# USING INFORMATION COMMUNICATIONS TECHNOLOGIES TO IMPLEMENT UNIVERSAL DESIGN FOR LEARNING

## A working paper from the Global Reading Network for enhancing skills acquisition for students with disabilities


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# ABBREVIATIONS

| | |
|---|---|
| AAC | Augmentative and Assistive Communication Devices |
| ADHD | Attention Deficit and Hyperactivity Disorder |
| AI | Artificial Intelligence |
| AT | Assistive Technology |
| CAST | The Center for Applied Special Technology |
| CC | Creative Commons |
| CER | Comparative Effectiveness Research |
| CRPD | (United Nations) Convention for the Rights of People with Disabilities |
| CSR | Corporate and Social Responsibility |
| DPO | Disabled Persons Organizations |
| EGR | Early Grade Reading |
| EGRA | Early Grade Reading Assessment |
| FLOSS | Free/Libre Open Source Software |
| G3ICT | The Global Initiative for Inclusive ICTs |
| ICT4E | Information and Communication Technologies for Education |
| IEP | Individualized Education Plan |
| LMICs | Low and Medium Income Countries |
| MIC | Middle Income Country |
| MS | Microsoft |
| MTSS | Multi-Tiered System of Support |
| NGO | Non-Governmental Organization |
| PIADs | Psycho-Social Impact of Assistive Devices Scales |
| SEN | Special Educational Needs |
| SETT | Student-Environment-Task-Tools |
| TTS | Text-to-Speech |
| UDL | Universal Design for Learning |
| UN | United Nations |
| UNESCO | United Nations Education, Scientific, and Cultural Organization |
| UNICEF | United Nations Children's Fund |
| USAID | United States Agency for International Development |

## PURPOSE

The purpose of this paper is to assist Ministries of Education, their donors and partners, Disabled Persons Organizations (DPOs), and the practitioner community funded by and working with USAID to select, pilot, and (as appropriate) scale up ICT4E solutions to facilitate the implementation of Universal Design for Learning (UDL), with a particular emphasis on supporting students with disabilities to acquire literacy and numeracy skills. The paper focuses primarily on how technology can support foundational skills acquisition for students with disabilities, while also explaining when, why, and how technologies that assist students with disabilities can, in some applications, have positive impacts on all students' basic skills development.

In 2018, USAID released the Toolkit for Universal Design for Learning to Help All Children Read, section 3.1 of which provides basic information on the role of technologies to support UDL principles and classroom learning. This paper expands upon that work and offers more extensive advice on using ICT4E[1] to advance equitable access to high quality learning. Like the UDL toolkit, the audience for this guide is mainly Ministries of Education and development agencies working in the area of education, but this resource can also be helpful for DPOs and non-governmental organizations (NGOs) wishing to pilot or spearhead ICT initiatives.

Content for this paper was informed by expert interviews and reviews of field reports during 2018. These included programs associated with United Nations, Zero Project, World Innovation Summit, UNESCO Mobile Learning Awards, and USAID's All Children Reading: A Grand Challenge for Development. Relevant case studies of select education programs integrating technology to improve learning outcomes for students with disabilities were summarized for this document.

[1] Information and Communication Technology for Education (ICT4E) are tools and resources used to communicate, create, disseminate, store, and manage information in education. See glossary of USAID, *Defining Effective Education Programs Using Information and Communication Technology,* 2015.

# INTRODUCTION

In 2017, UNESCO declared a "learning crisis," with 617 million children and youth—two- thirds of whom had already attended many years of school—failing to demonstrate minimum, 4th-grade level proficiency in reading or math.[2] Clearly, formal and non-formal school systems around the world were failing to produce the most essential learning outcomes.

Recent global data on schooling experiences of students with disabilities paint an even more dire picture. The "learning crisis" is especially severe for children and youth with disabilities, and will remain so without significant additional effort by the global community. At least four out of ten primary-aged students with disabilities, or 40 percent, do not attend school at all; this percentage rises to at least 55 percent at the secondary level.[3] The few who do attend often do not have full access to information in classrooms. Even in contexts where high-level policies are in place to defend the educational rights of students with disabilities, available curricula, teaching and learning materials, professional development practices, and assessment routines are rarely disability-sensitive or coordinated such that instructors and administrators are truly able to address the learning needs of their students with disabilities. Despite being approximately 15 percent of the population, people with disabilities are not noticeably present in higher education classrooms or the general workforce,[4] which strongly suggests that they are not receiving the academic and professional preparation they deserve as children and youth.

Furthermore, students with disabilities are shaped by diverse experiences stemming from their social milieu. Physical accessibility, multimodal accessibility, communication opportunities, knowledge, language, and legal barriers all affect how a student with a disability can, or cannot, benefit from the schooling available in a given context. Students with disabilities also tend to be few in number and thinly dispersed, and this comparative isolation can have negative implications for learning. For example, more than half of all students who are blind have no classmates with similar challenges, and this may lead to students who are blind receiving sub-par educational services.

Increased adoption and use of technology-supported accessibility features not only promotes inclusion of people with disabilities in educational environments, but also enhances social, legal, and technical acceptance in the general community. Proactive, technology-assisted support to facilitate inclusion, to encourage interaction, and to amplify group communication can help "short-circuit" negative patterns of representation and retention of students with disabilities in education, with potential positive implications for greater participation of individuals with disabilities in society as a whole. The goal is not merely to increase inclusion for a few individuals, but to encourage all to thrive and grow.

In response to the severity of the learning crisis for children with disabilities, the United States Agency for International Development (USAID)—in its 2018 Education Policy—calls explicitly for the promotion of the Universal Design for Learning (UDL) framework in all partner countries and educational programs. At the heart of the UDL framework is the following set of principles for curriculum development and instructional practice:[5]

- Use of **multiple means of *Engagement***, wherein the tasks and approaches that most motivate each student to connect with learning are identified and leveraged;

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[2] UNESCO. "More Than One-Half of Children and Adolescents Are Not Learning Worldwide." *UNESCO Institute of Statistics,* Sept. 2017.

[3] Suguru Mizunoya, Sophie Mitra, and Izumi Yamasaki. "Towards Inclusive Education The Impact of Disability on School Attendance in Developing Countries." UNICEF Offce of Research-Innocenti. UNICEF, May 2016. www.unicef-irc.org/publications/pdf/IWP3 - Towards Inclusive Education.pdf.

[4] For more information, see UN Department of Economic and Social Affairs. *Factsheet on Persons with Disabilities*, https://www.un.org/development/desa/disabilities/resources/factsheet-on-persons-with-disabilities.html.

[5] Margaret King-Sears. "Universal Design for Learning: Technology and Pedagogy." *Learning Disabilities Quarterly,* 32(4) (2009): 199-201.

- Use of **multiple means of *Representation***, to afford all students every opportunity to encounter and interact with skills practice and curricular content through a mix of visual, auditory, tactile, concrete, representational, and abstract means;

- Use of **multiple means of *Action and Expression,*** empowering students to show what they know and what they can do through whatever means are easiest for them (i.e. allowing a student with ADHD to test using additional time).

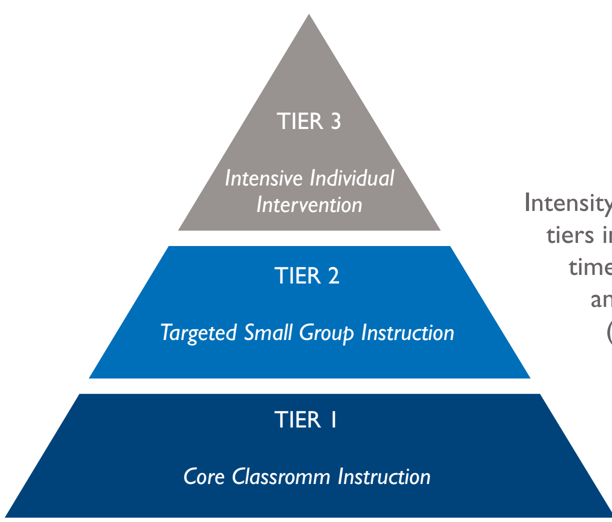
When used extensively and consistently, Universal Design for Learning enhances learning both for students with and without disabilities. **This paper makes the case that appropriate leveraging of sustainable educational technologies can accelerate uptake and application of UDL throughout education systems**.

**UDL: A Practical Example**

The word "universal" in the UDL framework emphasizes that the use of the framework has the potential to benefit all students. Universal design is a paradigm originally drawn from architecture, where adaptations such as curb cuts benefit wheelchair users, but also benefit the elderly, people with strollers, bicycle riders, etc. Examples of how technologies introduced in classrooms to support students with disabilities have ended up assisting all students include the way in which captioned videos and touchscreen (haptic) technologies intended to assist autistic students have now become popular with most teachers and students in integrated classrooms.

This paper suggests that teachers and administrators may find the Multi-Tiered System of Support (MTSS) model useful in operationalizing the principles of UDL through technology. This three-tiered system demonstrates how to increase the intensity of instruction in any format (i.e., whole class, small group, and/or individualized instruction), in order to meet the needs of students with widely varying abilities. Figure 1 shows the three tiers of the MTSS model that teachers can use to operationalize the UDL framework.[6]

FIGURE 1: Multi-Tiered System of Support Model




Intensity of instruction is embedded across tiers in terms of amount of instructional time, frequency of progress monitoring, and amount of practice in each session (Fuchs, Fuchs, & Malone, 2017). Individualization is embedded in terms of the application of UDL principals in a graduated decrease in the student-teacher ratio.

[6] Lynn S. Fuchs, Douglas Fuchs, and Amelia S. Malone. "The Taxonomy of Intervention Intensity." *Teaching Exceptional Children*, 50(1) (2017): 35-43.

Educational specialists have shown that MTSS can be particularly useful in operationalizing the three principles of UDL.[7] Based on their students' learning needs, teachers can analyze which modalities of student engagement, content representation, and student expression/action are most effective and appropriate for each of the three tiers. Through this analysis, they can improve the quality of instruction for their students with disabilities, and, by extension, for all the students in their classrooms.

Technology can play an important role in this MTSS and UDL "matrix analysis." In this paper, we focus on *information and communication* technology,[8] or technologies intended to support people of all abilities to problem-solve through seamless communication and the easy creation, dissemination, storage, and management of information.

In the paper, we consider three categories of technological tools for information and communication, as follows:

- **Majority Technologies:** Technologies like video projectors that are designed for general purpose use, and that may include no specific features to facilitate their use by a student with a particular disability. A standard video projector without an audio descriptor for students who are blind is an example of a majority technology.
- **Accessible Technologies:** Accessible technology is an umbrella term that includes products, equipment, and systems that provide persons with disabilities access to all services and content therein. These technologies have built in accessibility features that all students may use, but that teachers can easily leverage to address the learning needs of students with various disabilities. Speech-to-text apps, such as Google Live Transcribe or Live Captions, are examples of accessible technologies.
- **Assistive Technologies:** "Assistive Technology" is an umbrella term that includes products, equipment, and systems that enhance learning, working, and daily living specifically for persons with disabilities. Functionalities of assistive technologies are unlikely to be required for the majority of students in the general population. Computer apps that synthesize speech from text or devices, (such as Microsoft's Adaptive Controller or Apple's VoiceOver), which adapt to people with a wide range of dexterity abilities are examples of assistive technologies. The World Health Organization's 2016 priority list of assistive products, such as Braille notetakers, is highlighted in this document.[9]

Annex A outlines the features of accessible technologies and assistive technologies that support various categories of disability.

In the sections that follow, we present how, at each of the three tiers of the MTSS model, different types of technologies may be leveraged to enhance the application of UDL principles in classrooms. For example, teachers may be able, at the "core classroom instruction" level of the MTSS model, to employ majority technologies in creative ways to assist some students with disabilities, while also benefiting all students. With appropriate professional development, teachers can also learn how to leverage assistive

[7] Anne M. Hayes, Ann P. Turnbull, and Norma Moran. Universal Design for Learning to Help All Children Read: Promoting Literacy for Learners with Disabilities. United States Agency for International Development. 2018.

[8] International Labor Organization, "Learning and Training for Work in the Knowledge Society." Skills and Employability Branch (SKILLS). International Labor Organization, February 4, 2002.

[9] Braille is a tactile writing system for persons who are blind. It uses a code of six raised dots that can be felt with fingers to signify letters. Though it would be ideal for all individuals to be able to read and use Braille to encourage multiple modes of representing and understanding information, this has not yet been achieved in most high-income countries and may be even more challenging for low resource settings with low rates of basic literacy. Learning media assessments (see section 3.4.1 of the UDL toolkit) are used to determine which students would learn best using Braille.

technologies at the "individual, targeted instruction" level of the MTSS framework to help individual students with disabilities acquire foundational skills. Through careful planning, technology can greatly enhance teachers' ability to apply UDL principles while they organize their teaching according to the MTSS model.

USAID is committed to improving learning outcomes in all of its programs, in every context, with a focus on serving the most marginalized.[10] This commitment includes ensuring that children with disabilities have access to quality inclusive education. USAID also recognizes the value of ICT for education (ICT4E) as a means to enable effective learning experiences, and—in the case of learners with disabilities—as a means to provide access to communication, information, and practice that otherwise might not be possible. It is USAID's hope that this resource will enrich discussions in the development community about the identification, testing, and scaling of appropriate technologies for the implementation of UDL, and for enhancing skills acquisition among students with disabilities.

**Readers are encouraged to skim the following descriptions of the chapters in this paper, and to select in what order to read and use them, depending on their own contexts**. Introducing technologies to support learning for students with disabilities is a long-term endeavor. At different moments in this process, different aspects of this paper will serve different purposes for audiences wishing to accelerate the integration of different kinds of technology into their instructional routines. This paper is divided as follows:

- Part A of this toolkit discusses the interplay between the UDL framework and the MTSS model.
- Part B covers certain basic, essential concepts related to the use of technology, especially with students with disabilities.
- Part C introduces what the authors call the "Matrix Model," which is a model for reviewing and choosing options for technologies that could, in your particular context, enhance the application of UDL through the use of multiple instructional tiers.
- Part D discusses documented challenges to using ICTs that may affect your use of the "Matrix Model."
- Part E illustrates how the "Matrix Model" might be introduced in your particular technology implementation ecosystem.
- Part F discusses monitoring and evaluating the implementation of the "Matrix Model."
- Part G discusses future research and evaluation needed on the use of ICTs to benefit students with disabilities.

The paper's annexes provide a rich set of resources and strategies for integrating ICTs into education to ensure that learners with disabilities gain the academic skills they need.

[10] USAID. "USAID Education Policy." 2018. https://www.usaid.gov/sites/default/files/documents/1865/2018_Education_Policy_FINAL_WEB.pdf

## PART A: THE NEXUS BETWEEN UDL AND MTSS

USAID supports the use of UDL within its education programs, based on the premise that there is tremendous variability in how all children learn, and that they need to use all of the resources available to them to develop language fluency, literacy, and numeracy.[11] The UDL framework is a way to improve learning outcomes for all students, including those with disabilities.[12] UDL can be described as a "framework to improve and optimize teaching and learning for all people based on scientific insights on how humans learn." The three principles of UDL recognize that students are motivated to learn differently and receive and express information in a variety of ways.[13]

**UDL and ICT: The Big Idea**

Implementing UDL does not depend on access to technology. However, ICT can enhance the implementation of UDL principles in the classroom.

Although UDL was first introduced to support the learning of students with disabilities, it has been increasingly applied for broader educational and cross-cultural purposes, as it is a set of principles for curriculum development and instructional practices that can give all students (i.e. those with and without disabilities) equal opportunities to learn.[14] It reduces barriers in instruction and provides appropriate support for all students, while maintaining high achievement expectations for all.

FIGURE 2: UDL's Merger of Neuroscience and Learning Science

| BRAIN NETWORKS | UDL PRINCIPLES |
|---|---|
| ***Affective networks*** enable students to engage with the environment consistent with their emotions and proactivity. These brain networks drive how students get engaged and stay motivated. Affective tasks include how students are challenged, excited, or interested. | Multiple means of ***Engagement*** — the "why" of learning, or "the reasons and feelings that lead students to be motivated to learn." (Affect greatly impacts learning). Students diverge in the ways in which they can be engaged or **motivated** to learn. This UDL principle helps teachers present tasks that stimulate interest and motivation for learning, invoking a students' emotions and interests to provide a foundation for acquisition of skills. |
| ***Recognition networks*** enable students to perceive and understand input. These brain networks drive how students gather facts and categorize what they see, hear, feel, and read. Identifying letters, words, or an author's style are examples of recognition tasks. | Multiple means of ***Representation*** — the "what" of learning, or "how students best receive information or learn information." Students differ in the ways they perceive and comprehend information. This UDL principle helps teachers present information and content in different ways (visual, auditory, tactile, concrete, representational, abstract, etc.), increasing a teacher's chances of helping a student activate his/her cognitive recognition networks. |
| ***Strategic networks*** enable organization, action planning, implementation, and self-monitoring. These brain networks drive how students organize and express their ideas. Writing an essay or solving a math problem are strategic tasks. | Multiple means of ***Action and Expression*** — the "how" of learning, or "how students best express knowledge and what they have learned." Students differ in the ways that they can navigate a learning environment and express what they know. This UDL principle helps teachers present planning and performing tasks that differentiate the ways that students can express what they know. |

[11] Anne Meyer, David H. Rose, and David Gordon. *Universal Design for Learning: Theory and Practice*. Wakefield, MA: CAST Professional Publishing, 2014.; USAID, 2018.
[12] Kavita Rao, Min Wook Ok, and Brian R. Bryant. "A review of research on universal design education models." *Remedial and Special Education*, 35(3) (2014): 153-166
[13] For more information on UDL and its application in LMICs, visit the USAID Universal Design for Learning to Help All Children Read Toolkit: https://www.edu-links.org/resources/universal-design-learning-help-all-children-read
[14] Margaret King-Sears. "Universal design for learning: Technology and pedagogy." *Learning Disabilities Quarterly*, 32(4) (2009): 199-201.

This is possible due to the ways in which the use of UDL supports the development of different brain networks. Merging both neuroscience and learning sciences, UDL emphasizes the value of varying abilities, rather than dwelling on concepts of disability.[15] Figure 2 provides a summary of select brain networks and how the application of UDL principles can help them to develop.

While many teachers may understand the benefits of Universal Design for Learning for all students, it can be challenging at first to implement UDL in instruction. In this paper, we suggest "operationalizing" UDL by using the MTSS model (see Figure 1). Teachers can think about their learning objectives in literacy and numeracy, can use the data and knowledge they have about their students, and can then determine how to work with students at different levels of intensity and using different means of engagement, representation, and expression. This kind of analysis may help teachers make intentional choices about applying UDL in their classrooms, and may help ensure over time that all students demonstrate mastery of key skills and learning objectives.

Let's consider an example of aligning UDL with MTSS. Suppose that Mohamed, a 2nd grade teacher in Morocco, is using French to work with his class on identification of basic geometric shapes (circles, squares, triangles, rectangles, etc.) according to their properties (number of lines, number of angles, etc.). He knows that, for most of the students in his class, French is a foreign language. He has administered a pre-test and knows that the math concepts he wishes to teach are new material for almost the entirety of the class. In his classroom, he has three students with disabilities, including students who are deafblind and have an intellectual and learning disability. Figure 3 suggests ways in which, for each tier in the MTSS model, Mohamed could expand and vary the means of engagement, representation, and expression included in his lesson in order to multiply the opportunities for students with disabilities to learn. For the purposes of this analysis, **we do not yet incorporate technology** in this example.

It is important to note that the use of MTSS relies on several best practices that may develop slowly in certain contexts. These practices are described in the 2017-2018 Handbook on the Use of MTSS.[16] In well-resourced environments, they may include: a) universal screening for all students early in each school year (which must be conducted by a trained specialist), b) increasing intensity of support for those who are struggling, c) integrated plans that address students' academic, behavioral, social, and emotional needs, d) use of evidence-based strategies, e) a school-wide approach to student support, f) professional development so staff can deliver interventions and monitor progress, g) family involvement so parents can understand the interventions and provide support at home, and h) frequent monitoring of student progress. **While each of these may not be possible in each programming context, it is useful to begin to consider how to move towards these best practices in all environments, as they greatly support the application of UDL principles**.

[15] Anne M. Hayes, Ann P. Turnbull, and Norma Moran. Universal Design for Learning to Help All Children Read: Promoting Literacy for Learners with Disabilities. USAID. 2018.

