and adaptive algorithms that should be considered for incorporation into future assistive technologies for PWA/AOS. Such applied research might probe, for example, whether it is possible to prolong overall user engagement times during autonomous practice through algorithmic sequencing of target stimuli to maintain overall success rates within some target range of percentages, using Table 3 as an initial reference. Independently, understanding the nature of the phenomena that promote successful full monosyllable production when onsets are correctly produced following video-based stimuli—but not drawing-based stimuli—seems a potentially useful target for future research, both to probe the extent of its reach—e.g., bisyllabic targets? longer?—and to explore systematic manipulation of the stimuli to influence performance patterns. Development and testing of such capabilities may reveal opportunities for adaptive algorithms to be developed for incorporation into personalized interactive therapy exercises capable of responding purposefully to performance improvement patterns that appear emergently during autonomous practice. App developers might use such findings to improve their offerings, to modulate the presentation of stimuli on principled bases, and to select upcoming stimuli based on observed patterns of strengths, challenges, recent improvements, and engagement behaviors of a particular user.

#### Limitations

As with all research, there are limitations to the current report. We report a case study, based on analyses of the performance of an adult female with moderate-severe aphasia and severe apraxia of speech. Only follow-on research can establish how widespread the reported phenomena are among PWA/AOS generally, a question of no small import. These findings emerge from an observational study, which in principle cannot provide explanations for the phenomena it reveals; only prospective, scientifically controlled research studies can address causality. In addition, this study is limited in that it only examined the ability of two particular stimuli presented via technology to facilitate correct productions in aphasia. Moreover, performance success was determined only at the impairment level (i.e., production accuracy). Clinical application will require future research to apply these findings and technology to an aphasia treatment paradigm. These studies should include measures of activity limitation, participation restriction, and quality of life in order to examine the impact of the treatment beyond impairment level outcomes such as percent correct.

#### Conclusion

The current report illustrates types of contributions that can emerge from an observational study by juxtaposing alternative human-computer interaction designs, analyzing linguistic properties of stimuli, and scrutinizing user behaviors during autonomous practice. It reveals several phenomena that merit follow-on research, to explicate underlying factors, demographic scope, and therapeutic uses. Broadly, one contribution from this study is the demonstration of how factors that have been studied singly in past research may exert unanticipated effects when studied conjointly. These may be either factors of a common type, such as linguistic (e.g., constituent onset typicality / word frequency), or of disparate types, such as linguistic and HCI-related (e.g., onset typicality / interface stimulus condition). The task at this point is to understand how best to extract and apply such emerging knowledge for the benefit of the PWA/AOS. Current findings suggest mechanisms for use in adaptive therapeutic algorithms, for instance, that might purposefully shape user time spent on task, performance success rates, and therapeutic difficulty structuring. We know that many PWA will be engaging with therapeutic technologies autonomously in the future; indeed, many are already doing it. For SLPs, app developers, and the PWA, it is important to understand how to continue improving user outcomes in a rapidly evolving world of processing and communication technologies.

### Declarations

This content is solely the responsibility of the author(s) and does not necessarily represent the official views of ATIA. The first author is an employee of Lingraphica, manufacturer of the equipment used in this study. Beyond this, no financial disclosures and no non-financial disclosures were reported by the author(s) of this paper.

### References

Aftonomos, L. A., Appelbaum, J. S., & Steele, R. D. (1999). Improving outcomes for aphasic patients in advanced community-based treatment programs. *Stroke, 30*(7), 1370–1379. <https://doi.org/10.1161/01.STR.30.7.1370>

Aftonomos, L. A., Steele, R. D., & Wertz, R. T. (1997). Promoting recovery in chronic aphasia with an interactive technology. *Archives of Physical Medicine and Rehabilitation, 78*(8), 841–846. <https://doi.org/10.1016/S0003-9993(97)90197-0>

Aichert, I., & Ziegler, W. (2004). Syllable frequency and syllable structure in apraxia of speech. *Brain and Language, 88*(1)*,* 148–159. <https://doi.org/10.1016/S0093-934X(03)00296-7>

Ball, A. L., de Riesthal, M., & Steele, R. D. (2018). Exploring treatment fidelity in persons with aphasia autonomously practicing with computerized therapy materials. *American Journal of Speech-Language Pathology, 27*(1S), 454–463. <https://doi.org/10.1044/2017_AJSLP-16-0204>

Biederman, B., & Nickels, L. (2008). Homographic and heterographic homophones in speech production: Does orthography matter? *Cortex, 44*(6), 683–697. <https://doi.org/10.1016/j.cortex.2006.12.001>

Brookshire, R. H. (1997). *Introduction to neurogenic communication disorders.* Mosby.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*, *41*(4), 977–990. <https://doi.org/10.3758/BRM.41.4.977>

Cholin, J., Dell, G. S., & Levelt, W. J. M. (2011). Planning and articulation in incremental word production: Syllable-frequency effects in English. *Journal of Experimental Psychology*, *37*(1), 109–122. <https://doi.org/10.1037/a0021322>

Centers for Medicare and Medicaid Services (CMS). (2014). *Medicare coverage document – speech generating devices*. <https://www.cms.gov/medicare-coverage-database/view/medicare-coverage-document.aspx?MCDId=26>

Dabul, B. (2000). *Apraxia battery for adults – second edition*. Pro-Ed, Inc.