[16] For more information on MTSS, visit the Handbook available at https://www.dvusd.org/cms/lib/AZ01901092/Centricity/Domain/8005/2017.18%20MTSS%20Handbook.pdf

FIGURE 2: UDL's Merger of Neuroscience and Learning Science

| MTSS TIER | MULTIPLE MEANS OF ***ENGAGEMENT*** | MULTIPLE MEANS OF ***REPRESENTATION*** | MULTIPLE MEANS OF ***EXPRESSION/ACTION*** |
|---|---|---|---|
| **Core Classroom Instruction** (all students) | Mohamed has his students use a long, closed rope to form a variety of shapes. Using ankles or wrists for vertices, his students experience how line segments are joined by vertices to create shapes.<br><br>Students work in small groups with each group being given a designated shape. They develop sentences about why their shape is especially important to learn about, in groups or individually. They write their story and read it to the class. | Mohamed puts up a Frayer model poster on the board. All students do four different representations of "CIRCLE": "Draw one,"- drawing the shape on the poster; "Make one," making the shape out of any available materials; "Find one," finding an object that has the shape; and "Show me," showing the shape with any body parts or movements.<br><br>Charts are posted around the room with a drawing of a geometric shape and name of the shape written in French and the primary languages of students. | Students create geometric artwork unknowingly by filling a page with intersecting lines.<br><br>Students have work sheets of geometric shapes. For each shape, they write the name in French and in their primary language using the charts as a guide and as a means of checking their accuracy. |
| **Targeted Small Group Instruction** | Mohamed gives a wood board with small nails in rows and columns to each small group of students. Using a string, the groups create a variety of shapes on the board, discuss the shape properties, and develop a poster of the shapes they create on the board.<br><br>A community volunteer sits with the small group and supports them in their language learning. She teaches them a riddle that they can share with their family and friends. | Mohamed provides groups with a variety of leaves, with opportunity for geometric construction. Each student in the group takes turns in creating, drawing or labelling shapes made using the leaves. The group uses Moroccan Sign Language to identify the shapes.<br><br>Students who have a diffcult time with French pronunciation listen to and/or see the teacher saying each word and immediately afterward repeat the word in a group exercise; when mistakes are made, group members provide assistance. | Mohamed has each group create a play or a path to express their knowledge of shape properties. The student who is deafblind and other students in the group create a raised path of a shape for movement.<br><br>Students who have diffculty independently completing work sheets play a card game that involves matching shapes and saying the name of the shape in French and their primary language. |
| **Intensive Individual Instruction** | The student who is deafblind learns the vocabulary for various shapes using tactile Moroccan Sign Language (MSL). Mohamed provides bridge activities where the student makes associations between tactile MSL and the names of the shapes in French.<br><br>The student who has an intellectual disability chooses the two shapes that she is most interested in learning about and concentrates on those. Students choose a peer tutor with whom they would most like to work. | Mohamed provides tactile objects of different shapes for the student who is deafblind for concrete experiences. For representational experience, Mohamed provides a set of card boards with shape outlines for the student who is deafblind to draw the shapes. The objects have Braille markers in French.<br><br>Students with disabilities are paired with a peer (who has the same primary language); the tutor reads posters in the primary language followed by the French pronunciation; the tutee says the French term and picks out each shape from a pile of wooden shapes. | The student who is deafblind demonstrates her knowledge by creating a variety of shapes in wet clay or flour on the table, the desk, or the floor.<br><br>Students work individually with a volunteer to find pictures of shapes in magazines and match the pictures with a word card; the card has the name of the shape in French on one side and in their primary language on the other side. |

It is a major premise of this paper that the introduction of appropriate ICTs can facilitate the analysis of how to use the MTSS framework to advance the implementation of UDL, and that this in turn will benefit students both with and without disabilities. It has long been established that using ICT in a UDL classroom enhances the learning of **all** students.[17] ICT can support the operationalization of all UDL principles, providing options for diversifying the means of engagement, means of representation, and means of action and expression used in any given class situation.[18]

Use of the UDL framework supports students in becoming purposeful, motivated, resourceful, knowledgeable, strategic, and goal-directed in society. ICT, used properly, lends itself to differentiation and accommodations across the three tiers of the MTSS framework, and can provide many options for UDL-based teaching in the classroom. In Part C, we describe in depth the use of ICT for students with disabilities, according to the MTSS framework, to maximize the application of UDL.

[17] David H. Rose, Ted S. Hasselbring, Skip Stahl, and Joy Zabala. "Assistive Technology and Universal Design forLearning: Two Sides of the Same Coin." Handbook of Special Education Technology and Research and Practice edited. (2005).

[18] David H. Rose, Jenna W. Gravel, and Yvonne M. Domings. "UDL Unplugged: The Role of Technology in UDL." Guilford Press. (2010).

## PART B: TECHNOLOGY AND STUDENTS WITH DISABILITIES: THE BASICS

Technology is often cited as a way for governments to better achieve the UN Sustainable Development Goals, including Goal 4: Ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.[19] The United Nations Convention on the Right of Persons with Disabilities (CRPD) recognizes the importance of technology in providing persons with disabilities with all of their rights. In its Article 9 on Accessibility, the CPRD recognizes the role of ICTs to improve access to information and communications. Furthermore, CPRD Article 32 on International Cooperation emphasizes the need for donors to provide "technical and economic assistance, facilitating access to and sharing of accessible and assistive technologies, and through the transfer of technologies."[20] General Comment No. 4 on the Right to Inclusive Education[21] also emphasizes the need for governments to develop innovative technologies to enhance the learning of children with disabilities, and the need to facilitate access to accessible and assistive technologies.[22]

**Expansion of ICT for Inclusive Education: The Big Idea**

Global investment in implementation of ICT4E has assured an uptick in the use of mobile and smartphone devices to research information and gain new skills. Still, despite research pointing to its benefits for facilitating learning, access to technology by children with disabilities remains limited worldwide. When relying on ICT4E to support inclusion, planners should ensure children in all disability categories benefit. Teachers and specialists can select technologies according to identified needs, and utilize these to enhance, rather than replace, their classroom-based learning.

For physical environments, evolving social compacts and legal mandates have led to the widespread development and deployment of universal access interfaces, even in some low and medium income countries (LMICs). These interfaces have evolved over time to serve the full continuum of abilities and differences among students with a broad range of disabilities. For example, the implementation of ramps and curb cuts for students has evolved not only to serve people with a range of mobility disabilities, but also those with vision disabilities. Curb cuts now have gentle slopes, as well as tread and striped markers that serve people with a range of mobility, visual, and tactile abilities. These universal accessibility interfaces aid not only students with disabilities, but also the general public, including those with situational needs. For example, a physical universal accessibility interface—such as a sidewalk ramp—benefits not only students with a permanent ambulatory disability (e.g., paraplegic) or those with temporary ambulatory disabilities (e.g., broken leg), but also students and others with situational needs (e.g., school worker delivering a heavy package with the help of a trolley).

ICTs can be an effective way to strengthen learning for all students, including students with disabilities, and they are also constantly evolving. Digital and computing interfaces have emerged, such as captions for students with hearing disabilities, and auditory descriptions for people with vision disabilities. In

[19] Technology's centrality to achieving Sustainable Development Goals was cited in the *United Nations' Addis Ababa Action Agenda of the Third International Conference on Financing for Development* on July 27, 2015. For more information see https://undocs.org/A/RES/69/313

[20] United Nations. "Convention on the Rights of Persons with Disabilities." 2006.

[21] This paper uses the definition of inclusion presented in the USAID Universal Design for Learning to Help All Children Read Toolkit. As such, inclusive education is defined as students with disabilities receiving an education in their local schools in the same classroom as their age-appropriate peers, with the supports and services they need to be academically successful. Like the UDL toolkit, this document also supports the World Federation of the Deaf definition of inclusive education for students who are deaf and hard of hearing, which ensures that students who are deaf or hard of hearing receive an education in a sign-language rich environment where they communicate directly with their teachers, peers, and administrators.

[22] United Nations. "General comment No. 4 on the right to inclusive education. Convention on the Rights of Persons with Disabilities." 2016.

the section that follows, we provide a brief review of findings on the use of technology in education in general, and then focus on major, relevant data about the use of ICTs to support learning for students with disabilities. We also highlight some of the gaps that exist in the use of technologies for students with disabilities between well-resourced and low-resourced contexts.

## B1. Evidence for ICT4E in Teaching Students With Disabilities

**For All Students**

- Research shows that using ICT4E as an educational tool can support learning for students with and without disabilities.
- In the U.S., studies conducted in several states showed significantly higher test scores and grades for writing, reading, and mathematics in classes where technology was employed appropriately.[23]
- Two-thirds of teachers who use video report that their students learn more when it is used, and 70 percent found that videos increase student motivation.[24]

**For Students With Disabilities**

- Accessible and assistive technologies, paired with a strong instructional paradigm like UDL, are effective tools to support learning. They facilitate access to information and increase communication and motivation for students with disabilities.
- Using a mix of technology and UDL has been shown to lead to a significant gain in vocabulary performance for students with and without disabilities as well as for bilingual students.[25]
- A comprehensive review of the use of assistive technologies with students with learning disabilities reported that the most effective applications included word processing, multimedia tools, and hyper-text, with smaller positive effects for speech-text systems.[26]
- The use of assistive technology with students with visual disabilities has been shown to improve many student outcomes related to academics and learning.[27]
- Both hearing and deaf students show significant academic gains when provided with subtitles/closed captions.[28]
- Students who are deaf/hard of hearing showed academic gains when provided with sequential text highlighting, available on digital learning materials or with tablets enabling touch-based interactions with their classrooms.[29]
- Deaf preschoolers using sign language developed early reading skills significantly when they used shared interactive storybooks with sign language videos.[30]

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23 Anthony Saba. "Benefits of technology integration in education." 2009.

24 Emily Cruse. *Using Educational Video in the Classroom:* Theory Research and Practice. (2013): 1-24.

25 Bridget, C Dalton. Patrick Proctor, Paola Uccelli, Elaine Mo, and Catherine E. Snow. "Designing for diversity: The role of reading strategies and interactive vocabulary in a digital reading environment for fifth-grade monolingual English and bilingual students." *Journal of Literacy Research*, 43(1) (2011): 68-100.

26 Bogi Perelmutter, Karla K. McGregor, and Katherine R. Gordon. "Assistive technology interventions for adolescents and adults with learning disabilities: An evidence-based systematic review and meta-analysis." *Computers & Education*, 114 (2017): 139-163.

27 Austin M. Mulloy, Cindy Gevarter, Megan Hopkins, Kevin Sutherland, and Sathiyaprakash Ramdoss. "Assistive technology for students with visual impairments and blindness." *Assistive Technologies for People with Diverse Abilities* (pp. 113-156). Springer, New York, NY. 2014.

28 Michael Whitney and Bryan Dallas. "Captioning Online Course Videos: An Investigation into Knowledge Retention and Student Perception." *In Proceedings of the 50th ACM Technical Symposium* on Computer Science Education, ACM (2019) 511-517; Joong-O Yoon and Minjeong Kim. "The effects of captions on deaf students' content comprehension, cognitive load, and motivation in online learning." *American annals of the deaf* 156, no. 3 (2011): 283-289.

29 Leandro Flórez Aristizábal, Sandra Cano, César A. Collazos, Andrés Solano, and Karin Slegers. "Collaborative learning as educational strategy for deaf children: a systematic literature review." Proceedings of the XVIII International Conference on Human Computer Interaction (Interacción '17). ACM, New York, NY, USA, Article 38 (2017).

30 Jean F. Andrews, Hsiu-Tan Liu, Chun-Jung Liu, Mary Anne Gentry, and Zanthia Smith. "Increasing early reading skills in young signing deaf children using shared book reading: A feasibility study." *Early Child Development and Care*, 187(3-4) (2017): 583-599.

**For Students With Disabilities**

- Students with intellectual disability and complex support needs demonstrated increased functional skills when exposed to flexible technologies that maximized their learning strengths and compensated for challenges.[31]
- Device designs based around mobile computing, touchscreen elements, speech recognition, and multichannel input are facilitating the connection of students with Down's Syndrome to the use of technology.[32]
- Multimedia books can be helpful to students with ADHD or other root causes of distractibility.[33]
- App-based interactive storytelling has been shown to be promising for literacy development with pre-school children in Kuwait.[34]
- Multimedia dictionaries that present the print and signed versions of a word, along with an image, have been shown to improve learning outcomes in Indonesia.[35]
- Adapted video gaming (that relies on elements other than sound) has been shown to be a promising route to increasing sign language and written literacy among deaf children.[36]

If used properly, and in support of an evidence-based instructional paradigm, ICTs can be an effective tool to support improved learning outcomes for all students. Technologies offer opportunities to develop skills in many settings, with potentially unrestricted access to learning materials, depending on licensing arrangements and basic inputs (like a user's access to electricity).[37] Within the last decade, for example, widespread growth in availability of smartphones and tablet devices has established a familiar, available, and accessible platform upon which to build, for all. Availability and familiarity have led to such devices supplanting traditional computers as the preferred means of accessing content. Usage rates of mobile accessible technology worldwide have increased faster than recent population growth in the United States and many other countries.[38] West and Chew (2014) comment that, "mobile devices are the most ubiquitous information and communication technology [ICT] in history. More to the point, they are plentiful in places where books are scarce."

Even in the high-income countries, technologies have played a critical role in the reduction of learning disparities. For example, Korea's online Cyber Home Learning System (CHLS) has been successful at increasing opportunities for isolated rural students. The system relies on a full broadband Internet infrastructure to provide tutoring and educational enhancement programs to reduce the imbalance of opportunities between urban and rural areas.

31 Michael L. Wehmeyer, Sean J. Smith, Susan B. Palmer, Daniel K. Davies, and Steven Stock. "Technology use and people with mental retardation." *International Review of Research in Mental Retardation*. Laraine Masters Glidden, ed.. San Diego, CA: Academic Press. 2003.

32 Vanessa G. Felix, Luis J. Mena, Rodolfo Ostos, and Gladys E. Maestre "A Pilot Study of the Use of Emerging Computer Technologies to Improve the Effectiveness of Reading and Writing Therapies in Children with Down Syndrome." *British Journal of Educational Technology* Vol 48 No 2 (2017): 611–624.

33 Ariana G. Bus, Zsofia K. Takacs, and Cornelia A.T. Kegel. "Affordances and limitations of electronic storybooks for young children's emergent literacy." Developmental Review 35 (2015): 79–97.

34 Asmaa Alsumait, Maha Faisal, and Sara Banian. "Improving literacy for deaf Arab children using interactive storytelling." Proceedings of the 17th International Conference on Information Integration and Web-based Applications & Services (iiWAS '15). ACM, New York, NY, USA, Article 7 (2015).

35 Andreas W. Yanuardi, P. Johannes Adi, and W. Alfeus Christantyas. "Multimedia sign language dictionary for the deaf and hard of hearing." *In Proceedings of the 5th International Conference on Rehabilitation Engineering & Assistive Technology*, p. 7. Singapore Therapeutic, Assistive & Rehabilitative Technologies (START) Centre, 2011.

36 Sandra Cano, Jaime Muñoz Arteaga, César A. Collazos, and Viviana Bustos Amador. "Model for Analysis of Serious Games for Literacy in Deaf Children from a User Experience Approach." *Proceedings of the XVI International Conference on Human Computer Interaction (Interacción '15)*. ACM, New York, NY, USA, Article 18 (2015).

37 Paul Kim, Elizabeth Buckner, Hyunkyung Kim, Tamas Makany, Neha Taleja, and Vallabhi Parikh. "A comparative analysis of a game-based mobile learning model in low-socioeconomic communities of India." *International Journal of Education*. vol. 32 (2) (2012): 329–340. Glenn Russell. "Trends in adolescents' use of information technology." Metro Education 11 (1997): 3.

38 Glenn Russell. "Trends in adolescents' use of information technology." *Metro Education* 11 (1997): 3.

**Growth of ICT Use in International Education**

The last few decades have shown an increased use of technologies in the classroom to support learning.[39] For example, the USAID-supported Technology Tools for Teaching & Training (T4) program used radio, video, computers, multimedia content, and the Internet to reach 42 million students in eight Indian states.[40] Another example is Interactive Radio Instruction (IRI), a relatively low-cost technology that has been shown to have a positive impact on learning through different approaches across many different countries.[41] ICT also provides an effective way to establish public-private partnerships. For example, a USAID-supported technology program in Pakistan has partnered with more than ten leading technology firms including Apple, Google, and Microsoft to improve access to instruction.[42]

For more than 20 years, there has been a consensus that educational technologies also offer promising opportunities to support skills building in literacy and numeracy for students in LMICs.[43] Throughout this time, agencies have invested and intervened to support the implementation of technologies in these contexts, with varying results. In more recent years, digital technologies such as computers, tablets, phones, and e-books are increasingly used in the Global South.

Hanemann (2014)[44] reviewed the evolution and availability of information and communications technologies used in the classroom, listing a range of technologies from radio, television, and audio and video recordings to more recent digital technologies including computers, tablets, phones, and e-books, and found growing access and availability *across countries where UNESCO is present*. This technology includes infrastructure such as satellite systems, network hardware, and software platforms including operating systems, and productivity software such as authoring solutions, video conferencing, or email.

USAID has been a leader in bringing appropriate educational technologies to LMICs, including through programs such as All Children Reading Grand Challenge for Development,[45] which has piloted 50+ applications of technology for teaching children to read in low-resource contexts. Through programming and research, USAID has supported mobile delivery of educational content, Internet-enabled computer labs, and IRI.[46] Digitally-based content to support literacy growth, such as online books and skill games, has been incorporated into early grade reading (EGR) programs to augment regular classroom learning.

**However, growing support for ICT applications, in both high-income countries and LMICs, has not translated into broad, instructional application of technology to benefit students with disabilities**. The WHO estimates that only 5-15 percent of individuals who require assistive devices and technologies have access to them.[47] Literacy rates and basic education completion rates among students with disabilities lag considerably behind those of other students, and gaps between students with and without disabilities have increased substantially over the last 30 to 40 years. This is

39 M.Behrmann, and J. Schaff. "Assisting educators with assistive technology: Enabling children to achieve independence in living and learning." *Children and Families* 42, no. 3 (2001): 24-28.

40 USAID. *Using Technology to Deliver Educational Services to Children & Youth in Environments Affected by Crisis and/or Conflict*. 2013. https://www.usaid.gov/sites/default/files/documents/2155/ICTs%20in%20Conflict%20Compendium%20FINAL.pdf.

41 USAID. *Defining Effective Education Programs Using Information and Communication Technology*. 2015.

42 USAID West Bank/Gaza. *Fact Sheet: Information and Communication Technology (ICT)*. 2013.

43 Mark Warschauer. *Technology and social inclusion: Rethinking the Digital Divide*. MIT Press. 2004.

44 Ulrike Hanemann. "Harnessing the Potential of ICTs for Literacy Teaching and Learning: Effective Literacy and Numeracy Programmes Using Radio, TV, Mobile Phones, Tablets, and Computers." UNESCO Institute for Lifelong Learning, 2014.

45 More on All Children Reading Grand Challenge for Development can be found at https://allchildrenreading.org/.

46 Sam Carlson and JBS International. Using Technology to Deliver Educational Services to Children and Youth in Environments Affected by Crisis and/or Conflict, 2014.

47 World Health Organization. "Assistive devices/technologies: What WHO is doing." (2017).

due to a lack of understanding about student needs, a shortage of trained teachers, and a lack of adequate facilities, classroom support, and learning resources, including technologies for learning support.[48]

This is in spite of the fact that research has shown that ICTs can help students with disabilities in LMICs better communicate, have better mobility, and better access information, instruction, and content.[49] In his literature analysis of various technological interventions in the classroom to support literacy outcomes for students with disabilities, Banes (2018) found that the use of technology, including accessible and assistive technology, can benefit students with disabilities by making the academic content available, accessible, and interactive for learning. Assistive technologies have also been shown to increase students' independence and self-esteem.[50]

Majority technologies can provide support for students with disabilities in skills practice and application, as well as in content creation. Accessible and assistive technologies have been shown to provide students with disabilities with greater access to information, and are proven to both facilitate knowledge expression and enhance the overall learning environment.[51] There is a range of low-tech devices (e.g., slide readers, colored acetates, page up holders, and pencil grippers) that should not be discounted as useful for people with a disability in LMICs, and may help students without disabilities as well. Digital technologies such as automatic speech-to-text apps like Google's Live Transcribe or Live Captions provide a flexible platform with features like these, upon which approaches to literacy and numeracy can be built. These technologies, individually or combined, offer opportunities to develop literacy and numeracy skills in any setting, and can provide potentially unrestricted access to learning materials.[52]

Spurred in part by governmental policy and financial incentives and requirements, the educational industry has developed a range of software and hardware options that make it easier for students with vision, hearing, speech, and other disabilities to communicate and learn. Furthermore, many students without disabilities also find these technologies invaluable. For instance, hearing students have become dependent on captions when they are used in class, and have protested if these captions are discontinued after a deaf student stops attending class. Similarly, some studies have found that sighted students have preferred eBooks with audio input, originally provided to classmates who were blind, to plain print books, since sighted students can also listen to audio e-books while driving or doing other tasks.

Due to the importance of assistive technologies to support education, many high-income countries, including the United States, establish separate policies that mandate access to appropriate assistive devices for students with disabilities. For example, the *Technology-Related Assistance for Individuals with Disabilities Act of 1988* grants federal funds to states so they can provide assistive devices to students with disabilities.[53] However, even in these resource-rich contexts, different kinds of public policies can sometimes work at cross-purposes. For instance, federal law in the United States stipulates that an assistive technology device can be defined as "any item, piece of equipment, or product system, whether

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48 Chata Male and Quentin T. Wodon. "Disability gaps in educational attainment and literacy (English)." *The Price of Exclusion: Disability and Education*. Washington, D.C: World Bank Group. 2017; UNESCO. Education and Disability: Analysis of Data from 49 Countries. 2018.

49 Cynthia M. Okolo and Jeff Diedrich. "Twenty-five years later: How is technology used in the education of students with disabilities?" *Journal of Special Education Technology, 29*(1) (2014): 1-20.

50 Janet Jendron. *Assistive Technology and Learning Disabilities*. (2011).

51 Loui Lord Nelson and Mindy Johnson. "The Role of Technology in Implementing UDL." *Handbook of Research-Based Practices for Educating Students with Intellectual Disability*, Michael J. Wehmeyer and Karrie Shogren, eds. New York, NY: Routledge. 2017.

52 Refer to the introduction in this paper for the difference between majority, accessible, and assistive technologies; Paul Kim, Elizabeth Buckner, Hyunkyung Kim, Tamas Makany, Neha Taleja, and Vallabhi Parikh. "A comparative analysis of a game-based mobile learning model in low-socioeconomic communities of India." *International Journal of Education*. vol. 32 (2) (2012): 329–340.

53 Ann P. Turnbull, H. Rutherford Turnbull, Michael L. Wehmeyer, and Karrie A. Shogren, *Exceptional Lives* (8th ed.). Columbus, OH: Merrill/Prentice Hall. 2016.

acquired commercially, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities."[54] Many U.S. health insurance plans, however, do not use this definition for "assistive technology devices," as it is so broad that it creates the possibility for reimbursement benefits for assistive devices to be almost entirely open-ended, which is not in the corporations' financial interest.[55] Therefore, the companies write their own, more restrictive definition for "assistive devices" that may significantly disadvantage some learners and people with disabilities.

In LMICs, when we consider the ICT landscape to support the application of UDL to improve literacy and numeracy acquisition for students with disabilities, challenges are apparent at the policy level, and beyond. ICT is not always considered in educational policies for students with disabilities. Where it is, the consideration may not address the fine-grain differences between majority, accessible, and assistive devices. Also, many kinds of educational technologies cannot be purchased or selected individually by students, and are in a certain sense public goods. Their development and accessibility often depend on policies that require public and private organizations to make learning more accessible and that promote research and development to make all sorts of technologies more usable and accessible to students with different abilities. This sort of policy environment is also often nascent or only partially formed in different country contexts around the world.

The development of a supportive policy context for the use of technology to advance learning for students with disabilities has often been slowed by systemic discriminatory factors, including ingrained ableism.[56] The fact that students with disabilities are often isolated, geographically dispersed, and underrepresented in education systems typically means that the evolution of policies focusing on applying ICTs to support skills acquisition for students with disabilities is slower than would be ideal for any individual student. Also, a tendency in low-resource contexts has been to focus on the application of low-tech devices to educational challenges. While this is understandable in the face of certain constraints (i.e. like frequent population migration or a lack of Internet connectivity), it has oriented attention away from responding to those students with disabilities who may need access to a comparatively high-tech device to best support their learning. Change, however, is possible. The case study below provides an example of how federal laws in one country spurred a massive uptake in the use of a fairly easy-to-replicate technology.

**Accessible Content – Brazil Case Study**

There are around 360 million deaf people around the world, and 80 percent of them do not understand the spoken and written language of their respective countries. In Brazil, the HandTalk product has been developed as a response. The service consists of two main products: the Website Translator, a very practical tool that solves the lack of accessibility problem with a simple click and has become popular in Brazil due to federal laws that require a percentage of television content to be signed, not just captioned. After the Translator activation, the user is introduced to Hugo, a friendly interpreter program, that translates the website's Portuguese text to LIBRAS, also known as Brazilian Sign Language. Besides this, HandTalk also has an app that works like a pocket translator. The mobile app has already been downloaded more than 2 million times and translates voice and text automatically from Portuguese to LIBRAS. It also has a LIBRAS dictionary function for academic vocabulary, which is very useful for deaf students during the schooling process.

**Source:** For more information, see www.handtalk.me

54 For more information see: https://uscode.house.gov/view.xhtml?req=granuleid:USC-1999-title29-section3002&num=0&edi on=1999.

55 AAPM&R, The Foundation for PM&R (American Academy of Physical Medicine and Rehabilitation.) *Access to Assistive Technologies Improving Health and Well-Being for People with Disabilities*. (2003):9.

56 Ableism is discrimination and social prejudice against people with disabilities or who are perceived to have disabilities.

## B2. Principles of Using ICT with Students with Disabilities

Although technology can play a key role in supporting skills acquisition for students with disabilities, it is essential to keep in mind certain principles as one guides and supports the provision of technology to support students with disabilities. These principles build upon the "10 Key Principles for Developing ICT in Education Programs"[57] supported by USAID, and also address specific elements related to technology and students with disabilities. These principles also build upon the core principles of literacy acquisition for all students presented in the USAID Toolkit on Universal Design for Learning to Help All Children Read. (See section 3.1.1 of the toolkit for more information). These principles are:

- **Technology should not be medicalized for people with disabilities; instead, it should be designed to be as universal and inclusive as possible**. For instance, in the United States, Medicare will not pay for inclusive apps such as a text-to-speech app on a consumer phone but will pay for a far more expensive single functional medical device for text-to-speech generation. The single functional medical device will not be widely available due to expense and lack of updates.

- **Technology can benefit all children and youth with disabilities; provision of technology should not be prioritized or pursued based solely on a disability label**. All children can learn, and all children have value. Provision of technology should look to support learning gaps and expand technology access in a manner that strengthens the overall education system. Technology access should not be provided in a way that prioritizes one disability category over others.

- **Technology can be an important tool to enhance education, but it does not replace other foundational skills[58] that students with disabilities require to be academically successful**. It is important that technology be provided in a way that augments, but does not attempt to replace, many of the foundational skills that students with disabilities must acquire in order to obtain literacy and numeracy. While more and more service and product designers are incorporating accessible technology into their educational products to ensure that their products are becoming more inclusive and universal, the teaching role continues to be essential.

*For example, although subtitles/closed captions for videos can support students who are deaf and hard of hearing to access auditory content, they do not replace the need to learn and communicate directly using local sign languages with peers and trained professionals who are fluent in sign language. Likewise, while there are several technologies that are helpful for students who are blind, such as text to voice software and audiobooks, research shows that learning to read and write in Braille is still needed to understand spelling and how text is formatted.*[59]

- **Technology is *not* a substitute for trained teachers and specialists**. Professionally trained teachers and high-quality instruction are essential to student success. In order to adapt or customize technology to best support students with disabilities, teachers need to be able to identify learning needs and assess how technology can help augment instruction. As stated by Intel's President, Dr. Craig Barre, "computers aren't magic; teachers are."[60]

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57 For more information, visit the 10 Key Principles for Developing ICT in Educational Programs available at https://www.usaid.gov/sites/default/files/documents/1865/E1-FP_ICT_Compendium.pdf.

58 USAID defines foundational skills as reading, math, and social and emotional learning. This paper is mainly focused on reading and mathematics.

59 American Foundation for the Blind. "Braille." 2018.

60 Craig Barrett. *Keynote Address Paper* presented at the National Educational Computing Conference (NECC), Atlanta, Georgia. (2000).

- **Technology should be accompanied with appropriate training on how to use the device to support learning**. Technology provision without appropriate training can result in ineffective use or inappropriate selection of technologies for specific children. For example, due to misperceptions, in many LMICs children with low vision, including those with albinism, are often taught literacy in Braille but could benefit from having access to large text. All teachers, including general and special education teachers and specialists must be taught not only use of the technology, but also how to select the most appropriate technologies to serve the needs of specific students.[61] Younger children's responsiveness to selected technologies may be factored into any adjustments in approach.

- **Accessible and assistive technologies for students with disabilities should be individualized to the specific learning need of the student; not all technologies are applicable for all students with the same disability label**. Determining a student's accessible and assistive technology needs is an individualized process. All students, even those that share the same disability label, learn differently. As students are individuals, it is important when pairing students with possible technologies to consider the individualized needs of students with disabilities, including their strengths, challenges, and motivations. It is also important to consider: a) what accessible and assistive technology devices will be used, b) how accessible and assistive technology will be used across home, school, and community environments, c) how the student, teachers, and parents will be trained on accessible and assistive technology, and; d) how accessible and assistive technology will be monitored and evaluated. This ideally would be captured through a more comprehensive evaluation and included within a student's individualized education plan (IEPs). For more information on evaluation and IEPs, please see Sections 3.2.2 and 2.3.1 of the UDL Toolkit.

**There is No Magic Wand:**
**Challenges and Lessons Learned in MICs and LMICs with Technology**

As use of educational technology becomes more prevalent in MICs and LMICs, the international community is learning that large edtech investments may not yield the desired results if a system's absorptive capacity for new technology is limited. For example, in Peru, the InterAmerican Development Bank (IDB) invested in the OLPC program, but did not achieve measurable impacts on reading or math outcomes because integration of the laptops into classroom routines was variable.[62] Similarly, the OLPC initiative in Ethiopia prepared a $2 billion request to the World Bank to procure laptops for every primary grade child in the country. However, the nationwide provision of sets of six textbooks, instead of provisions of the laptops, would have only cost 4 percent of that amount.[63] These experiences demonstrate that, while technology is a tool with catalytic capabilities, it cannot replace other fundamental components of education and may not always be the most cost-effective option. Budgeting should include research and a robust monitoring and evaluation system tied to learning outcomes, to ensure that technology provision is approached effectively and efficiently, for all students.

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61 Michael J. Kennedy and Joseph R. Boyle. The Promise and Problem with Technology in Special Education: Implications for Academic Learning. *Handbook of Special Education*. James M. Kauffman, Daniel P. Hallahan, and Paige Cullen Pullen, eds. (2017): 606-615. New York, NY: Routledge, Taylor & Francis Group.

62 Eugene Severin, Ana Santiago, Julian Cristia, Pablo Ibarraran, Jennelle Thompson, and Santiago Cueto. Evaluation of the "Una Laptop Por Nino" Program in Peru: Results and Perspectives. InterAmerican Development Bank: Washington, D.C. (2011).

63 EuGuest Writer. "12 Consideration in Designing ICTs to Better Support Children." 2013. https://www.ictworks.org/12-considerations-in-desiging-icts-to-better-support-children/#.XJYv8qR7lUR.

# PART C: THE "MATRIX MODEL" AND TEACHER PROFESSIONAL DEVELOPMENT

In this section, we propose a method by which teachers and education stakeholders can consider:

- The three principles of Universal Design for Learning;
- The evidence base and principles for the application of technology to instruction for students with disabilities (also see the previous section); and
- The MTSS model to make choices about the use of ICTs on behalf of a wide range of students, including those with disabilities.

Teachers and educational leaders who use this method will be able to employ the UDL framework to ground decision-making and select ICT tools that will support variable instructional strategies in their classrooms.[64]

**The Matrix Model: The Big Idea**

Decisions about technology should be driven by student ability and need. By using both the UDL principles and the MTSS model, teachers can identify the majority, accessible, and assistive technologies school systems and classrooms should make available. Intensive professional development and in-class support will likely be needed to help teachers integrate the use of these technologies.

Although every teacher and group of stakeholders might use this method differently, the steps to implementing this will likely resemble the following:

1. Gather data on skill levels and abilities of students in a given class, school, or district.
2. Use that information to determine, according to the MTSS model, which students will complete certain segments of the curriculum, mostly through the "core instruction" tier of the model (Tier 1), which students will need targeted small group instruction (Tier 2), and which students will need individual intensive instruction (Tier 3).
3. To the degree possible, work with a range of colleagues, (including, as needed, those outside the school), to determine which students in need of either Tier 2 or Tier 3 instruction **are also** students with disabilities.[65] *Note that Tiers 2 and 3 of the MTSS model are **not always** exclusively reserved for meeting the needs of students with disabilities.*
4. Based on a review of which students have been identified for which tiers of support in the MTSS model, and their particular needs for engagement, representation, and expression (the three pillars of the UDL framework), consider what needs and options arise for the use of ICTs in instruction. Those technologies may be either majority, accessible, or assistive, depending on the students' characteristics.

[64] Loui Lord Nelson, and Mindy Johnson. "The Role of Technology in Implementing UDL." *Handbook of Research-Based Practices for Educating Students with Intellectual Disability*. Michael Joehmeyer and Karrie Shogren, eds., New York, NY: Routledge. 2017.

[65] Screening and identification of students with disabilities is not the job of the classroom teacher. See the UDL toolkit for additional information about screening and identification.

The steps above are inspired by a proven approach to integrating ICT4E into classroom instruction, known as the TECH approach.[66] TECH stands for:

> Target the students' needs and learning outcomes
>
> Examine the tech choices, then decide what to use
>
> Create opportunities to integrate ICT4E with other technology activities
>
> Handle the implementation and monitor the impact of student learning

This TECH approach recommends the following steps:

- **Step 1:** Match the technological content to specific curricular outcomes.
- **Step 2:** Match student's use of technology to the purpose of the student's learning needs.
- **Step 3:** Use age-appropriate ICT4E that does not draw attention to student's disability/ies.
- **Step 4:** Consider low-tech, less-expensive options and use them if they address the purposes of instructional activities and support the student's strengths and needs.

The result of this four-step process, captured on paper, could be a "matrix" as in Figure 4.

FIGURE 4: "Matrix Model" of ICT4E-Supporting All Students with Disabilities

| MTSS TIER | MAJORITY TECHNOLOGY | ACCESSIBLE TECHNOLOGIES | ASSISTIVE TECHNOLOGIES |
|---|---|---|---|
| **TIER ONE: Core Classroom Instruction**<br>This tier represents technologies that can support core classroom instruction for all children. | Technologies that are widely used in the classroom. Examples include electronic boards, computers, laptops, tablets, or other mobile devices. | Devices that are designed for accessibility for students with disabilities that are eventually beneficial for all classroom instruction (e.g., text to speech functions, speech to text or captioning functions).<br><br>Devices and functions specifically designed for students with disabilities, and may also benefit all students (e.g., highlight or magnifier functions). | Lecture notes/visual aids shared to students via individual devices that allow students to customize their screen to fit their needs. |

*continued on following page*

[66] Margaret E. King-Sears and Anna S. Evmenova. "Premises, principles, and processes for integrating TECHnology into instruction." *TEACHING Exceptional Children, 40*(1) (2007): 6-14.

| MTSS TIER | MAJORITY TECHNOLOGY | ACCESSIBLE TECHNOLOGIES | ASSISTIVE TECHNOLOGIES |
|---|---|---|---|
| **TIER TWO: Targeted Small Group Instruction**<br>This tier represents technologies that can help facilitate instruction in a small group. | Technologies that promote small group instruction (e.g., group chat, group discussion board, apps that promote group work, shared multimedia folders). | Technologies that include accessible features, such as a speech to text function, for small group instruction.<br><br>Shared features can also benefit small group instruction. For example, changing color contrast settings within tablets or mobile devices for students with low vision can help those students follow along with a small group. Highlight functions for students with learning disabilities can do the same. | Technologies that are used in group activities where students with disabilities use specialized assistive features that are appropriate for small group instruction (e.g., shared communication pictorial technologies). |
| **TIER THREE: Intensive Individual Instruction**<br><br>This tier represents technologies that support a focused intervention. | Technologies (i.e., tablets or software programs) that include customized features where the student can make modifications appropriate for this individual instruction.<br>Individualized learning programs (e.g., ST Math; Khan Academy) that allow individuals to practice until they master the desired set of knowledge and/or skills. | Technologies that provide accessible content and service appropriate for the student in individualized instruction.<br><br>"**e**-individualized" learning programs that provide accessible content (digital accessible content), such as digital storybooks where deaf students can read a story bilingually. | Examples of specialized technologies specifically designed for students with disabilities, including Braillers.[67] |

The "Matrix Model" for selecting technology for education reinforces that **all** children can benefit from using technology to enhance learning, which in turn reflects the UDL core assumption that, when modalities of engagement, representation, and expression are suffciently diversified, all students, including those with disabilities, benefit. When using the model, stakeholders can seek to invest in: a) technologies that can benefit **all** students, and then, also, b) any accessible or assistive technologies needed to make instruction profitable for a given student or group of students with certain disabilities.

This "Matrix Model" recommends developing financial and human resources management systems that support ICT4E across all the MTSS tiers to the greatest extent possible. If investment is only made in majority technologies for core classroom instruction (Tier 1), then the opportunities to support UDL through technology will be reduced, and the positive impacts on all students, including those with disabilities, will be fewer than if resources are used to support progress in technology integration across all tiers and ICT types in the matrix.

[67] A Brailler is a "Braille typewriter" with a key corresponding to each of the six dots of the Braille code, a space key, a backspace key, and a line space key. It is used for individuals with vision disabilities.

**Resources for Additional Technology Options**

It is important to remember that one technology can support multiple types of disabilities, although some technologies will require higher levels of skills and resources to be implemented effectively.

Annex A provides a detailed matrix of technologies and functions, and their uses for multiple disabilities.

The following websites include glossaries of assistive technologies and open source technologies, or guidance on how to use technology to inform literacy and numeracy instruction.

www.cast.org
www.edutopia.org
www.readingrockets.org
www.stmath.com
www.teachthought.com
www.thetechedvocate.org
www.understood.org

A useful glossary of assistive technologies is housed on the Center on Technology and Disability's website: www.ctdinstitute.org.

A collection of open source assistive technologies can be found at www.openassistive.org.

Of course, the success of using the "Matrix Model" will depend in large part on the care with which the technologies selected under each tier are chosen, and then, on the care with which they are integrated into classroom and school processes. ***Ensuring that people with disabilities participate as active stakeholders in making these decisions at the individual and policy levels will likely promote useful and cost-effective technology development, integration, and investment across the tiers and technology categories in the "Matrix Model."*** High-quality teacher professional development to support the integration of technology into classrooms under the model will also be essential. Teacher professional development is addressed in Section C6.

## C1. Technologies for MTSS Tier 1 (Core Instruction)

Mainstream, or majority, technologies provide a foundation upon which access to literacy and numeracy can be built. Many technologies have inherent accessibility features that can easily assist students with and without disabilities and incur no additional costs. Many companies such as Microsoft strive to embed accessibility features throughout all of their software. Accessibility features like color filter customization or high-contrast settings (which can help students with low vision better access text) or filters that remove distracting format or content from websites can be helpful for individuals with autism or learning disabilities.[68] Such features can also help students who are color blind and students without disabilities who are easily visually distracted. Many computer- or tablet-based technologies can be customized to directly support the needs of a variety of students, including those with disabilities.

Using the principles of UDL, Figure 5 provides examples of how technologies in Tier 1 can support the literacy and/or numeracy learning of all students, followed by a case study that describes the use of a majority technology to reach children with a wide range of disabilities among marginalized students in India.

[68] Microsoft. "Microsoft accessibility overview." 2019. https://docs.microsoft.com/en-us/windows/uwp/design/accessibility/accessibility-overview.

FIGURE 5: Technology Options for Core Classroom Instruction

| UDL PRINCIPLE | TECHNOLOGY OPTIONS |
|---|---|
| **Multiple Means of Engagement** (what motivates students to learn) | • The Internet can allow for students to research information and obtain new perspectives that are not always available through the use of traditional print materials.<br>• Radios or audio tape recorders can provide information in different ways, such as learning concepts through music.<br>• Online games, puzzles, and chat can encourage students to interact with words and numbers, and to play with language and numbers, practicing and generalizing skills.<br>• Videoconferencing increases connection between students and teachers globally, and can be either synchronous or asynchronous. Both kinds of videoconferencing facilitate interactive learning and cross-cultural understanding among diverse groups.<br>• Synchronous, real-time, group video-conferencing enables students to participate in enrichment activities (such as virtual field trips to museums) and supports connections between peers and mentors who are widely dispersed. All types of video-conferencing also support quick connectivity with tutors and mentors anytime, who can, in turn, use other technologies to allow students to be engaged in the tutoring experience from a distance. |
| **Multiple means of representation** (how students learn best) | • Online videos can provide demonstrations of concepts that are difficult to demonstrate in a LMIC classroom.<br>• Tablet-based materials allow for students to easily access and link to vocabulary or learn new terminology.<br>• Text to speech functions allow students to hear words in spoken language as they learn to decode the text (accessible technology).<br>• Screen color background and image modification (i.e., black background with yellow fonts) allows students who are low vision and color blind to see projected information better. |
| **Multiple means of action and expression** (how students communicate what they learn) | • Tablets can allow students to draw pictures of concepts using different colors and techniques, even in environments that lack art supplies.<br>• Using a keyboard may be easier for some students to produce text than holding a pen (assistive technology).<br>• Word completion software will help students select the correct spelling as they type. |

**CASE STUDY: Tier 1 Technology Example – Sesame Workshop India Radiophone**

Sesame Workshop uses technology to improve literacy (vocabulary, storytelling, wordplay, sound discrimination); numeracy (problem-solving, numbers and counting, cause and effect); healthy habits; and physical, social, and emotional health in marginalized children, including children with disabilities. The project model is based on the idea that low-cost technology solutions, combined with entertaining, relevant content, are effective in educating children, families, and communities. Sesame's Radiophone uses a combination of community radio and telephone-based systems to deliver content through Galli Galli Sim Sim (GGSS, the Indian Sesame Street). The content addresses parents, teachers, and the community on the importance of girls' education and health, and encourages discourse on the social development needs of marginalized families.

Preliminary results from research, conducted using an ethnographic qualitative and participatory methodology with the community radio stations, show that communities are increasingly discussing issues around community participation (28 percent), the Galli Galli Sim Sim radio program (23 percent), and improvements in their own capacity and skills (20 percent). Three-month data shows that 32 percent of stories document "changes in the quality of life" in listeners, and 32 percent mention "changes or improvements in children's learning levels." 12 percent of these stories also document changes in practice and behavior for those participating in three months or more of exposure to the radio show. The project is exploring various sustainability strategies, such as having listeners pay to access the GGSS content.

**Source:** Wise Qatar 2018; Shilpi Kapoor – Barrier Break India

## C2. Technologies for MTSS Tier 2 (Targeted Small Group Instruction)

ICT4E can be an effective way to make targeted small group instruction effective for groups of students both with and without disabilities. Small group instruction is used to reinforce or reteach specific skills and concepts, and provides a reduced student-teacher ratio. ICT4E can provide accessible information or communication platforms to students in groups to work together. Many technologies have inherent accessibility features (e.g., group messaging and Google folder sharing) that can be used for students and incur no additional costs. It incorporates features that allow users to personalize their group experience to address their needs. Accessible design not only supports users with a defined disability, but also supports those experiencing barriers due to setting or context, especially in small group instruction.

Using the principles of UDL, Figure 6 provides examples of how technologies in Tier 2 can be adapted to support students with additional learning needs and students with disabilities, while also benefiting students of all abilities. The case study that follows demonstrates how an accessible technology is being used to support learners of differing abilities in South Africa.