Frattali, C. M., Thompson, C. K., & Holland, A. (1995). *Functional assessment of communication skills for adults (ASHA FACS).* American Speech-Language-Hearing Association.

Fridriksson, J., Hubbard, H. I., Hudspeth, S. G., Holland, A. L., Bonilha, L., Fromm, D., & Rorden, C. (2012). Speech entrainment enables patients with Broca’s aphasia to produce fluent speech. *Brain*, *135*(12), 3815–3829. <https://doi.org/10.1093/brain/aws301>

Goldrick, M., & Rapp, B. (2007). Lexical and post-lexical phonological representations in spoken production. *Cognition*, *102*(2), 219–260. <https://doi.org/10.1016/j.cognition.2005.12.010>

Goodglass, H., Kaplan, E., & Barresi, B. (2001). *Boston diagnostic aphasia examination – third edition.* Lippincott Williams & Wilkins.

Haley, K. L., & Jacks, A. (2014). Single-word intelligibility testing in aphasia: Alternate forms reliability, phonetic complexity, and word frequency. *Aphasiology, 28*(3), 320–337. <https://doi.org/10.1080/02687038.2013.855702>

Helm-Estabrooks, N. (2001). *Cognitive linguistic quick test.* The Psychological Corporation.

IBM Corporation. (2020). IBM SPSS Statistics for Windows (Version 27.0) [Computer software]. IBM Corporation.

Jefferies, E., Crisp, J., & Ralph, M. A. L. (2006). The impact of phonological or semantic impairment on delayed auditory repetition: Evidence from stroke aphasia and semantic dementia. *Aphasiology*, *20*(9), 963–992. <https://doi.org/10.1080/02687030600739398>

Katz, R. C. (2001). Computer applications in aphasia treatment. In R. Chapey (Ed.), *Language Intervention strategies in aphasia and related neurogenic communication disorders, fourth edition*, 718-738. Lippincott Williams & Wilkins.

Kertesz, A. (2007). *Western aphasia battery - revised*. The Psychological Corporation.

Laganaro, M. (2008). Is there a syllable frequency effect in aphasia or in apraxia of speech or both? *Aphasiology, 22*(11), 1191–1200. <https://doi.org/10.1080/02687030701820469>

Lomas, J., Pickard, L., Bester, S., Elbard, H., Finalyson, A., & Zoghaib, C. (1989). The communicative effectiveness index: Development and psychometric evaluation of a functional measure for adult aphasia*. Journal of Speech and Hearing Disorders*, *54*(1), 113–124. <https://doi.org/10.1044/jshd.5401.113>

 Martin, N., Saffran, E. M., & Dell, G. S. (1996). Recovery in deep dysphasia: Evidence for a relation between auditory verbal STM and lexical errors in repetition. *Brain and Language*, *52*(1), 83–113. <https://doi.org/10.1006/brln.1996.0005>

Nishitani, N., & Hari, R. (2002) Viewing lip forms: Cortical dynamics. *Neuron, 36*(6), 1211–20. <https://doi.org/10.1016/S0896-6273(02)01089-9>

Nozari, N., Kittredge, A. K., Dell, G. S., & Schwartz, M. F. (2010). Naming and repetition in aphasia: Steps, routes, and frequency effects. *Journal of Memory and Language*, *63*(4), 541–559. <https://doi.org/10.1016/j.jml.2010.08.001>

Porch, B. E. (1967). *Porch index of communicative ability*. Consulting Psychologists.

Roach, A., Schwartz, M. F., Martin, N., Grewal, R. S., & Brecher, A. (1996). The Philadelphia naming test: Scoring and rationale. *Clinical Aphasiology*, *24*(1), 121–133. <http://aphasiology.pitt.edu/215/1/24-09.pdf>

Staiger, A., & Ziegler, W. (2008). Syllable frequency and syllable structure in the spontaneous speech production of patients with apraxia of speech. *Aphasiology, 22*(11), 1201–1215. <https://doi.org/10.1080/02687030701820584>

Steele, R. D., Aftonomos, L. B., & Koul, R. K. (2010). Outcome improvements in persons with chronic global aphasia following the use of a speech-generating device. *Acta Neuropsychologica, 8*(4), 342–359. <https://actaneuropsychologica.com>

Steele, R. D., Kleczewska, M. K., Carlson, G. S., & Weinrich, M. (1992). Computers in the rehabilitation of chronic, severe aphasia: C-ViC 2.0 cross-modal studies. *Aphasiology*, *6*(2), 185–194. <https://doi.org/10.1080/02687039208248590>

Stenneken, P., Conrad, M., & Jacobs, A. M. (2007). Processing of syllables in production and recognition tasks. *Journal of Psycholinguistic Research*, *36*(1), 65–78. <https://doi.org/10.1007/s10936-006-9033-8>

Walker, G. M., & Schwartz, M. F. (2012). Short-form Philadelphia naming test: Rationale and empirical evaluation. *American Journal of Speech-Language Pathology*, *21*(2), S140–S153. <https://doi.org/10.1044/1058-0360(2012/11-0089)>