FIGURE 6: Technology Options for Targeted Small Group Instruction

| UDL PRINCIPLE | TECHNOLOGY OPTIONS |
|---|---|
| **Multiple Means of Engagement** (what motivates students to learn) | • Videos with subtitles/closed captions allow for students who are deaf and hard of hearing to obtain additional information visually, while also providing motivation for students with learning disabilities, complex support needs, and intellectual disability.[69] Automatic subtitles/captions allow students to make their videos accessible for all (accessible technology).<br>• Multimedia technology features can allow students to combine high-quality video, text, and graphics on screen and then print and display these as their group projects. For example, a group of students might create a collaborative project that includes a sign language video, a written text, and graphics (majority and accessible technology).<br>• Technology allows students to contribute to group activities with group communications functions (i.e., group messaging), and role assignment features (i.e., a random assignment wheel), that allow equal participation based on their needs and capacity (majority technology). |
| **Multiple means of representation** (how students learn best) | • Audio books can support learning for students with learning disabilities and students who are blind/low vision. Students without disabilities also benefit from this (accessible technology).<br>• Mind maps can help students with dyslexia understand related concepts in language. Such maps help everyone in the group organize and communicate the information effectively (majority technology).<br>• Text to sign allows students to click on text and see words in sign language as they learn to decode the text (accessible technology). |
| **Multiple means of action and expression** (how students communicate what they learn) | • Google's voice typing software is free and works on all google documents and allows for students who have writing challenges to express themselves using spoken language with automac dictation to text (assistive technology).<br>• Spelling and grammar checks can support students with dyslexia who may have challenges with spelling and basic grammar. Word prediction software can help students to construct sentences helping to extend their vocabulary (majority technology).<br>• Augmentative and assistive communication devices (AAC) allow students with limited communication abilities and students who are autistic to communicate using pictures (assistive technology). |

[69] For adults who are DHH, please note that this accessibility feature should only be used as a last resort, as individuals may have limited ability to comprehend text depending on their background and upbringing.

**CASE STUDY: Tier I Technology Example – Sesame Workshop India Radiophone**

DionWired allocates its full corporate social investment budget, through Edit Microsystems, towards investment in SMART Technology and Clicker literacy software for children with disabilities. Since 2011, the DionWired Special Needs project has been working in more than 15 schools around South Africa, selected through a stringent needs and capacity assessment. DionWired schools received Clicker 6 literacy software, which can be used by students of all ages and abilities, including those with dyslexia, learning difficulties, and physical disabilities. Edit Microsystems is accredited to provide installation, support and teacher training to each school, as well as monitor and evaluate the implementation of the technology. Lessons and resources for Clicker can be downloaded, modified, and even created from scratch by teachers, and shared amongst other teachers over the Internet.

Following the success of the project, the Western Cape Department of Education has adopted this model in its own pilot project. Using the *Clicker 6* literacy program, the South African Sign Language (SASL) Project has implemented Clicker in all schools for the deaf that offer SASL as a subject. Clicker 6 has been shown to be an excellent tool for teaching and learning sign language. The project illustrates the value of framework programs which offer teachers the opportunity to create content that can be tailored to individual needs.

**Source:** For more information about DionWired, see www.dionwired.co.za/dionwired/en

## C3. Technologies for MTSS Tier 3 (Intensive Individual Instruction)

Many students with disabilities benefit from more specialized technologies that go beyond the accessibility features present in majority technologies. These specialized technologies, (referred to as assistive technologies), can be defined as any tool or equipment, both low and high tech, that can be used to increase, maintain, or improve the functional capabilities of children with disabilities.[70] Although assistive technologies are usually initially developed for a specific population, they can, in turn, benefit other populations. Examples of assistive ICT4E for individualized learning are touchscreen gestures and drawings, augmentative and assistive communication devices (AAC), and academic sign language website or apps for individualized instruction (see Figure 7 for other examples).

Evidence highlights the educational benefits of using assistive technology, especially for students with disabilities. Historically, however, there has been limited application of these technologies in LMICs. There are many reasons why uptake of such technologies has been limited. Lack of awareness and information about such technologies has been one barrier, and the high cost of some technologies has been a factor in many countries. Successful implementation of these technologies to support literacy and numeracy learning also requires teachers to be able to assess the individualized needs of students with disabilities (including their strengths, challenges and learning motivations), as well as to be able to then pair students with particular technologies (See section C6). A case study of an application of an assistive technology accompanied by intensive teacher training and coaching appears at the end of this section.

[70] U.S. Department of Education, Office of Special Education Programs (OSEP). *Individuals with Disabilities Education Improvement Act of 2004*. IDEA 2004.

FIGURE 7: Technology Options for Intensive Individual Instruction

| UDL PRINCIPLE | TECHNOLOGY OPTIONS |
|---|---|
| **Multiple Means of Engagement** (what motivates students to learn) | • Electronic worksheets can support students with learning disabilities to complete assignments.<br>• Accessible multimedia activities allow students to engage with text in the form that they prefer.<br>• Smart speakers and voice interaction allow pupils to operate with concepts at a much higher level than is achievable with print alone. |
| **Multiple means of representation** (how students learn best) | • Braillers and refreshable Braille displays can be used for students who are blind or DeafBlind to read text.<br>• FM radio transmitters and induction loops can increase the volume of, and isolate, the teacher's voice so that students who are hard of hearing can better access instructional information.<br>• Websites/apps in subject areas (e.g., mathematics, science, social studies) in sign language allow deaf and hard of hearing students to learn academic content effectively. Some hearing students who are visual students can benefit from learning this way.<br>• DAISY talking books can synchronize text with speech output representing meaning in an integrated manner. Symbols can augment text for readers who benefit from visual representation of concepts. |
| **Multiple means of action and expression** (how students communicate what they learn) | • Augmentative and Alternative Communication (AAC) Devices, tools that help supplement or replace speech or writing for individuals who struggle to communicate in traditional ways, allow students with complex communication needs to communicate what they have learned using symbols or text-to-voice software.<br>• Alternative keyboards can support students with mobility disabilities or motor planning challenges to better express information.<br>• Switches combined with an onscreen keyboard can allow students to select letters, words, and phrases regardless of level of physical ability. |

**CASE STUDY: Providing a Range of Technologies in the Classroom – Macedonia**

The "Active Inclusion" project, conducted by Close the Windows Macedonia, introduced assistive technologies, computer-assisted communication, and other accessible technologies into selected primary schools, along with training of teachers. The assistive technology was adapted according to the needs of each child. For example, one 10-year-old boy who attends an inclusive class received a laptop, a wireless mouse, a mini keyboard with keyguard, a five-button adapter, and alternative assistive communication software. Teachers attended training sessions that were led by inclusive education specialists, and the project team promoted networking and knowledge transfer through exchange visits between educational institutes in participating countries, groups on social media, email, and partnerships with University of St. Cyril and Methodius in Skopje, the University of Novi Sad, the University of Athens, and LIFEtool Austria. Two educational software solutions were developed to teach basic reading, writing, and math skills. They are available in Macedonian and Albanian.

As a result of the project, assistive technologies were introduced to 10 percent of Macedonian primary schools (31 schools countrywide) and two secondary schools, as well as six primary schools in and around Novi Sad, Serbia. As of 2018, approximately 360 pupils now use assistive technology in schools in the two countries. The investment allowed over 90 percent of those with a disability to access a computer through assistive devices and software adjustments. 1,300 teachers were trained in accessibility and Inclusive Education. The majority of these teachers were observed applying individualized teaching methods with students with disabilities following their training.

**Source:** www.openthewindows.org

## C4. Technology Experiences to Inform the Use of the "Matrix Model" for Literacy and Numeracy Instruction

**Literacy and Numeracy Definitions**

*For the purposes of this paper:*

**Literacy** is defined as the ability to use an appropriate and diverse set of literacy materials to learn concepts and to express those concepts through different means. Literacy definitions need to allow for flexible, multisensory approaches and for students to use a variety of technologies (both low and high tech) to help them gain and communicate learning on an individual basis.

**Numeracy** is the ability to use numbers and solve problems in real life applications. With it comes the confidence and skill to use numbers and apply mathematical concepts in daily lives or work. Children start to develop numeracy as soon as they develop literacy. They learn numeracy as they grow up, in and outside the classroom.

As teachers and educators begin using the "Matrix Model" to consider how best to deepen their use of UDL in their contexts by leveraging majority, accessible, and assistive technologies, they will want to become more informed about recent similar experiences in a variety of environments. In this section, we provide examples of how technologies have recently been used to strengthen students' literacy and numeracy outcomes. Hopefully, these program experiences will inspire readers to use the "Matrix Model" to enhance skills acquisition for students with disabilities (and, by extension, all students) in their contexts.

Examples of recently developed innovations to support the development of **literacy** for students with and without disabilities include:

- All Children Reading Grand Challenge for Development publishing and Reading Book tools – **Bloom, Storyweaver**, and **World Around You** – provide a simple user-friendly platform for communities to publish their own reading and viewing materials in languages they use and understand. The books in Bloom (bloomlibrary.org) and Storyweaver (storyweaver.org.in/prathambooks) can be downloaded in the .pdf version for offline reading and are accessible to all students with disabilities, especially those who rely on text-to-speech features. They, however, do not have sign language videos.

- **World Around You** has interactive signed stories for deaf children worldwide (deafworldaroundyou.org). Recently, the Global Digital Library (GDL) https://www.digitallibrary.io/ has also begun to explore providing sign language versions of the open source reading content.

- **Interactive Storytelling Tools** – The strength of the parent-child interpersonal relationship is one of the primary predictors of a child's literacy. Most early vocabulary development comes from a child's interaction with a parent or parental figure. Interactive storytelling tools used between a parent and child support that vocabulary development. Acquisition of language is especially important for children who are deaf and deafblind. Some examples of interactive storytelling tools tailored to students with disabilities are Canales and VL2 StoryBook App.

- **Bookshare** – Bookshare is the world's largest online library of accessible ebooks for people with print disabilities. The Bookshare India Project, for example, provides students with low to no vision in Maharashtra access to simple technologies and high-interest books with Marathi audio and hard-copy Bharati Braille. The project also supplements guided and independent reading practices (Benetech Technology Inc., 2017, p. 14 ).[71] School to School International evaluated the Bookshare India Project and found that students who participated in the project showed significant gains across EGRA subtasks from baseline to endline. This trend was observed across gender, grade, and vision status. The platform does not have sign language videos.

- **Kinetic Stories: Gesture Recognition Technology in Children's Interactive Storybook** – The gesture recognition feature allows children to interact with a storybook with full-body gestures. Kauppinen et al. (2013)[72] conducted a case-study involving 4- to 6-year-old children to demonstrate that gesture-based interactive storybooks maintain excitement among young children to read and hear the stories. The study found children have potential to become an active part of the storytelling experience. This can also benefit students with disabilities who rely on gestures to communicate. As of this writing, the product is still in the prototype stage.

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71 For more information on Bookshare and the evaluation results, see https://benetech.org/wp-content/uploads/2017/09/Benetech-ACR-Final-Report-082117.pdf.

72 Sami Kauppinen, Satu Luojus, Julius Tuomisto, and Anu Ahlgren. "Utilizing Gesture Recognition Technology in Children's Interactive Storybook." Proceedings of International Conference on Making Sense of Converging Media(AcademicMindTrek '13), edited by Artur Lugmayr, Heljä Franssila, Janne Paavilainen, and Hannu Kärkkäinen. ACM, New York, NY, USA (2013).

- **Jot-a-Dot Technology** – Jot-A-Dot is a pocket-size mechanical Brailler weighing less than 500 grams. It features direct six key Braille entry for speed and accuracy. It has both line and cell indicators. The cell indicator shows the position of the embossing head on the line, and the line indicator gives instant feedback on which line you are writing. The student can read as he/she writes. It is portable and can be carried with a neck strap. It can sit stable on hard surfaces with its built-in reading stand. This technology is only good for those who use Braille. School to School International evaluated this technology with primary students who are blind and low vision in Lesotho and found that the students felt more engaged when using the Jot-a-Dots and felt that it improved their reading (All Children Reading, 2017, p. 11).[73]

- **www.psl.org.pk** – This web-based platform, developed by the Deaf Reach program of the Family Education Services Foundation in Pakistan, integrates video to support text, providing deaf children across Pakistan access to digital learning resources in Pakistan Sign Language (PSL). The platform features a 5,000-word visual lexicon in both English and Urdu on a searchable Web portal, DVD, and Phone app. It also has stories in PSL and a book that contains translations from PSL into the four main regional spoken languages. The findings have demonstrated that the use of this technology has a significant impact on the development of literacy skills among children who are deaf.

- **SmartSignPlay** – Chuan et al. (2016)[74] developed this tablet-based interactive game. SmartSignPlay is digitally based, and provides context-award and interactive education about the sign languages of daily use and things. The application requires children to follow the path of a sign in the form of a couple of static images. After following the path, the users will get immediate feedback on their sign language. The application aims to make users learn the sign language by trial and error. This product helps students learn stand-alone signed words and phrases.

- **Strategic Reader** – CAST created Strategic Reader, a technology-based system blending UDL and Curriculum-Based Measurement in a digital learning environment, to improve reading comprehension instruction. Hall et al (2014)[75] highlighted in their analysis of the use of Strategic Reader with students with learning disabilities that: "The real innovation in the Strategic Reader, then, is not the technology per se but rather how teachers effectively use Strategic Reader to spark interactive and meaningful learning. The success of the Strategic Reader project may help provide guidance for future policies, along with having especially innovative potential for learning materials for students with disabilities. Reading environments such as this one that leverage new technologies to support teachers can help ensure that every student is highly engaged in meaningful learning and practice that optimize his or her development as a skillful student." The combination of technology and UDL in the study led to all participating students demonstrating large and statistically significant increases on Gates- MacGinitie[76] pre- to post-scores.

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73 All Children Reading. *Supporting Technology-Based Innovations to Improve Early Grade Reading Outcomes for Students Who Have Low Vision or are Blind* (2017). https://sts-interna onal.org/wp-content/uploads/2018/12/wherewework_acr_content2.pdf.

74 Ching-Hua Chuan, and Caroline Anne Guardino. "Designing SmartSignPlay: An Interactive and Intelligent American Sign Language App for Children who are Deaf or Hard of Hearing and their Families." *Companion Publication of the 21st International Conference on Intelligent User Interfaces (IUI '16 Companion)*. ACM, New York, NY, USA (2016): 45-48.

75 Tracey E. Hall, Nicole Cohen, and Ge Vue. "Addressing Learning Disabilities with UDL and Technology: Strategic Reader." *Learning Disability Quarterly* 8 (2). (2015): 72-83.

76 Gates-MacGinitie Reading Tests enable schools to determine students' general levels of vocabulary and reading comprehension. To locate the test, check http://www.nelson.com/assessment/classroom-GMRT.html.

Examples of recently developed innovations to support the development of **numeracy** for students with and without disabilities include those listed below.

- Common tools and adaptations for mathematics classrooms, including:
  - **Calculators** – Calculators can help simple and complex math problems. Calculators with large buttons with large numbers and symbols can benefit young children, including students with disabilities.
  - **Talking Calculator app** – This app speaks button names, numbers, and answers aloud through a customizable built-in directory that lets users record their own voice.
  - **Dictation** – Dictation lets students write out math problems by speaking. For instance, math notation tools sometimes allow for dictating equations.
  - **Electronic math worksheets** – These are software programs that can help a user organize, align, and work through math problems on a computer screen. Numbers that appear on screen can also be read aloud via a speech synthesizer. This may be helpful to people who have trouble aligning math problems with pencil and paper.
  - **Game apps** – There are numerous apps that promote numeracy. Some apps provide captions.
  - **Graph papers/screens** – These have an electronic grid. For students who have low or no vision, there are voice-over descriptions of what they have been working on.
  - **Math notation/equation tools in MS Word** – These let students write or type out the special symbols and numbers used for math equations. Writing out these equations by hand can be challenging for people who have trouble writing numbers and symbols.
  - **Paper-based computers or apps** – This technology records and links audio to what a person writes, using pen and special paper or an app. It enables the user to take notes while simultaneously recording someone speaking (e.g., a teacher). The user can later listen to any section of his/her notes by touching the pen to his/her corresponding handwriting or diagrams or using the app.
  - **Text-to-speech (TTS)** – TTS reads aloud numbers and calculations. When used for math, TTS is often combined with other tools, like a talking calculator.
  - **Touchscreen technology** – Touchscreens allow students with disabilities to manipulate the information on a touchscreen. High functioning children with autism work with this technology for basic numeracy learning processes well.
  - **Free gaming websites and apps**, such as mathgames.com – These help children play in order to learn numeracy skills.

- The **Nemeth Braille Code** is a math code for encoding mathematical and scientific notation linearly, using standard six-dot Braille cells for tactile reading. The most significant difference between Nemeth Braille and standard literary Braille, besides the new symbols, is the use of context-dependent rules that require shifting back and forth between the Nemeth code and the literary code. Students who need braille will need to be exposed to, and formally instructed in, the Nemeth Code at an early age, at the same age-span when their sighted peers learn numbers.

- **The DIAGRAM Center** by Benetech, creators of Bookshare, offers free quarterly webinars for content creators on image description and accessible math, as well as other topics.

- **Global Math Project** – The Global Math Project is a worldwide movement committed to inspiring teachers everywhere to ignite and sustain a love for learning mathematics.[77] It provides some novel mathematical lessons, such as Exploding Dots, which can be accessible for all students, including students with disabilities.

- **IXL** – Developed by IXL Learning, this is a cost subscription platform to deliver an individualized and deeply engaging learning experience to students. It covers more than 3,700 distinct math topics from kindergarten through grade 12 (www.ixl.com). It meets the unique needs of each student by providing individualized guidance and real-time analytics. It is not tested in developing countries.

- **Khan Academy** – Khan Academy provides a free, personalized learning platform that can be used by anyone, anywhere. It offers practice exercises, instructional videos, and a personalized learning dashboard that empower students to study at their own pace, in and outside of the classroom. It holds a library of instructional videos in mathematics, science, computer programming, history, art history, economics, and more. In the math category, Khan Academy guides students from kindergarten to calculus using state-of-the-art, adaptive technology that identifies strengths and learning gaps. As of this writing, it is exploring the possibility of integrating sign language videos into the platform.[78]

- **MyScript Calculator** – The MyScript Calculator app allows students to write down equations freehand. Its handwriting recognition system allows users to write down equations and have the app calculate results. MyScript supports basic arithmetic, as well as percent, square roots, trigonometric (and inverse) functions, and many more. The app is free for download. It benefits those who might struggle with holding a pencil or pen, and who struggle with typing equations using the keyboard.

- **Spatial-Temporal (ST) Math** – MIND Research Institute developed ST Math (stmath.com), a fully visual instructional program that builds a deep conceptual understanding of math through rigorous learning and creative problem solving. The program is intended to engage, motivate, and challenge preschool to 8-year-old students toward higher achievement. According to their website: "ST Math starts by teaching the foundational concepts visually, then connects the ideas to the symbols and language. With visual learning, students are better equipped to tackle unfamiliar math problems, recognize patterns, and build conceptual understanding. Without language barriers, the problem is accessible to all students, regardless of skill level or language background." ST Math has not been tested internationally. It is a subscription cost program and does not provide voice over or descriptions for students who have low vision or no vision.

[77] "Global Math Project." Global Math Project. https://globalmathproject.org/. Accessed October 29, 2019
[78] For more information see Khan Academy at https://www.khanacademy.org/

- **Sugarlabs** – Sugar (sugarlabs.org) is an activity-focused, free/libre open-source software (FLOSS) learning platform for all students. The platform contains a library of hundreds of learning activities and games that introduce students to mathematics, programming, computational thinking, and problem solving. Students can reshape, reinvent, and reapply both software and content into powerful learning activities. Sugar's focus on sharing, criticism, and exploration is grounded in the culture of free software.[79]

In some cases, teachers may have an opportunity to participate in, or to give input to, the processes by which technologies, from majority to assistive, are chosen for classrooms. In cases like this, the Student Environment Task Tools (SETT) framework can assist in guiding teacher decision-making.[80] This framework helps teachers and educational teams to create Student-Centered, Environment-aware and Task-focused Tools systems that foster educational success for students with disabilities.[81] An introduction to the SETT framework, which is highly compatible with the principles of diversified modalities of engagement, representation, and expression called for in the Universal Design for Learning paradigm, can be found in Annex B.

### C5. Procuring Technologies Included in a "Matrix Model"

With expert support, it is possible to devise a minimum package of technologies for the UDL classroom that can reach a broad range of students, including students with complex needs. Annex C describes key steps in setting up a procurement process, and provides detailed questions on infrastructure and maintenance. These steps and questions will assist in identifying potential technology-related constraints specific to any given context, such as limited power outlets, or limited capacity locally to repair or replace cracked screens.

A technology procurement might also include a request to convert existing literacy and numeracy learning content into accessible content, in order to enable its use on accessible or assistive devices. Assistive technologies often come in the form of add-ons to majority technology solutions, and less often in the form of individualized solutions. It will be important that any technology procurement reference any required accessibility functions of technologies to be purchased for classrooms. For example, a common error found in literacy programs is the lack of text to speech options in the language of instruction. Specifying a need for this technology **at the procurement stage** can "fast-track" its provision. In addition, procurements should clarify the disability category(ies) and learning functions that requested technologies are intended to support. See Annex A for more information on the features of different technology categories; those details and that content can easily be copied from this paper into a procurement document.

It is important to identify what local sources are available for procurement, and to find out if they have sole vendor or distributor rights within the market. Local vendors may be listed directly on a given manufacturer's website. There may be options to secure activation codes for software, where the software is downloaded from the web directly. Increasingly, software for mobile devices is only available through an online marketplace such as the Apple App or Google Play stores. The very low cost of such apps might lend itself to providing funding to a school or district to download and install such apps, rather than purchasing a tool that fulfills the same functions through a separate Request for Proposal.

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79 For activities, see http://activities.sugarlabs.org/en-US/sugar/.

80 Joy Zabala. "The SETT Framework Revisited." *SETTing the stage for success: Building success through effective selection and use of assistive technology systems.* (2006).

80 Joy Zabala. "A Brief Introduction to the SETT Framework." (2002).

Many NGOs and DPOs could develop a local industry for fabrication of hardware devices and peripherals, as they have engaged in other mobility aid manufacture, if seed funding were available. Such enhanced provision could include development of services based upon 3D printing of aids and appliances to support specific needs. These services would then have the capacity to market themselves more broadly, beyond the education sector.

### C6. Professional Development and School-Community Support for the Integration of ICT

The UDL Framework and the "Matrix Model" we have presented here, and the technology examples above, can all help promote the use of ICT to improve learning outcomes for students with disabilities. However, merely filling out the MTSS-based matrix and sorting needed technologies into three tiers of instructional practice will not be sufficient to leverage the power of ICT to bolster students' literacy and numeracy skills. **For the use of the "Matrix Model" to result in actual skills building, the majority, accessible, and assistive technologies placed in the matrix in a given context will need to be fully integrated into teachers' professional practice**.

The three primary areas of capacity building necessary for ICT4E are: a) the ability to identify students' learning needs, b) the ability to understand the content and subject, and c) the ability to apply ICT4E as a tool to deliver content in tandem with the principles of UDL. Figure 8 includes useful questions for preparing professional development programs that will build teachers' capacity to use to use ICTs to apply the UDL principles.

FIGURE 8: Gap Analysis for Designing Teacher Capacity-Building Programs for Integration of ICT4E into Classrooms

**Teacher and School Staff Professional Development**

- Are teacher professional development needs identified and addressed to build capacity within schools, assisting teachers to understand needs, content, and potential uses of the technology?
- Are a variety of means of delivery of teacher professional development available and blended?
- Are appropriate sources of additional on-demand training identified and distributed?
- Are the training needs of students and families considered and met?
- Are social networks and communities of practice available and supported to sustain learning?

**Technology Matching**

- Do teachers understand how to match needs to technology to support literacy and numeracy learning?
- Is there an agreed-upon framework to identify student needs, which also includes analysis of the environment, the technology, and the tasks to be completed?
- Does the process of identification of needs and accommodations factor in the range of possible technologies available to meet student needs?
- Do teachers have a source for further advice where technologies are insufficient to address students' needs?
- Are students with a disability encouraged to be engaged in the selection of suitable technologies for their needs? Is this strategy encouraged through policy?

**Technology Support**

- What sources of technical support in customizing ICT4E are available?
- Are school staff provided the training and knowledge to address frequent IT issues and act as the initial technical support when technology goes wrong?
- What is the repair and replacement mechanism for technologies that do not operate as expected?
- Are there teacher-to-teacher support networks to disseminate fixes to common problems?

**Research and Further Development**

- Is feedback from teachers, students, and families gathered to consider the impact of use of technology in improving literacy and numeracy?
- Does feedback inform product development cycles for the future?
- Are new and emerging accessible technologies reviewed and considered for future implementation to support students?

The long-term success of using the "Matrix Model" to select ICT resources for literacy and numeracy teaching may depend not only on the quality of the teacher professional development, but also upon the degree to which the families and communities that rely on their school have an opportunity to support the implementation of technology-enhanced education. Alongside teachers, families can play an instrumental role in helping to select the best technologies for their child, maintaining and caring for the technologies at home, and using the technologies at home to reinforce learning that takes place at school.

Educating parents on how ICT4E can improve the education of their children improves their ability to advocate on their child's behalf, so that their child can gain access to the most appropriate technologies available in his/her community and country context. Likewise, communities can also be a helpful resource in the procurement and repair of assistive technologies. Families and communities should reach out to DPOs and disability leaders who can provide advice and input based on their first-hand experience of having a disability.

Implementing the TECH and SETT processes described here, and conducting gap analyses of teachers' ability to operationalize the UDL principles through technology-informed use of the MTSS tiers, can all be complex. These efforts will be more successful and have a greater impact on learning for students with disabilities if family and community members are associated with the technology selection and teacher professional development processes from the start.

# PART D: CHALLENGES TO INTEGRATION OF ICTs IN SUPPORT OF INCLUSIVE EDUCATION

No paper proposing the use of a new matrix with which to make choices about technologies to enhance the use of UDL in literacy and numeracy instruction would be complete without a consideration of the challenges likely to arise in diverse contexts during and after the technology selection process. In this section, we consider those challenges, and in the next section, we explore a model of technology ecosystems that might assist in overcoming some short-term and long-term challenges over time.

**Reorienting constraints to ICT4E towards inclusivity: The Big Idea**

Ministries of Education, development partners and industry need more information on appropriate technology and learning outcomes from current deployments to orient inclusive education policy, strategy and the market towards priority assistive technologies, effective design for learning, and reduction of provision and maintenance costs. The "Matrix Model" presumes a country is overcoming local/sub-regional infrastructure and skilled specialist gaps, which are factors in technology choice and sustainability. Uneven adoption exacerbates inequities between and within disability sub-communities and overall.

General constraints working against the large-scale integration of technology in education in LMICs are well-documented. A recent study stated that, "Educational technology will continue to be implemented incrementally in many parts of the developing world. More rapid uptake and success are unlikely to occur unless five items are addressed – power, Internet connectivity and bandwidth, quality teacher training, respect and better pay for teachers, and the sustainability of implementations."[82] In Bangladesh, one study found that factors that influenced the implementation of technology in education included poor administrative support, lack of appropriate training for teachers and principals, a lack of qualified ICT coordinators to assist teachers in integrating ICT in the classroom, and a receptive school culture.[83] Similarly, Snoeyink and Ertmer (2001) found that primary barriers to implementation of educational technology included lack of equipment, reliability, technical support, and other resource-related issues. Secondary barriers included school-level factors such as organizational culture and teacher-level factors, such as beliefs about teaching and technology and openness to change.

There are additional challenges related to the planning for, and provision of, accessible and assistive technologies for students with disabilities. They include:

- **Lack of research on the appropriateness of technology:** Due to the fast pace of development, technologies are often placed on the market without undergoing rigorous research.[84] As a result, special and general education teachers often make choices and use technologies without empirical input on the appropriateness of the selected tools.[85] Studies show that teachers are defaulting to the technologies that are most accessible and that make them most comfortable, with obvious negative consequences for some students.[86]

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82 Clayton R. Wright. "5 Key Barriers to Educational Technology Adoption in the Developing World." Educational Technology Debate. 2014. http://edutechdebate.org/2014-ict4edu-trends/5-key-barriers-to-eductional-technology-adoption-in-the-developing-world/

83 Shahadat Hossain Khan, Md., Mahbub Hasan, and Che Kum Clement. "Barriers to the introduction of ICT into education in developing countries: The example of Bangladesh." *International Journal of Instruction 5*(2) (2012): 61-80.

84 Michael J. Kennedy and Joseph R. Boyle. The Promise and Problem with Technology in Special Education: Implications for Academic Learning. *Handbook of Special Education*. James M. Kauffman, Daniel P. Hallahan, and Paige Cullen Pullen. eds. (2017): 606-615. New York, NY: Routledge, Taylor & Francis Group.

85 Michael J. Kennedy. Multimedia instruction: The runaway train spontaneously changes direction and speed. *DLD New Times, 31*(3) (2013): 1-3.; Naomi Zigmond. "Reading and writing in co-taught secondary school social studies classrooms: A reality check." *Reading and Writing Quarterly, 22*(3) (2006): 249-268.

86 Emily C. Bouch, Sara Flanagan, Bridget Miller, and Laura Bassett. "Rethinking everyday technology as assistive technology to meet students' IEP goals." *Journal of Special Education Technology, 27*(4) (2012): 47-57. ; Dave L. Edyburn. "Critical issues in advancing the special education technology evidence base." *Exceptional Children, 80*(1) (2013): 7-24.

- **Challenges of measuring impact of interventions:** There are several barriers to accurately measuring the impact of a specific technology on the learning of students with disabilities. These include lack of universality of learning assessments between and within countries, especially where the students have had significantly reduced opportunities for language development. The breadth and depth of measures of impact are also problematic; some have too narrow a focus on reading scores without recognizing other significant intermediate or long-term impacts related to facilitating access to technology (such as motivation and other factors, discussed in UDL). Tools such as *Psychosocial Impact of Assistive Devices Scales* (PIADS)[87] have been piloted by such programs as the UNICEF Innovation Fund in LMICs to evaluate the broad impact of technology intervention (PIADS' use is discussed in more depth in Part F and Annex D).

- **High cost of technology in LMICs:** The cost of procuring assistive technology on a larger scale can serve as a barrier in many low-income countries.[88] USAID, other development partners, and the global private sector are working towards identifying priority assistive technologies that might be targeted for innovative funding and partnership schemes that can reduce cost and procurement barriers. Associated costs also arise from maintaining and repairing assistive devices. Assistive devices can come with additional costs, which also need to be factored into their affordability. The One Laptop Per Child program is an important example of a costly program that did not factor in important education supports to make it cost-effective (see case study in Section B2). Cost-effectiveness research in this area is limited (For more information, see Part F).

- **Lack of special education teachers and specialists:** In general, there is a lack of appropriate academic support such as inclusive education teachers and specialists in many LMICs.[89] Access to professionals who, in addition to understanding inclusive education, are also competent in how to use ICT4E to improve learning outcomes is even more restricted. In these contexts, access to professionals who are truly competent in how to use ICT4E to improve learning outcomes is often fairly limited. A review of findings on this challenge reveals that:

    - It can be difficult to set up academic communities for students with disabilities. The main issue is that it is hard to find others who either share the students' differences or live with people with similar differences. People with disabilities tend to be low incidence populations and to be widely spread. A virtual community can be a lifeline. With appropriate support, the community can function as a resilient and flexible network where participants build webs of personal relationships that aid them in organically developing their interests and abilities, so they can thrive in all facets of their lives.

    - Students with disabilities often encounter attitudinal barriers amongst their peers and mentors, who often do not understand the complex ways in which access barriers manifest for students with disabilities. Attitudinal barriers often include prejudices, assumptions, and judgements about individuals' general abilities, cognitive abilities, and/or communication and language abilities. As a result of societal and attitudinal barriers, students with disabilities remain underrepresented at all levels of education.

87 Hy Day and Jeffrey Jutai, "Measuring the Psychosocial Impact of Assistive Devices: The PIADS." *Canadian Journal of Rehabilitation* 9 (1996): 159-168.

88 Johan Borg and Per-Olof Ostergren. "Users' perspectives on the provision of assistive technologies in Bangladesh: Awareness, providers, costs and barriers." *Disability and Rehabilitation: Assistive Technology,* 10:4 (2015): 301-308.

89 Anne M. Hayes, Ann P. Turnbull, and Norma Moran. *Universal Design for Learning to Help All Children Read: Promoting Literacy for Learners with Disabilities*. USAID. (2018).

- Teachers, mentors, and peers who lack sufficient training in inclusive education may not understand that students with disabilities have an array of learning strategies and styles that are grounded in their individual modes of communication/language. For example, deaf students are inclined to be visual learners, whereas peers without disabilities may often rely on auditory input for language development. With the majority of classes made up of peers without disabilities, students with disabilities encounter severe exclusion risks, unless their teachers and classmates are either trained in inclusive education strategies or are working with a specialist who can help advocate for and provide appropriate accommodations.

- **Equity challenges specific to students with disabilities:** In LMICs, where access to new ICTs and Internet services is expanding unevenly, it is often the case that the most privileged segments of society are the first to benefit from the presence of those new services. This raises concerns as to whether students with disabilities, (and other students in the minority), will have either access to new ICTs or the ability to manipulate them. These equity challenges will need special attention when the "Matrix Model" is used to select and promote the use of ICTs to enhance the application of UDL. Equity challenges include, but are not limited to, ease of use of web and mobile applications for students with physical disabilities, access to verbal, pictoral, or vibrating reminder/instruction apps for students with intellectual disability, availability of video content in sign language and/or with captions for deaf and hard of hearing students, and purchasing of technology designs that are gender-neutral and able to support education equitably for all genders.

- **Sustainability challenges specific to students with disabilities:** All ICT programs in LMICs face sustainability challenges, but for students with disabilities, these challenges may be unique. If technologies are introduced based on the use of the Matrix Model, and if students with disabilities become accustomed to using those technologies for learning purposes, and if those technologies then have to be withdrawn from the learning environment because local systems cannot sustain them, then the students with disabilities may be placed at a tremendous disadvantage in continuing their learning. In addition, with the pace at which technologies become obsolete, the "shelf-life" of any technology needs to be carefully considered before it is selected, so that the investment made in it will not lose value so fast that only a few students with disabilities can profit from its presence before it becomes antiquated. For all of these reasons, consideration for ICT incorporation in education should include affordable and easy-to-use ICTs, especially for schools in remote areas that have no or limited Internet access, little training for technology use and maintenance, and few resources for maintenance and replacement.

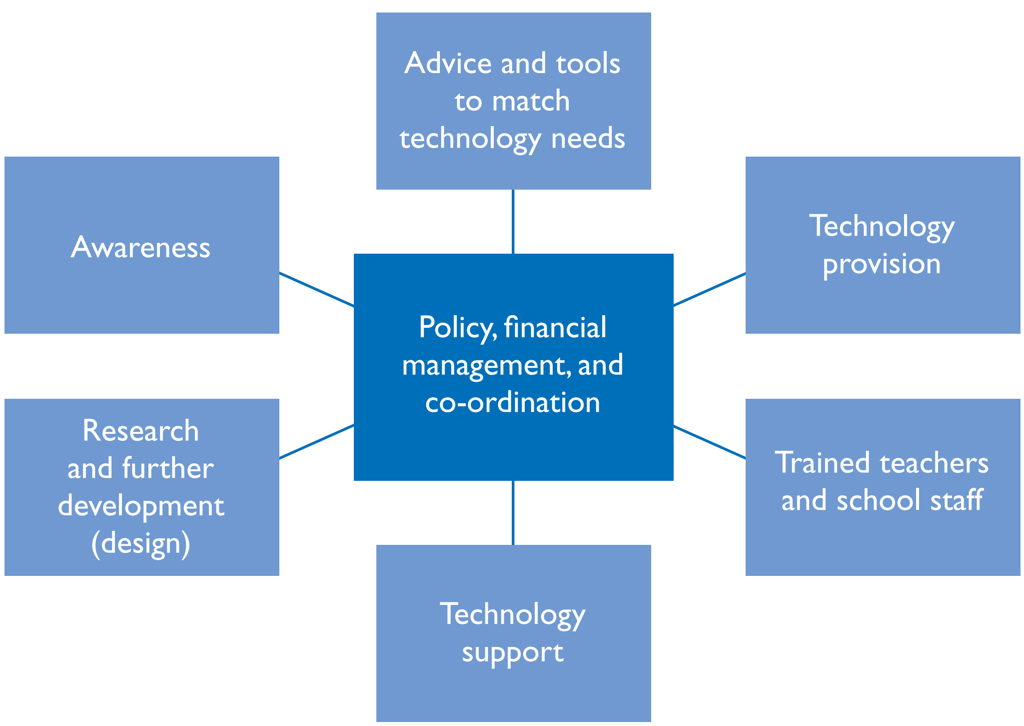
## PART E: THE TECHNOLOGY IMPLEMENTATION ECO-SYSTEM

Although the "Matrix Model" is evidence-based and can assist in generating options for rendering all education more inclusive through the power of technology, implementing a technology selection plan based on the "Matrix Model" can be complicated. In part, this is because the challenges listed in Part D all need to be addressed to the greatest degree possible for ICT4E plans to best serve students with disabilities. In fact, integrating any technology into any learning environment requires addressing a broad range of factors that are often conceptualized as making up a single "technology implementation ecosystem." These factors include elements explored in Section C6, such as: teacher and staff capacity, availability of advice and tools to match technology to needs, technology supports, and continued research and development. Figure 9 is a full diagram of the typical "technology implementation ecosystem."

**The interdependency of private and public sector: The Big Idea**

Strong public-private engagement facilitates ICT4E gap analyses and implementation of MTSS-based ICT4E integration plans. Public-private collaboration on technology design and ease of use drives down costs of consumer technology devices, and leads toward increasingly liberal licensing practices for software, with much code being open-licensed. The private sector can also play a central role in training and technical support, local language (content) adaptation, and longer-term sourcing options to build sustainable ICT4E programs that serve learners of all abilities.

FIGURE 9: The Technology Implementation Ecosystem




Public, private, and NGO actors all share responsibility for creating, nurturing, and adapting this implementation ecosystem.

Groups of stakeholders using the planning tools in Part C to identify which technologies are needed to support maximal literacy and numeracy gains for their students will automatically find themselves interacting with stakeholders from across the "implementation ecosystem." Roles and responsibilities in the system of actors from different sectors are summarized in Figure 10. While these roles as described here are not set in stone, and may vary across circumstances, if all of the responsibilities described here are not shared across the range of actors in the ecosystem, the progress of integration of ICTs in support of the implementation of UDL will be slow.

FIGURE 10: Key Actors and Their Responsibilities

| ACTOR | RESPONSIBILITIES |
|---|---|
| Public Sector Actors (government agencies, Ministry of Education administrative offices, school-based personnel) | Using the "Matrix Model" to plan for ICT support to UDL; coordinating overall technology selection, provision, and delivery; identifying gaps or risks and mitigating them accordingly. |
| Disabled Persons' Organizations | Bringing the perspectives of individuals with a disability to the decision-making process; ensuring that assistive technology decisions are based upon student needs and evidence-based practices. |
| Private Sector | Ensuring sustainability of products and services, based upon making enough margin to sustain business while offering products and services that are scalable. |
| Non-Governmental Organizations | Advocacy (particularly for cost control), innovation, procurement, distribution, training support, monitoring and evaluation, data-sharing, etc. |

**In considering the implementation ecosystem, the importance of private sector engagement with the mission of controlling costs and accelerating widespread availability of inclusive technologies cannot be overemphasized**. Businesses founded on the use of openly licensed products and materials can offer a means of purchasing services within the ecosystem to address needs (training, support, digital content etc.), while ensuring that the products can be maintained if the company should no longer be available. In some countries, partnerships have provided the basis of assistive technology associations such as the Assistive Technology Industry Association in the United States or the British Assistive Technology Association in the United Kingdom. Organizations like these may have a board of directors or steering group composed of representatives from all sectors, to ensure that all voices are heard, and that the needs of the local market are addressed. This board may also act as a representative body to the government to ensure that the need for assistive technology is addressed.

In the rest of this section, we consider two of the ecosystem elements in particular: design and cost. We then offer a short guide to conducting a gap analysis across the ecosystem to provide data that will help those integrating the use of ICTs for UDL-based instruction to address lacunae that could otherwise inhibit the implementation of any plans made based on the "Matrix Model" described in Part C.

## E1. Research and Development (Design)

### Design Philosophies

There are several design philosophies for developing ICT4E for children with disabilities: assistive, accessible or universal design. Understanding the purpose of a given technology, and how and why it was designed, will assist in determining how to place it in your Matrix Model and which of your students' needs it can best support. A Matrix Model that maximizes the use of universally designed technologies will maximize the ways in which ICTs catalyze the use of UDL in any given classroom context.

Options for what technologies can be placed into the Matrix Model in any context will be largely driven by what occurs in the "research and design" portion of the technology ecosystem. Therefore, we offer here a few key concepts about design to assist in understanding and promoting robust efforts to research and develop technologies responsive to any students' instructional needs.

- Any technology can be purposed as ICT4E if it incorporates both the technology itself and an intentional pedagogy that provides the means to eliminate or overcome barriers to learning.
- Technologies may augment individual abilities (e.g., with glasses or hearing aids), change the general environment (e.g., ordering only accessible textbooks that have description and/or captions), or function thanks to some combination of these two adaptations (e.g., digital books that can be read, heard, or felt with the appropriate user interface).
- Technology design philosophies have evolved as paradigms about disability have evolved. An older paradigm is the "medical model," which typified students with disabilities as patients who needed cures, and which gave rise to certain kinds of ICT4E designs for people with disabilities. A newer paradigm is the human rights model, where students with disabilities are considered part of the human tapestry of diversity and have legal, social, and educational rights equal to those of all others. This "human rights" paradigm can catalyze a very different kind of design than the "medical model."
- Technical, environmental, budgetary. and other factors can influence which design philosophy is used for ICT4E design and development. Some developers specialize in *assistive design*, focusing on developing a separate service or product to help a person with a disability perform tasks through augmentation of his/her existing abilities. Many companies already set goals for *accessible design*, a more inclusive design philosophy that entails designing a service or product to meet the broadest range of experiences and needs possible. *Universal design*, although not currently always used, is a long-term global goal as it focuses on designing a service or product so that it is usable by **all** people.

Designs have to be tested for both accessibility and usability to be accepted by customers. Usability is customarily defined as the effectiveness, effciency, and satisfaction with which a specified set of users can achieve a specified set of tasks in a particular environment.[90] **Unfortunately, people with disabilities are usually not included in usability tests**. Therefore, many products that perform well in usability tests are not accessible to people with disabilities.

[90] International Organization for Standardization. Reference ISO 9241-11 Ergonomics of human-system interaction—Part 11: Usability: Definitions and concepts. 2018. https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en

The Center for Universal Design (1997) outlines the following factors that aid in Universal Design or Personalization (adaptations of a given technology making it accessible to students with any given type of disability):

1. **Equitable use:** The design is useful and marketable to students with diverse abilities.

2. **Flexibility in use:** The design accommodates a wide range of individual students' preferences and abilities.

3. **Simple and intuitive:** Use of the design is easy to understand, regardless of the student's experience, knowledge, language skills, or current concentration level.

4. **Perceptible information:** The design communicates information effectively to the user, regardless of environment or ability.

5. **Tolerance for error:** The design minimizes hazards and the adverse consequences for accidental or unintended responses.

6. **Low physical effort:** The design can be used effciently and comfortably with a minimum of fatigue.

7. **Size and space for approach and use:** Appropriate size and space should be set aside for approach, reach, manipulation, and use, regardless of the person's body size, posture, or mobility.

**Multimodel Communication**

The absence of a sense affects not only learning and interaction, but also one's development and contextual knowledge of the world. For example, a young boy who was blind since birth once continually requested longer and longer sticks. His parents and teachers did not understand why he was doing this until he explained that he was seeking to find the height of the ceiling outdoors. The boy, being blind, did not realize that there was no ceiling outdoors (Lewis, 1987). Today, with access to a multi-modal communications interface, the blind boy would be able to interact with others in a virtual online world and easily learn through his investigations there that the sky is unbounded.

The process of universal design or personalization can significantly extend the range of users for many products and environments. It can also make the use of adaptive technologies much simpler and less obtrusive. For example, web pages that are designed to be easily used by computer screen readers (a personalization) do not inhibit users who do not need the screen reader from using them.

An awareness of the ongoing evolutions in ICT4E design will help stakeholders and those using the Matrix Model to identify technologies for use in their context that meet the greatest number of student learning needs. Online learning and communication systems can assist in the translation and presentation of information from one modality to another. Information and communication mediated by technology is moving away from single modal interfaces (e.g., telephone or text chat) and towards multimodal communication, in order to emulate the physical world interaction and leverage multiple senses (sight, sound, touch, and smell) as communication modalities.

Improved online learning for students of all abilities is increasingly better supported by a trend in favor of FLOSS projects designed to provide free educational tools for students to learn, reconstruct, and apply their knowledge and skills to real world applications. Developing both open source code for inclusive technologies and a technical community to support it requires close partnerships with software engineers in LMICs who can eventually take on maintenance of the code. It also requires documentation and tutorials for new software contributors, as well as training/mentorship from existing developers. Open source software option considerations include 1) increase software flexibility, 2) improve product reliability, and 3) reduce product and operating costs.

Because the factors that drive students' success or failure in literacy and numeracy are complex and interrelated (school resources, teacher preparation, course placement, bias and exclusion, poverty, family income levels, parental education levels, and representation, etc.), a broad range of stakeholders will need to be engaged in ICT4E design and promotion efforts. Entities like state and non-governmental organizations have key roles to play in the leveraging of resources to support the design of inclusive technologies, as well as in the creation of legal frameworks that require access to those technologies for all. Educational experts will be needed to advise on a range of topics, including how inclusively designed assessments can retain their reliability and validity as measures of learning. Teachers working to complete a Matrix Model for ICT selection should reach out across the entire ecosystem of stakeholders in their context to understand how design considerations and local realities will influence and support classroom level integration of the technologies they've identified in their matrix.

### E2. Cost and Financial Management

Historically, funding available for ICT4E for students with disabilities has been sparse. In many cases, programs and initiatives seeking to introduce ICT4E for students with disabilities in LMIC contexts have neglected to thoroughly plan for long-term sustainability and funding. Those using the Matrix Model proposed in this paper will need to be sure to address these financial considerations from the moment they prepare their ICT plan for the implementation of UDL in their classrooms.

Fortunately, at a global level, many devices, operating systems, and applications are now being designed in ways that make them inherently accessible and, in some contexts, readily available to teachers. Often, the functionality once only available on a dedicated assistive device can now be accessed through an app on a consumer-grade smartphone or tablet. More and more accessible services and features are being included in computing devices, as major technology companies such as Apple, Microsoft, or Google continue to integrate the latest accessibility features and tools for sensory, cognitive, and motor disabilities/differences in their products and services.

Trends in the general technology environment that are driving this greater availability and integration of potentially beneficial ICT tools are shown in Figure 11.

FIGURE 11: Trends in the Evolution of Accessible and Assistive Technologies

| TECHNOLOGY SHIFT | BUSINESS SHIFT | USER SHIFT |
|---|---|---|
| Increasingly<br>• Portable<br>• Pervasive<br>• Always connected<br>• Accessible Media | • Change to the distribution model as a result of closed ecosystems related to Operating System<br>• Creation of single source stores<br>• Changing business models<br>• Selling to leasing (from selling to ad-supported models)<br>• Decreasing cost of raw information | • Consolidation of individual sales stores to App store or large online stores<br>• Expectation of lower prices<br>• From ownership to subscription<br>• Expectation of being always available via on-demand services, distribution and support |

These shifts are having a major impact on cost and availability, with important implications for provision in LMICs. World-wide, phone use and ownership has become nearly universal, with close to 100 percent in high income countries, and over 80 percent in MIC countries.[91] In LMICs the smartphone and tablet market are dominated by Android-based solutions, often accessed through low-cost, imported devices. Such phones are available for US$25 in some countries and hence are within reach of many users. **This increasing availability of affordable base devices in LMICs is, in turn, driving a greater use of Android-based assistive technologies such as magnifiers, text to speech, speech to text, and other communication tools, even in contexts with modest education budgets**.

Nonetheless, people with disabilities worldwide are not yet greatly benefiting from these trends and advances. Furthermore, the true costs of integrating technologies across the three tiers of any locally contextualized Matrix Model, with the explicit goal of meeting all students' needs, are potentially daunting.

Some options for controlling or mitigating these costs include:

- **Gathering information on all costs** associated with the selection, purchase, distribution, and integration of any ICT solution. Frequently, even where devices or adaptations are offered for free, training and technical support may still incur costs, and it is best to know what these may be at the outset of implementing an ICT integration plan.

- **Focusing on inclusive solutions via devices already widely available in the environment** (i.e. mobile phones) and working with the companies supplying these devices to maximize their potential for offering low-cost accessible solutions for identified learning needs.

- **Ensuring that device-level accessibility services and features are built into the technologies selected**, so that the adaptations needed for different languages or circumstances in different contexts can be found and used on that same device, and don't require the purchase of a new device.

- **Ensuring a diverse base of products and services for a given context or intervention**. Projects that seek to supply every item of a project from a sole source may have problems in scaling the work at a later stage, as the potential benefits of competition are not brought to bear. For instance, if an assistive solution is created that will be made available only on a specific device, the opportunity to scale that application on to multiple devices and platforms at a later stage is often lost.

- **Investing in open-licensed technologies, both hardware and software**. This can reduce implementation and maintenance costs, facilitate going to scale within a community, and support the introduction of similar ICT-based solutions for learning to other communities where further translation or localization might be required.

- **Leveraging corporate and social responsibility programs available from well-known multinational technology companies**. For example, Google's Impact Challenge has funded proposals such as Learning Equality to take digital content offline for students without Internet access.[92] Similarly, Microsoft funds initiatives such as Zyrobotics' "Increasing reading fluency with Artificial Intelligence (AI)."[93]

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[91] Laura Silver. "Smartphone Ownership Is Growing Rapidly Around the World, but Not Always Equally." Pew Research Center's Global Attitudes Project. Pew Research Center, August 22, 2019.

[92] Learning Equality: https://www.google.org/our-work/education/learning-equality/.

[93] Zyrobotics: https://blog.zyrobo cs.com/2018/10/04/zyrobotics-announced-as-the-first-ai-for-accessibility-grantee/.

Both the public and the private sector have important roles to play in reducing the costs of ICT solutions that have utility for students with disabilities. In most countries, including the United States, accessibility has long been viewed as a public good or as a human rights issue, whose cost is borne by those providing products and services that must be accessible, including the government. Those costs in turn, can be passed on through higher prices or taxes. Unfortunately, this unifocal reliance on the public sector as the main supplier of ICT4E for students with disabilities has created environments where individuals and small business have been able to gain exemptions from government regulations requiring accessibility, and where enforcement of laws, policies, and procedures meant to accelerate access to ICTs to support learning has been variable. As efforts to provide students with disabilities in LMICs with the educational technologies they need gain momentum, a more equitable partnership between the public and private sectors at both global and local levels will be needed.

The public sector can support awareness programs in retail stores or other public places, offer accessible devices at subsidized prices, and work directly with NGOs to increase distribution. The public sector can also further engagement from companies by promoting the use of universal service funds, a system of telecommunications subsidies and fees managed by national commissions in some countries, to support access for students with disabilities.

The private sector, even in LMICs, can participate more actively in shared funding models (which are also encouraged under USAID's 2018 Education Policy). These models bring together corporate and social responsibility (CSR) initiatives from private enterprises with the public sector's need for expanding inclusive education programming. Many telecommunications companies have CSR programs that seek to support students with disabilities. Examples of positive private sector engagement in the telecommunications arena in order to benefit people with disabilities include:

- In the United Arab Emirates, the operator "Du" funded the development of a specific app for children with autism called BabNoor[93] through their CSR department.[94]
- In Qatar, local telecommunications companies offered subsidized devices and tariffs to those with disabilities to enable them to get online and access content on a regular basis.
- In Sharjah, United Arab Emirates, a local bank offered 0 percent financing to fund assistive technologies for persons with disabilities in educational programs. This allowed costs to be spread out over time and reduced the associated costs.
- In some countries, telecommunications providers have been convinced by the government to market mobile phones with a marginal cost for the inclusive educational content to be pre-installed on the device. Such "Family Phones" have all the functionality of regularly available handsets, but are preloaded with content, reducing both the time and data costs of installing the content individually.

Shared funding models where investment from both private and public sources creates low, stable costing for needed ICTs can facilitate the integration and scaling up of technologies selected by a given group of teachers through the use of the Matrix Model.

[94] For more information on BabNoor, see https://www.du.ae/about-us/sustainability-approach/society/babnoor-app.

**Inclusivity and Cost-Efficacy: A Case for Digital Repositories in Support of UDL**

The cost of providing alternative formats for print books for small numbers of pupils can be extremely high and require specialist skills (example, Braille translation). At-scale digital repositories of reading materials such as Global Digital Library, Pratham/Storyweaver, WorldReader, African Storybook, and e-Kitabu are working towards ensuring reading materials are in accessible formats, while Bookshare (Benetech) has developed an eLibrary exclusively dedicated to individuals with print disabilities. These types of initiatives could bring about cost savings in the supply chain. The use of open-licensed materials under Creative Commons allows titles to be freely distributed commercially and non-commercially without individual permissions, and some large publishers with a significant portfolio have already made titles available under open access. Palmer et. al (2016)[95] note that "the cost to implement a digital reading program based on a library model is about 12-13 times more expensive than the cost to implement a…structured reading program where each child is reading the same book at the same time." If provision of accessible materials through digital repositories for those with disabilities is incorporated into wider digital learning initiatives, the additional costs of provision to students with a disability will be marginal, especially where freely licensed or embedded assistive technologies are utilized on common devices to access learning material.

## E3. Technology Implementation Ecosystem Gap Analysis

It is beyond the scope of this paper to provide explanations of details related to every element in the technology implementation ecosystem. However, every component of the ecosystem is an important variable that will affect how teachers, schools, districts, and countries implement the plans they develop using their Matrix Model. For this reason, it will be useful, during the development of the Matrix Model in a given context, to also undertake a complete gap analysis of the technology ecosystem in that context.

Figure 12 indicates the types of questions that might be asked vis-à-vis elements of the technology implementation ecosystem related to policy, financial management, coordination, and awareness during a gap analysis. These represent important enabling supports that will heighten the impact and sustainability of elements of the ecosystem described in Part C.

FIGURE 12: Gap Analysis of the Enabling Ecosystem

**Policy, Financial Management, and Coordination**

- Does public policy put in place a requirement for students with a disability to be accommodated within an inclusive education system, and state the right of students with a disability to receive appropriate accommodations?
- Does policy require schools to implement a pedagogy based on UDL principles, where teaching materials and practice accommodate the widest possible diversity of needs?
- Are individual schools required to establish a whole-school policy and development plan on access for pupils with disabilities, including details of how support will be ensured throughout the entire school?
- Does policy identify how inclusive practice will be monitored by the ministry responsible for education, and how a process of review and a right of redress will be invoked if needs are not being adequately addressed?

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[95] Aileen Palmer, Shubha Jayaram, Sonaly Patel, Nicholas Burnett, Kanika Bahl, Cammie Lee, and Arjun Upadhyay. "Global Book Fund Feasibility Study," Results for Development Institute. 2016.

- Is there a clear policy on the procurement and distribution of technologies to schools to accommodate children's needs?
- Are accessible and assistive technologies made available through local vendors or by being imported? What criteria for the provision of technologies are established?

**Awareness**

- What sources of information on general technology and assistive technology use are available locally?
- Are teachers aware of the potential of accessible and assistive technologies to increase the literacy for children with disabilities?
- Are case studies of successful students and initiatives from within the community that the schools serve available and distributed?
- What communication channels are available, have proven most effective, and can be optimized to reach stakeholders (school heads, teachers, and parents, etc.) about technologies available to accommodate disabilities? (e.g. social media, other campaigns, educational publications, community groups, etc.)

As a gap analysis of the implementation ecosystem is performed in LMICs, organizations and initiatives such as the International Disability Alliance and their member organizations (i.e. All Children Reading Grand Challenge for Development, The Global Initiative for Inclusive ICTs, UNICEF, and Zero Project) are good sources of information about best practices in the use of ICT4E for foundational skills development for students with disabilities in those contexts. During a gap analysis of a technology ecosystem, it is also important to hear the perspective of in-country DPOs to understand how well ICT4E is being optimized locally to accommodate the needs of students with disabilities.

A strong gap analysis is a useful step in determining current practices, habits, and potential in a given context for the use of ICTs to promote the implementation of UDL in classrooms. Findings from a gap analysis of the entire implementation ecosystem can inform both the speed and scale at which a given technology included in a Matrix Model can be introduced to classrooms. However, it is important to note that if a technology included in the Matrix Model is needed for a given student(s), gaps identified during the analysis of the ecosystem should not be allowed to inhibit provision of that technology. Rather, steps should be taken to resolve the gaps, so that the technology in question may be provided as planned.

# PART F: MONITORING AND EVALUATING THE IMPLEMENTATION OF THE MATRIX MODEL

When providing ICT4E for students with disabilities, it is important to evaluate the impact of implemented interventions. The elements of a proposed impact evaluation are listed in more detail below.

**Monitoring, Evaluation, and Learning: The Big Idea**

Evaluating interventions planned using the Matrix Model requires examining: a) whether the introduction of a given technology accelerated students with disabilities' mastery of particular foundational skills, b) the depth and breadth of the program's learning impact, (if any), c) the cost-effectiveness of the intervention (value for money), and d) the degree to which the intervention can be scaled. The goal is to ease the burden of provision and accommodation on the teacher, cost-effectively, while expanding access, learning, and ultimately the quality of life for the children with disabilities.

- **Depth and Breadth:** One of the critical factors to consider in identifying intervention outcome measures is the depth and breadth of impact. Data on the number of people reached is important in helping to determine the cost of taking an initiative to scale, but it is an insufficient picture of the actual progress made by students. It reflects efficiency rather than effectiveness. A deeper investigation of impact upon the learning process, along with a thorough cost-benefit analysis, will also be needed. In other forms of intervention for students with disabilities, notably those involving assistive technology and therapeutic interventions, more holistic impact measures have been developed. PIADS offers a form of outcome measure that studies the wider impact of technology on the lives of persons with disabilities (see Annex D).[96] The outcomes are classified into effectiveness, social significance, and subjective well-being. The PIADS measures of success are further described below.

  - Effectiveness is concerned with how assistive products might affect users' functioning or change in health conditions. It embraces the full effects of assistive products.

  - Social significance reflects the extent to which outcomes are important to society, notably in terms of economic effect.

  - Subjective well-being includes users' evaluation of how the products have affected their lives.

The PIADS could be adapted for particular use in literacy and numeracy instruction.

- **Cost-Effectiveness:** There is a clear educational need to provide accessible learning materials, integrated with accessible and assistive technologies. The most cost-effective way to deliver access to literacy and other basic education is by embedding the use of ICT4E for students with disabilities into inclusive classrooms through high-quality teaching. Metrics for measuring cost-efficacy, therefore, will need to examine to what degree increasing access to technology for all pupils renders the marginal costs of meeting the needs of those with a disability increasingly negligible.

  The extent to which an intervention offers cost effectiveness is determined by the outcome measures. For students with disabilities, measures should encompass much wider facets of

[96] Hy Day and Jeffrey Jutai, "Measuring the Psychosocial Impact of Assistive Devices: The PIADS." *Canadian Journal of Rehabilitation* 9 (1996): 159-168.

development than simple literacy scores. Both literacy and digital literacy are essential skills in the 21st century. As a result, the focus of future research should seek to address which form of technology has the greatest learning impact, moving on from discussion as to whether technology intervention itself is beneficial. It is also useful to consider whether the investment in ICT4E to support literacy and numeracy development has implications beyond school. The development of commercially available and accessible ICT4E may have both an impact on literacy and numeracy learning within the classroom and a wider impact on an individual's quality of life and employment prospects. In this case, these outcomes add significant value to the ICT4E investment being evaluated. Research suggests that impact from investment in accessible ICT4E often expands beyond the target audience, if an intervention is planned and implemented effectively.

**The Case of WorldReader**

In making comparisons between digital and non-digital delivery, researchers often focus too much on cost and ignore many other educational benefits that access to technology provides for children with a disability. In one case, it was found that WorldReader had distributed 721,129 digital books to 12,381 children in nine African countries. But it was found the costs would be prohibitive for this to be brought to scale. This was wrongly based uniquely upon analysis of the utilized device, costed at approximately US $90, and assumed to last 5 years. This overemphasized price and ignored how the devices had assisted those with disabilities, as this was harder to quantify.

**Source:** Author's opinion. Figures derived from Global Education Monitoring Report. Every Child Should Have a Textbook. Policy Paper 23, January 2016.

- **Considerations for Scale:** Assuming any technology pilot is being considered for scale, there should be close monitoring of the effectiveness of the program's support structure both during the program and through an end-of-project performance evaluation. Critical questions to consider include:

  - First and foremost, do teachers have the capacity to transfer knowledge of foundational skills to students with disabilities? Do teachers have the skills and capacity to use digital technologies effectively? Do weaknesses exist in pedagogy, content knowledge, integration or selection of technologies, classroom management, specialist support needed, leadership, etc? What considerations need to be made at the system level to deepen capacity, and what mix of teacher and specialist resources seems ideal in a UDL classroom?

  - To what extent do students have access to devices with accessible learning content in their school, home, and community? What are the opportunities and barriers to procuring technologies on a larger scale, and to wider dissemination and production of accessible content?

  - Does the infrastructure (i.e.power, connectivity) exist to support digital delivery? Can this be provided sustainably and more broadly? Are there cost, maintenance, human resource, and/or other constraints that might need to be overcome before expanding?

  - Are there serious climate effects that could be engendered by taking this project to scale? Are there ways to cope with the environmental pollution the program may create at scale?

Should analysis of these questions reveal significant barriers to access or improved learning that existed during piloting, a robust response strategy will need to be planned, costed, and implemented before a given intervention can be scaled.

# PART G: FUTURE RESEARCH AND EVALUATION

Due to both the fast-paced environment of technology development and a historical lack of funding related to ICT4E and inclusive education, there is an overall lack of research related to which specific ICTs can support learning of students with disabilities, and how they can best do so. Further research will help determine which interventions have the greatest impact on the learning and lives of those with a disability.

**Research Agenda: The Big Idea**

Evaluating research for this type of intervention should move away from control groups to take into account the number of variables involved in technology implementation, and use a more comparative approach. The research agenda should inform technology innovations that can effectively address literacy and numeracy learning, as well as the range of supports needed to sustain those outcomes.

These realities suggest that additional comparative effectiveness research (CER) will be very useful in building out a research agenda about inclusive ICT4E and the application of the MTSS-based Matrix Model to operationalize UDL in classrooms. While not widely applied to education, CER seeks to identify which interventions work best for improving learning. Interventions include not only the elements of teaching and learning, but also any innovations in delivery, organization, and practice. Variables in a CER study could focus on different technologies, strategies for teaching and learning, or even the environment. CER studies can provide an increased understanding of which technology-related and other intervention factors are most essential to support the learning of students with disabilities.

Any future research agenda to promote the use of technology to support literacy and numeracy for students with disabilities in LMICs needs to address two substantive areas: Technology development (design, cost, usability, etc.) and technology use. Topics and questions related to both these areas are outlined in Figure 13.

FIGURE 13: Research Topics to Promote the Use of Technology for Learners with Disabilities in LMICs

**1. Developing technology to support literacy and numeracy for people with disabilities in LMICs**

- A comparative study outlining the benefits and risks of current and emerging technologies with the potential to have the greatest impact on literacy learning in LMICs, recognizing the variations of needs, technology, infrastructure, expertise, and experience that influence each project.
- Use of ICT4E to provide the technical support required to maintain and sustain effective implementation of technology.
- Potential return-on-investment of open licensed ICT4E, including both hardware and assistive software for scale and replication of pilot projects.
- Establishment of resources and services to support the localization of ICT4E, in particular assistive technologies, for language and cultural communities.
- Development of building blocks of accessible ICT4E for target communities, and what investment would best ensure availability.

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2. Supporting use of technology for literacy and numeracy and for students with disabilities in LMICs

- Identify those technologies that best accommodate pupil needs at each stage of emerging inclusive classrooms.
- Further develop a maturity model of technology-supported inclusive education for LMICs, to guide intervention and implementation.
- Identify how teachers can be motivated and encouraged to engage with technological change and education.
- Create a teachers' guide to the availability of accessible digital learning materials, and support access to all ICT4E tools appropriate to the context.

New programs don't necessarily have to be created to implement a new learning agenda on ICT4E for students with disabilities. Research on the use of ICTs to augment the application of UDL in classrooms could also be implemented through any of the many technology-focused initiatives currently in progress globally, provided that these initiatives worked to initiate programs that would use the Matrix Model to attempt to increase the use of UDL through ICT applications. Some of these current initiatives are noted in the box below.

**A Closer Look at ICT4E: Using Innovation to Advance the Research Agenda**

Some of the most effective programs have included open calls for innovation, awards and prize calls, and hackathons with clearly stated outcomes and requirements. Examples include:

- **USAID Development Innovation Ventures**. The USAID Development Innovation Venture scheme (DIV) seeks to test and scale breakthrough solutions to any global development challenge. The scheme is open to anyone to propose ideas at any time. The venture fund offers three stages of investment, for any type of organization, in any country in which USAID operates: Stage 1: Proof of Concept (Up to $200,000 – up to 3 years); Stage 2: Testing and Positioning for Scale ($200,000 to $1,500,000 – up to 3 years); and Stage 3: Scaling ($1,500,000 to $5,000,000 – up to 5 years). In addition to tiered funding, DIV provides evidence grants (up to $1,500,000) to support research and evaluations that generate rigorous evidence of an innovation's impact per dollar and potential for expansion. There has not yet been a direct investment in accessible and assistive technologies as a focus of a DIV project or initiative.
- **All Children Reading: A Grand Challenge for Development** (ACR GCD) advances EdTech innovation and research to improve reading outcomes for marginalized children in low-resource contexts. ACR GCD is a partnership between USAID, the Australian Department of Foreign Affairs and Trade, and World Vision that sources and tests solutions that address barriers to child literacy in three key areas: books in underserved languages, children with disabilities, and foundations for literacy. It identifies and brings to scale promising technology solutions for addressing barriers that prevent children with disabilities from learning to read. These efforts have significantly increased the quantity of books and teaching materials available to children with disabilities, particularly in low-resource contexts. ACR GCD also adapted the Early Grade Reading Assessment (EGRA) for children who are blind/low vision or deaf/hard of hearing, so these students can be included in measurements of literacy acquisition and skills. ACR GCD's "Sign On For Literacy" prize awarded three innovators with creative solutions for expanding access to local sign languages, sign language-enabled early grade reading materials, and reading instruction by engaging families, schools, and communities. The challenge's "Book Boost: Access for All Challenge," which was a joint initiative with Pearson and

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Project Literacy, awarded two innovators who tested new business models for optimizing and increasing the number of accessible titles developed in their contexts. ACR GCD has funded 80+ innovators, and offers EdTech for literacy solutions, technology-related research, and other resources on its website, allchildrenreading.org.

- **UNICEF Innovation Fund**. The UNICEF Innovation Fund offers a model of investment that supports the use of open source technologies to catalyze literacy and communication, targeting businesses and commercial activities in LMICs. The fund is distributed through an open call for proposals. Awardees receive not only funding, but also mentoring from business advisors and experts.

- **Google AI Impact Challenge**. The program invites proposals on how to use AI to help address societal challenges, including access to education and language.

- **Microsoft AI For Accessibility.** The program provides access to advanced Microsoft Azure cloud computing resources to individuals and organizations working on empowering people with disabilities. The AI for Accessibility program awards grants to projects that build on recent advancements in Microsoft Cognitive Services and Machine Learning to develop accessible and intelligent AI solutions in three areas of focus: employment, daily life, and communication & connection.

- **Microsoft Hackathon**. Microsoft funds and runs an annual hackathon around the theme of accessibility. Since the first hackathon in 2014, they have formed over 150 "Ability Hacks" focused on how to reduce barriers often encountered by persons with disabilities. The integration of the Microsoft Ability Hack into the company's broader diversity, access, and inclusion agenda increases the likelihood of the hackathon projects eventually being brought to market. The scale of the project allows for the hack to be stored and distributed, and an analysis of what facilitates success to be offered. Successful projects have included learning tools for literacy.

- **Accessibility and Assistive Technology Incubation – Israel**. This incentive program encourages the development of technological solutions for people with disabilities to improve their quality of life and better integrate them into society, the community, and the labor market. The incentive program is open to all Israeli companies and non-profit organizations interested in developing technologies that support persons with disabilities. Non-profits receive support for 85 percent of the approved expenses for R&D, with no repayment of royalties. Commercial companies receive support for 65 percent of the approved budget, processed as a conditional, two-year grant, up to a total of approximately US$220,000 a year. Each team receives guidance from expert industry mentors and a select group of professionals from disability NGOs. Mentoring includes support for go-to-market efforts, research and regulation strategy development, finance and funding processes, and the resolution of any challenges that arise for the entrepreneurs during implementation of the grants.

- **AT Makers.org**. This program introduces makers to assistive technology (AT) users and gives these two communities the tools they need to collaborate. The designs and instructions that the makers create are then available for distribution and local replication/fabrication. Such designs can effectively stimulate a local AT industry through the manufacture of designs that have been fully tested.

In addition to multiple types of research, there is a significant amount of guidance still needed across the global community to further improve the quality of ICT4E programming in order to accelerate the implementation of UDL. Needed products and outputs include:

- A toolkit for gap analysis of technology implementation capacity within target LMICs

- A best practice guide on the role and challenges for the private sector in building inclusive ICT4E ecosystems

- A compendium of resources for LMICs to build capacity in using technology
- Resources for community engagement to support technology intervention and inclusive education

To ensure that any new research agenda about using the Matrix Model informs future development, policy, and practice in ICT4E, there is a need to find new ways of sharing and disseminating research outputs. Many stakeholders who might seek to replicate and implement ICT4E concepts locally to improve the quality of instruction for children with disabilities lack access to the evidence and ideas that could stimulate increased investment in and use of technology in LMICs. Key challenges include:

- Much of the evidence is only published in academic journals, which require expensive subscriptions and are most often only available to other academics; and
- Much of the research is shared at international conferences, where the cost of travel and attendance are often prohibitive for many stakeholders in LMICs.

These challenges create barriers in translating evidence into practice, unless sources of information and discussion are made more widely available.

The potential growth of virtual conferences and exhibitions has been suggested as a way forward for bringing together widely and thinly spread communities of people with disabilities and their allies. Events provided on a local, regional, or rotating basis, targeting specific communities known to be negatively affected by the digital divide, can also help facilitate the dissemination of research. The use of social media to share and distribute findings is also possible, but content needs to be curated and maintained for ease of access. The development of a "free to publish, and free to access" peer-reviewed journal similar to "Assistive Technology – Outcomes and Benefits"[97] would also be an effective way to address the limits of current modalities for the dissemination of ICT4E research about instruction for students with disabilities.

[97] This journal is published by the Assistive Technology Industry Association, https://www.atia.org/at-resources/atob/.

# CONCLUSION

Technology can serve as an important tool to support the learning of students with and without disabilities, and can support implementation of UDL within the classroom following the MTSS model and the Matrix Model of technology. ICT4E not only can serve as motivation for students to learn, but can also help many students access and express content in different ways. Investment decisions that are most likely to offer both depth and breadth of impact would include those that:

- Support the development of open technology building blocks, reducing cost and encouraging private sector investment in first language accessible and assistive technologies;
- Support the development of products and services that target delivery of the elements of the assistive technology ecosystem at all levels;
- Create openly licensed training materials on inclusivity in ICT4E for use in both commercial and non-commercial ventures, to support capacity building in local languages;
- Increase availability of openly licensed digital content for early literacy and numeracy;
- Increase availability and use of content creation tools in different languages;
- Support public and private sector localization of technologies that have proven impact in other settings;
- Encourage the private sector to build service offerings through openly sourced products with seed funding and the use of universal service funds; and
- Ensure that all technology interventions for education in LMICs include accessibility in procurement specifications.

The greatest single barrier to the impact of technology on learning for those with disabilities is teachers' ability to use the tools provided in creative and meaningful ways. Systems analysis to support teachers to use the MTSS-based Matrix Model to implement ICT4E interventions on behalf of students with disabilities will facilitate the expansion of UDL-inspired instruction.

Available research and evidence suggests that there is considerable potential value in addressing the challenge of global literacy and numeracy by investing in technology to address the learning needs of students with disabilities. However, such an approach needs to consider action for access across the entire delivery chain and the supporting ecosystem. Interventions should consider not only the technology to be used, but actions to build capacity around implementation.

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# ANNEX A: FEATURES OF ACCESSIBLE TECHNOLOGY AND ASSISTIVE TECHNOLOGY

The charts below outline the features of accessible technology and assistive technology that support various categories of disability. Solutions for access for students with a disability may require combinations of resources drawn from each of the categories below. Examples of instructional strategies used for a UDL classroom with these technologies are outlined in Part A and Part C.

## Accessible Technologies

These accessible technologies can address a broad variety of students' needs when integrated into teaching and learning. Technologies most accessible in LMICs are radios and tape recorders. In addition, desktop computers and tablets that are Windows-based, iOS, Android-based, or Chromebooks-enabled offer accessibility features and functions that are very useful in the UDL classroom. Table 1 lists functions and features of technologies likely already within reach of students with disabilities in LMICs (with proper planning). Table 2 notes functions that may need to be specially requested or procured for LMIC context, even though they are available on the global market.

TABLE 1: Functions and Features Built Into Desktops and Tablets in LMICs that *Increase Access to Learning and Effective Delivery of Basic Skills*

| | WINDOWS | IOS | ANDROID | CHROMEBOOKS |
|---|---|---|---|---|
| **Physical** | • Keyboard shortcuts<br>• Voice recognition<br>• Keyboard and mouse tuning<br>• On screen keyboard<br>• Touch screen support<br>• Eye tracking support | • Voice recognition<br>• Word prediction<br>• Switch scanning<br>• Single handed use | • Universal switch support<br>• Head movement<br>• Detection and facial gestures<br>• Set dominant hand<br>• Reorder or remove menu<br>• Adjust touchpad size<br>• Easy screen turn-on<br>• Touch and hold delay<br>• Interaction control | • Keyboard shortcuts<br>• Voice recognition<br>• Keyboard and mouse tuning<br>• On screen keyboard<br>• Touch screen support<br>• Eye tracking support |
| **Vision** | • Keyboard shortcuts<br>• Voice recognition<br>• Keyboard and mouse tuning<br>• On screen keyboard<br>• Touch screen support<br>• Eye tracking support | • Voice recognition<br>• Word prediction<br>• Switch scanning<br>• Single handed use | • Text to speech<br>• Adjustable font sizes<br>• High contrast fonts<br>• Show button shapes<br>• On-screen magnification<br>• Grayscale<br>• Color inversion | • Keyboard shortcuts<br>• Voice recognition<br>• Keyboard and mouse tuning<br>• On screen keyboard<br>• Touch screen support<br>• Eye tracking support |

*continued on following page*

| | WINDOWS | IOS | ANDROID | CHROMEBOOKS |
|---|---|---|---|---|
| **Deaf and hard of hearing** | • Video creation software<br>• Captions for videos<br>• Mono audio<br>• Visual on-screen alerts | • Video creation apps<br>• LED flash for alerts<br>• Mono audio<br>• Phone noise cancellation<br>• Audio volume balance<br>• Subtitles and captioning | • Video creation apps<br>• Sound detectors<br>• Notifications and on-screen alerts<br>• Turning off all sound<br>• Support to hearing aids<br>• Adjust sound balance for headphones<br>• Mono audio when using one earphone<br>• Subtitles | • Video creation<br>• Captions for videos |
| **Cognitive and learning** | • Reduce animations and on-screen distractions<br>• Simple reading view<br>• Text prediction and suggestions | • Word prediction<br>• Simple reading view | • Voice recognition<br>• Text prediction | • Speech recognition<br>• Keyboard shortcuts |

TABLE 2: Functionalities that May Need to be Specially Requested to Augment a Technology

| | LEARNING DISABILITIES | LOW VISION | PHYSICAL DISABILITIES | DEAF AND HARD OF HEARING | COMMUNICATION | COMPLEX SUPPORT NEEDS |
|---|---|---|---|---|---|---|
| **Text to speech** | xx | xx | xx | | xx | |
| **Magnification and text sizing** | xx | xx | | | | |
| **Word prediction technology** | xx | | xx | xx | xx | |
| **Video creation for sign language** | | | | xx | xx | |
| **Captioning on videos** | | | | xx | | |
| **Touch screen** | | xx | xx | | xx | xx |
| **Support for Braille devices** | | xx | | | | |
| **Switch scanning** | | | | | xx | xx |

## Assistive Technologies

Assistive technologies are those technologies that are designed to specifically meet the needs of students with a disability. They are usually additional to the access features that are built into the accessible technology devices noted above, and can include software, hardware, or peripherals. In other cases, assistive technologies come in the form of individualized solutions. Examples of instructional strategies used with these technologies are outlined in Part C.

TABLE 3: Add-ons/Adjustments to Technologies and Individualized Solutions

**ADD-ONS/ADJUSTMENTS TO TECHNOLOGIES**

| | LEARNING DISABILITIES | LOW VISION | PHYSICAL DISABILITIES | DEAF AND HARD OF HEARING | COMMUNICATION | COMPLEX SUPPORT NEEDS |
|---|---|---|---|---|---|---|
| **Screen readers** | | xx | | | | |
| **Keyboard alternatives** | xx | xx | | xx | | |
| **Mouse alternatives** | | | | xx | | xx |
| **Switch access** | | | | xx | xx | xx |
| **Braille displays** | | xx | | | | |
| **CCTV desktop magnification** | | xx | | | | |
| **Induction loops and FM transmitters** | | | xx | | | |
| **Communication devices** | | | xx | | xx | xx |
| **Voice recognition** | xx | | | xx | | |
| **Mind mapping** | xx | | | | xx | |
| **Writing support software** | xx | | | xx | | |

*continued on following page*

**INDIVIDUALIZED SOLUTIONS**

| | LEARNING DISABILITIES | LOW VISION | PHYSICAL DISABILITIES | DEAF AND HARD OF HEARING | COMMUNICATION | COMPLEX SUPPORT NEEDS |
|---|---|---|---|---|---|---|
| **Eye tracking devices** | | | | xx | xx | xx |
| **Gestural control** | | | | xx | xx | |
| **Smart speakers** | xx | xx | | xx | | |
| **Word banks for sentence construction** | xx | | | | xx | |

# ANNEX B: INTRODUCTION TO THE STUDENT-ENVIRONMENT-TASKS-TOOLS (SETT) FRAMEWORK[98]

## Part I—Gathering Data and Making Decisions

Using a collaborative approach, teachers can consider the following in determining which technologies and support will most support a child's learning.

### Student

- What is the area of learning need?
- What is the student currently achieving?
- In what areas does the student need support to achieve more?
- What language(s) does the student use for learning?

### Environments

- What are the significant characteristics of the environment in which the child is learning?
- What is the physical arrangement of the learning environment?
- What is the instructional arrangement in the learning environment, such as classroom, small group, or individual learning station?
- What materials and equipment are students and teachers using currently?

### Tasks

- What are the expectations for students in the setting?
- What specific learning tasks are essential in the student's achievement in this setting?
- Where are the gaps between student performance and expectations?

### Tools (both devices and services)

- What tools (low and high tech) are being used currently to support the child?
- What additional tools does this child require to perform in this environment?
- What strategies might be used to motivate performance?
- How will these tools provide an equitable learning experience for the child to meet desired learning outcomes?

[98] SETT has been developed and shared by Joy Zabala. Further details are available at: http://joyzabala.com/Documents.html

## Part II—SETT Implementation Plan

Teachers can then outline a plan for implementing assistive technology tools for a child. The plan must include:

- Consideration of the identified setting and the tasks.
- Identification of any human resources required and indications of their roles in supporting the child.
- Development of a timeline for implementation, including time required to assess effectiveness of the intervention.
- An outline of how the teachers intend to use given tools and strategies to support learning.
- Descriptions of the training that the student and staff need for successful use of the tools.
- Suggestions for how the effectiveness of the intervention will be measured.

# ANNEX C: KEY STEPS IN TECHNOLOGY PROCUREMENT

An assessment to inform technology procurement might be performed by a consultant or firm as part of the consortium implementing an inclusion project. The technology strategy will need to be outlined in detail during program implementation, allowing program implementers to work closely with Ministry of Education personnel, school heads and teachers, communities, and parents to decide the best technology to support literacy learning objectives of a new inclusion or UDL program.

The following (illustrative) pre-technology procurement research steps could inform the specifications for the technology procurement.

### STEP 1: SETT Framework

Once a gap analysis is performed to understand needs across the ecosystem for the development of a sustainable ICT4E program, program planners may use the Student-Environment-Tasks-Tools (SETT) Framework in a sample of schools to map out commercial or proprietary solutions that will support teachers to effectively deliver curriculum content and support inclusion (see Annex B).

### STEP 2: Technology Provision

Map potential technology solutions and conduct research on current and potential technology provision to inform government estimates for the intervention.

- Consider if there is functionality within current classroom devices or operating systems that meets the need. What is already available? Can you add to existing devices?
- Research the availability of open source and freely distributable technology available to meet the need (e.g., applications, interfaces or functionality that can be added on to existing devices).
- Research availability of accessible content and whether existing content needs to be altered.
- Find out if specialized solutions have been trialed by students; examine the results and determine if there is supporting rationale or evidence to justify expanding the availability of and types of technologies available to schools.
- Conduct a problem analysis of the local technology infrastructure.
- Research local market availability and impact of vendor-provider relationships on cost, availability, and support/maintenance. Some factors to consider may include models of payment for technology, dependency of functionality on app purchases, and whether a subscription model is appropriate and can be sustained.
- Develop a cost analysis to inform an updated government estimate.

### STEP 3: Rapid Assessment of Implementation Capacity

Conduct a rapid assessment of the capacity to implement the recommended core technologies and to support integrated assistive solutions within the current operating system (OS) and learning platforms available in schools. Here, the team might draw on what was learned during the gap analysis period related to understanding **teacher and staff capacity** and current **technology support** to factor in what specific supports might be needed as new technology is introduced. Build potential costs for technology training into the government estimate.

### Step 4: Develop Specifications for the Technology Procurement

The procurement specifications would include:

**A) An overview of the educational program:**

1. Provide a brief description of the inclusion or UDL program's goals, objectives, and length.
2. Note disabilities and additional needs that the technologies will address. Provide a profile of the extent to which students in the program might display one or more of these characteristics:
    - Blind and low vision (from mild to moderate vision to little or no vision)
    - Deaf and hard of hearing (from mild to moderate hearing to little or no hearing)
    - Physical (from mild to moderate hand/arm dexterity to little or no dexterity of limbs or body)
    - Cognitive/learning (including dyslexia, autism, memory, etc.)
3. Provide a description of how the technology will be used to support the curriculum – reading, writing, research, presenting, etc.
4. Note some specific functions that the technology will need to include so students can interface with learning content. Specify whether the technology will be used to produce or consume content, or both.
5. Identify and describe any current content that will need to be transformed into accessible content.
6. Note language of instruction and/or languages that will need to be considered for the technology interface.

**B) School's Physical Environment:**

1. Will the technology be used in a classroom, computer room, or any other shared space?
2. Will the technology need to be portable for use in other community locations or between classrooms?
3. Has the space available in classrooms been mapped for equipment to be maneuvered and to promote access for pupils with limited mobility?
4. What is the level of access to power and internet at the location?
5. Will the technology need to be amenable to extreme conditions including lighting, temperature, etc.?
6. How will the technology be stored and secured in the school/classroom?

**C) Technology Environment:**

1. Provide a mapping of technologies students already use in the classroom:
    - Desktop PC
    - Laptop PC
    - Mobile phone
    - Tablet
    - eBook readers
2. Outline the operating systems that need to be accommodated.
3. Decide whether connectivity to third party input/output devices is, or should be, made available.
4. List the productivity tools that are regularly used.
5. Describe any learning management system currently used across the school.
6. List collaboration and communication solutions currently used.
7. Request information on security and privacy requirements to be considered in the safe and secure use of the technology.
8. Note weaknesses in effectiveness and reliability of technology infrastructure.
9. Note technical support available or needed locally (e.g., local technicians integrating with vendor support, replacement services, and control panel access).
10. Note (initial) timescales and related dependencies for approval and installation of new technologies.

**D) Technology Provider Support:**

Request an outline of additional training, support required, and other implementation requirements from the technology provider. This would include:

- A staff training proposal for the program and schools, complete with costs
- Network management and network licensing requirements
- Information on how administration of the technology or software is controlled
- Information on remote troubleshooting support for an X to X month period
- Information on software maintenance agreements, including on-site and remote maintenance options, warranty and extended warranties available, and upgrades covered

### Step 5: Sustainability Planning

The USAID Mission, along with the Ministry of Education and program implementers, in consultation with technology providers, should develop a sustainability plan focused on renewing and refreshing technology as it approaches end of life. This work should begin at the outset of the program, to ensure that post-project needs can be met.

# ANNEX D: PSYCHOSOCIAL IMPACT OF ASSISTIVE DEVICES SCALES (PIADS)

PIADS is a self-report questionnaire designed to assess the effects of an assistive device on functional independence, well-being, and quality of life. The PIADS was researched and developed to fill the need for a reliable, valid, and economical measure that is generically applicable across all major categories of assistive technology. See www.piads.net for more information.[99]

Each word or phrase below describes how using an assistive device may affect a student. It is important that each element below be explored. For each question, the person completing the form rates the impact of the intervention on a scale of -3 to +3, to indicate whether the intervention has had a positive or negative impact on each indicator.

After the student or teacher has answered each of the 26 questions, the results are assimilated to measure core dimensions of psychological well-being, including independence, personal control, self-efficacy, and self-acceptance. These elements of well-being are useful indicators of wider impact of intervention across multiple areas, all of which can support lifelong learning. They are listed in Table 4. ICT4E has the potential to change an individual's "score" positively or negatively in any of these categories.

TABLE 4: PIADS Core Dimensions of Psychological Well-Being

| | |
|---|---|
| • competence | • skillfulness |
| • happiness | • well-being |
| • independence | • capability |
| • adequacy | • quality of life |
| • confusion | • performance |
| • efficiency | • sense of power |
| • self-esteem | • sense of control |
| • productivity | • embarrassment |
| • security | • willingness to take chances |
| • frustration | • ability to participate |
| • usefulness | • eagerness to try new things |
| • self-confidence | • ability to adapt to the activities of daily living |
| • expertise | • ability to take advantage of opportunities |

# ANNEX E: RAPID ANALYSIS OF COSTS AND BARRIERS TO IMPLEMENTING ASSISTIVE TECHNOLOGIES FOR CHILDREN WITH DISABILITIES IN LOW AND MIDDLE INCOME COUNTRIES[1]

## A. Matrix Analysis

The following is a matrix analysis of technologies that are commonly used both within and outside low- and middle-income countries to support primary school age students with disabilities in building literacy, numeracy, and other basic skills. **These technologies need additional financing, application, and research in LMICs**.[2]

The matrix is based on expert interviews with technology providers and other experts conducted in 2019. It is intended to be used as a *starting point for consultations and development of strategy* by stakeholders engaged in technology market expansion to support education programming in low and middle-income countries. See tables at the end for a list of initiatives that use these applications.

[1] Updated as of May 2019.
[2] This analysis would need to be continually updated to remain useful for strategy discussions. Also, if printing this annex, we recommend using legal-sized paper.

| TECHNOLOGY: ELECTRONIC HANDHELD MAGNIFIER | | | | | |
|---|---|---|---|---|---|
| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Such apps would support people with low vision not only for reading but also in looking at images and in undertaking close-up work. The tools would have value in daily life and employment including early reading. | | | | | |
| **Goal:** Reduce the cost of hand-held magnifiers to support learners with low vision in the classroom | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| This tech magnifies text from a printed page but also can be used to change colors and contrasts to increase ease of reading. | There are many dedicated handheld magnification technologies on the market with very similar functionality. | Handheld magnifiers designed for low vision sell for around $495, with added margins for LMICs.<br>New magnifiers designed for people working with fine detail and very small components and text are available from companies such as ION for $99.<br>Low-tech solutions/ lenses are available from $50-$150, depending on style and features such as a bulb. | Cost<br>Import<br>After sales support (repair, etc.) | Produce and promote an open source handheld magnifier app for deployment on android phones and tablets, replicating the core functionality of the dedicated devices. | • WeZoom magnifier and low vision aid<br>• Magnifier 4 Reader<br>• Visor |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>Dedicated handheld electronic magnifiers are usually beyond the reach of most LMICs due to cost. Therefore, analysis of alternatives looks at lenses vs. apps on smartphones. Lenses need a high level of care and scratch and chip easily, making them less than ideal for early years learners. They are also heavy and challenging to manipulate other than on a desk. Electronic magnification on a phone is easy to use and has considerably less stigma attached. These are useful for a broad curriculum and functional literacy. | | | | | |

| TECHNOLOGY: BRAILLE NOTETAKERS | | | | | |
|---|---|---|---|---|---|
| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Such notetakers support literacy skills from early grade through to employment. Such technology, if made available widely, could support those with low vision over an extended period. | | | | | |
| **Goal:** Reduce the cost and increasing use of Braille devices for learners who are blind or low vision | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Braille notetakers are used to both read and comprehend text and Braille-ready files through a refreshable Braille display bit; the notetakers are also used to record notes and documents using a chording keyboard. | Traditional Braille notetakers have been extremely expensive and beyond the scope of most LMIC budgets. Recently a new model has been made available at significantly lower cost (some 80-90 percent lower), and further investigation of their potential in a range of languages is warranted. | Traditional models have sold for around $5,000; the Orbit has been made available in the region of $500. | The latest lower cost technology requires testing in a variety of settings and importantly needs to be reviewed for a variety of languages. To date, it has been reviewed positively for both English and Arabic speakers. | The Orbit team has developed the product to support bidirectional documents and different character sets. Further investigation into the potential use for languages within LMICs would be required. | Such notetakers could support literacy skills from early grade through to employment. Such technology, if made available widely, could support those with disabilities over an extended period. |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>The technology described is based upon a refreshable Braille display and integrated keyboard and processor. One could explore removing the processing unit and using this technology purely as display powered and connected to a mobile phone. This would reduce cost further and increase potential value. | | | | | |

| TECHNOLOGY: AUGMENTATIVE AND ALTERNATIVE COMMUNICATION TECHNOLOGY | | | | | |
|---|---|---|---|---|---|
| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* AAC develops functional communication, which is an essential prerequisite for literacy from the early years through to adulthood. | | | | | |
| **Goal:** Increase use of augmentative and alternative communication solutions for learners with no speech to increase language skills to support future literacy | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| AAC devices are used to establish the basis of communication using text and symbols to construct sentences for functional communications. Such sentences introduce the fundamentals of syntactic and semantic structure to support the evolution of skills for literacy. | Dedicated devices are priced in the region of $3,000-$5,000 but have widely been replaced by proprietary app solutions for iPad and Android based on one-off payments of around $135 or annual subscriptions to software as a service. Increasingly, there has been interest in supporting open licensed software and symbol sets that reflect language and culture where the solution is free, but support and training are made available at a fee. | Commercial software is available in some languages for between $50 and $200; open source solutions are available for free as web applications or solutions for iOS and Android. | Many of the lower cost apps have been developed for iOS, and there is value in porting and testing these for Android devices. Testing of the quality of TTS, and familiarity with the symbol sets are both required. Many low-cost systems have low marketing budgets, and this creates a lack of awareness of the potential of such systems in LMICs. | There is great potential in the use of open AAC systems in LMIC contexts. Seeking new ways to promote awareness and distribution of open solutions with investment to increase functionality and tailor products to local market needs would extend use in LMICs. | The UNICEF innovation fund has been supporting open AAC solutions driven by products from Argentina, India, and China. Recent initiatives have ensured that symbols developed for cultural relevance have been stored and linked by concepts for use in emerging markets. |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>AAC systems, including relevant symbols, have been demonstrated to support emergent literacy skills and support the learning of reading in a second language. The underlying technology and resources in AAC systems can be applied broadly to those with a diversity of needs including learning disabilities and autism. | | | | | |

| TECHNOLOGY: DAISY READERS | | | | | |
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| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Daisy readers support learners who are blind or low vision, but also can be applied to literacy development for those with other print disabilities including physical and learning needs such as cerebral palsy or dyslexia. Benetech continues to develop open software and content to support reading through Bookshare. | | | | | |
| **Goal:** Increase use of Daisy format reading materials by reducing cost of devices to read files | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Daisy readers are software and hardware devices that can interpret Daisy format files into text and voice output. Daisy format files integrate and synchronize text to the speech output to allow learners with a visual or other print disability to match text to speech. | Daisy readers were initially dedicated devices that read Daisy format files distributed on CD or other media. Increasingly, such devices have been replaced by apps for smartphones and tablets, which replicate much of the functionality at a reduced cost. | Dedicated hardware devices sell in LMICs for around $400. Smartphone apps are available freely, but implementation may be limited in terms of appropriate content and the ability of the product to support local languages. | The most widely used open source application is AMIS for Windows. There is value in exploring how the functionality of AMIS could be reproduced for Android phones, or where support to other open source applications including Daisy tools could be enhanced. | Support to regional languages, operability on Android devices, and Daisy creation tools in local languages all need to be developed to maximize impact. | • Open Daisy readers for Android include Daisy Book Reader and Kota reader.<br>• RoboBraille offers online tools to convert written documents to a variety of formats including mp3, Braille, and Daisy format. |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>The expansion of readers and accessible content compatible with ePub3 and Daisy would support readers at a variety of levels including not only early grades but also those later in life with delayed literacy development. | | | | | |

## TECHNOLOGY: TEXT-BASED SUPPORT SOLUTIONS

**Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Real-time text communication supports people who are deaf and hard of hearing as well as people with limited speech. By conveying text in real-time, there is additional opportunity to extend use to include translation of text to facilitate wider communication partnerships. Due to phonocentrism, however, text-based information coming from people will likely be considered secondary to speech-based communication, despite its potential.

**Goal:** Increase usage of text for real-time communication for learners who are deaf or hard of hearing in conjunction with sign language

| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
|---|---|---|---|---|---|
| The use of real-time text in a functional communication context or conversation supports the development of functional literacy for learners who are deaf or hard of hearing. However, if a person who is deaf or hard of hearing has delayed or no language acquisition, then a focus should first be placed on natural language acquisition through sign language, (before implementing text-based support solutions). | The most widely used real-time text solution for people who are deaf or hard of hearing is the dedicated device, the UbiDuo. Such devices are not widely available in LMiCs. There is some evidence that suggests that the use of text to enhance functional communication helps to practice and strengthen literacy skills. | The cost of such dedicated devices is a significant factor. The design of such solutions mitigates against easy localization. Some apps for phones and tablets have been developed for real-time text using integrated keyboard, word prediction, and TTS for hearing communication partners. Such apps use Bluetooth connectivity between devices to maintain privacy. | Barriers not yet documented. | Enhancements to all of the available apps and exploring the range of ways devices could connect for fully interactive chat would be valuable; increasingly, devices have been developed using NFC as well as Bluetooth to support the rapid and secure transfer of data between devices. Enhancing such apps to incorporate emoji and images to convey tone as well as meaning would increase functional communication and thus literacy. | • DHChat for Android<br>• OviiChat for iOS<br>• AVA App |

**Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*

This technology should pair with, and not replace, sign language. For many within the deaf community, sign language is often the best means of communication.

| TECHNOLOGY: SCREEN READERS | | | | | |
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| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* The development of the underlying technology that underpins screen readers would hugely expand a multimodal approach to development of literacy skills. Such an approach would support those with a range of print disabilities including vision and cognitive needs such as dyslexia. | | | | | |
| **Goal:** Increase the ease of development of screen readers that support learners who are blind or low vision | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Screen readers are an essential technology for people who are blind or have low vision. They access any text and labels on the screen and convert them to speech output. The same technology may also provide Braille output to a refreshable Braille display. | Screen readers are widely available, ranging from those that are free (NVDA) to those that are expensive (Jaws). In addition, mobile and portable devices have some form of screen reader integrated into the OS that are fully functional, but that are of varying quality depending on language. | LMICs often lack the support infrastructure for the lower cost solutions. Technical support, advice, and training may not be in place to support implementation.<br>In addition, the quality of the TTS engine and voices may affect the perceived value of the technology and may contribute to reduced uptake. | Screen reader technology in LMICs is affected by the quality of the TTS and the supportive infrastructure.<br>Lack of awareness amongst DPOs of solutions for Android devices may reduce capacity to advise on a local solution. | Supporting innovation to increase the availability of high-quality open voices that can be distributed in a range of languages would increase access to literacy for many. Early grade readers would benefit from much simpler interfaces for screen readers as they learn to use the technology for the first time. | • Voice banking<br>• AI Tools for technical development |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>The expansion of TTS systems and creating technologies that make it easier to create localized voices would provide the building blocks of technology that would support a variety of needs in seeking to promote early literacy development. Creating tools aimed at younger readers would in addition support older users with learning disabilities. | | | | | |

| TECHNOLOGY: SIMPLIFIED MOBILE PHONE INTERFACE | | | | | |
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| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Ease of access to core functionality would increase the ease of use for those with a range of needs including physical, vision, and cognitive needs. Such simpler interfaces would benefit any user accessing digital content, including early grade readers with or without a disability. | | | | | |
| **Goal:** Create simplified phone interfaces in local language to increase access to tools for those with disabilities | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Mobile phones are increasingly the main means of electronic communication for many in LMICs. However, the interface out of the box may have too many options for ease of use. Simplified interfaces have been developed with fewer options and the ability to set accessibility options such as contrast and text size to start when the device is switched on. Such interfaces allow users to engage in communication including literacy more easily. | Throughout the review of solutions, the capacity to build functionality upon mobile devices has been identified. The interface between the user and the technology is often too complex for those developing literacy skills, and there have been a series of attempts to create simpler interfaces where teachers and family can tailor the experience toward greater ease of use and providing direct links to those tools that might support early grade reading. | Creating a simple to use and simple to personalize interface to devices, based on early levels of literacy, would expand usage of mainstream low-cost technologies and reduce the distraction factors inherent in platforms with open access to any app. | Developing open interfaces that can be based upon culturally relevant icons and local language would be helpful.<br>Many LMICs have historically not seen this as a priority for development. | A range of open interfaces for Android devices are available. Creating easier editing and localization techniques to support use in different locales would be valuable.<br>AI and machine learning offer the potential of expanding the options within such an interface as the user exhibits higher levels of literacy and digital confidence. | • Project Ray<br>• GPII<br>• Big Launcher |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>Creating simpler interfaces for access to technology would benefit all early grade learners and accelerate the impact of technology upon their literacy learning. Such interfaces would in addition have potential benefits for an older community of users who are confused by current options as a result of age, lack of experience, or learning disability. | | | | | |

| TECHNOLOGY: TOOLS TO SUPPORT CREATION OF ACCESSIBLE DIGITAL CONTENT | | | | | |
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| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Increasing the ease by which accessible content is generated and transformed into formats suitable for a variety of needs would have a significant impact upon the availability of early grade reading materials that could be accessed by those with learning disabilities, limited vision, and physical needs. | | | | | |
| **Goal:** Increase production of accessible content by developing and distributing tools to simplify content creation | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| The creation of accessible content including documents is essential in promoting and increasing the availability of written resources that support literacy. Such tools take two forms: those that ensure that any written documents created by a user are compatible with accessibility standards, and those that convert such documents into a range of formats to support a diversity of needs. | The production of accessible user-generated content is essential in supporting the creation of resources and early grade reading materials that can be accessed by those with a variety of needs and are appropriate to curriculum, language, and culture. | The cost of increasing access to tools for checking and addressing accessibility issues is a barrier to many LMICs, as it has only been recently introduced to OS or productivity.<br>Some third party and open solutions are available but are of mixed quality and cost. | A series of tools for testing the accessibility of content and transforming these into alternative formats are available. However, use is often limited by the need to own current versions of applications, and limited support for a variety of languages. | The creation of plugins for the testing of accessibility issues and transformation into alternative formats for legacy systems that are familiar for teachers would be beneficial.<br>Increasing the automation of such checking and remediation would have further impact by reducing the need for teachers to be confident in all the techniques. | • Office 365 Accessibility Checker<br>• Solutions for Google GSuite etc.<br>• Robobraille<br>• Easy Converter<br>• Express |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>Increased availability of accessible content would support a number of the other priorities that have been discussed. The work of other agencies in this area should be acknowledged, but the impact of increased accessible content would have benefits across the age and ability range. | | | | | |

| TECHNOLOGY: CONTENT SIMPLIFICATION AND ENHANCEMENT | | | | | |
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| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Increasing the ease by which learners achieve a functional level of comprehension of text will enhance motivation and increase the underlying capacity to read autonomously, regardless of age. Such tools have lifelong applications for those with learning disabilities or other forms of print disabilities. | | | | | |
| **Goal:** Develop technology that simplifies and enhances text/content to aid ease of understanding or comprehension | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Content enhancement tools present literacy learners with added visual cues to aid literacy and understanding of text. These might include an integrated thesaurus or dictionary, visual support such as symbols, and tools that review and recommend appropriate grammar.<br>Other tools are those that support simplification of written content by offering a precis or other simpler summary of the key points of complex text. | Content simplification and clarification seeks to identify the key messages within text and extract these and present them in an easier to assimilate format. Such tools can be useful both in allowing early grade readers to access text at their own level and also as a means of checking and testing comprehension.<br>Additional tools that check for spelling, grammar, and use of language are used to improve the quality of text production and comprehension. | Some tools are integrated into current versions of productivity solutions but do not support a diversity of language and are not usable by those developing literacy skills. The interface and advice are often complex for learners with emerging literacy. | Cost<br>Availability<br>Appropriateness for language and culture | AI and machine learning-driven solutions based upon the needs of early grade readers with recommendations and suggestions presented in a style that is suitable for the level for reading and ability. | • Grammarly<br>• Global symbols<br>• Content clarification |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>Content simplification and enhancement is of great value to many learners with additional needs or where existing or traditional educational systems have failed to achieve desired levels of literacy. Increasing ease of access to information and ideas through such tools can have significant impact on education and the workforce, and hence may support economic development. | | | | | |

| TECHNOLOGY: TEXT TO SPEECH | | | | | |
|---|---|---|---|---|---|
| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Access to high quality TTS is an essential component of natural interfaces for many with limited literacy. While such TTS would support those developing literacy skills, the impact of such technologies increases digital access for significant parts of the population. | | | | | |
| **Goal:** Increase availability of high quality and low-cost first-language text to speech functions to support development of new applications | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| TTS is an essential building block of many assistive solutions used by people with a disability. TTS interprets the text displayed on a screen and interprets it into speech to support a variety of needs, including literacy, for those that have little or no vision, dyslexia, or other cognitive disability. | TTS are available in many languages, but high-quality voices are expensive, and a lack of quality voices reduces uptake and production of accessible technologies. | Costs are variable from locale to locale, but cost of a licensed high-quality voice has a severe impact on the quality of entry-level AT. | A lack of open tools to create new voices limits creation. Further activity to produce a pipeline for production of voices that streamlines production would assist in many locales. | New interventions such as voice banking may offer technologies that would have potential application in this field.<br>The creation of pipeline tools that allow elements of the creation process to be submitted by a range of participants might encourage open development. | Voice banking |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>It would be valuable to complete a global mapping exercise on TTS, cost, and quality. Such a map would allow us to more fully understand the scale of the issue and hence the potential return on investment for intervention. | | | | | |

**TECHNOLOGY: SPEECH RECOGNITION**

**Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Voice recognition via mobile phones is an increasingly popular technology for many people across the globe. The potential scale of use across internet connections would have potential impact on much of the population with low levels of literacy.

**Goal:** Increase availability of speech recognition tools in a range of languages

| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
|---|---|---|---|---|---|
| Speech or voice recognition takes the speech signal and converts that to text, creating sentences as spoken. Such technology is extremely valuable in supporting the creation of written text by those with learning disabilities, physical needs, and other conditions such as dyslexia. | Production of text with speech is a valuable tool to support functional literacy for those with print disability including dyslexia and physical disability. Such technology also has an impact for those who cannot type as a result of seng or context and provides the basis for natural interfaces for communication and access to information. | Speech recognition is not available in many languages common in LMICs. | Further research on how to increase the availability of voice-driven interfaces would be beneficial and would support functional literacy for those facing significant barriers. | Seeking improved solutions to community development of speech recognition would help to accelerate such availability. The extent to which machine learning of speech for a corpus of text is feasible might increase pace of development. | There are a range of projects to develop open source technologies, but these are mostly confined to English.<br>These include:<br>• Project DeepSpeech<br>• Kaldi<br>• Julius<br>• Wav2Leer++<br>• DeepSpeech2 |

**Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*

Research similar to that carried out for text to speech would be valuable.

| TECHNOLOGY: ALTERNATIVE KEYBOARDS | | | | | |
|---|---|---|---|---|---|
| **Benefits to Learners** *(What needs would be addressed with this including early reading, other basic skills, etc?.):* Keyboards remain an important tool for the creation of and interaction with text. The limitations of standard keyboards reduce ease of access for many with limited movements or low vision. | | | | | |
| **Goal:** Increase production and distribution of alternative keyboards to create easier access to writing | | | | | |
| **Implication for Literacy**<br>*Why and how does this tech support learning and literacy?* | **Current Status**<br>*Brief description of what is currently available in the market (as of May 2019)* | **Cost for LMICs**<br>*Current cost of product in LMIC market (or, elsewhere if LMIC price not known)* | **Barrier for LMICs**<br>*What are the challenges for using this technology in LMICs (i.e. procurement and sourcing, power or internet connectivity)?* | **Potential Innovation**<br>*How could we resolve the need through innovation?* | **Examples of Initiatives and Application**<br>*Is any current work being undertaken to address the issues?* |
| Alternative keyboards are widely used to support literacy in the early years. Keyboards with large keys, alternative layouts, color-coded keys, and high visibility support the creation of words and sentences through ease of use. | A wide range of keyboards are available to support English and some other Western languages. Such keyboards can accelerate production and interaction with text for those with physical or other barriers that make standard keyboards challenging. | Many keyboards that have been developed are in a form with keytops that are suited to U.S. or U.K. English only. Creating print runs of keyboards for specific languages has proven to not be cost effective. | 3D printing offers the opportunity to scan the design of keys for specific keyboards and complete adapted designs that can be printed in different colors and with appropriate text/letters for use in a range of languages.<br>In addition, keyboard stickers in a suitable size and layout could be of value. | A keyboard remapping tool to change the outcomes of keypresses to different layouts and languages would increase the use of a range of keyboards. Keyboards should have USB or Bluetooth compatibility for use with as wide a range of devices as possible. | Open hardware projects such as AT Makers, who distribute AT designs, offer the expertise to undertake the development of open designs. |
| **Analysis:** *(To what extent is this technology a priority for development compared to other options to address the need?):*<br>Increasing the range of keyboards available in community languages would help to increase access to text creation. Universal keyboards with mappable key presses would be a short and medium term intervention to support access. | | | | | |

## B. Further Information on Products

| PRODUCT | OPEN SOURCE | DEVELOPER LINK |
|---|---|---|
| Ion Handheld magnifier | N | https://www.ashvision.com/products-2/handheld-microscopes/ion-4-3/ |
| We Zoom | N | https://loviapps.jimdofree.com/english/ |
| Magnifier 4 | N | https://play.google.com/store/apps/details?id=com.hanstorm.Magnifier&hl=en |
| Visor | N | https://www.visorapp.net/magnifer-app |
| Orbit | N | https://www.orbitresearch.com/product/orbit-reader-20/ |
| cBoard | Y | https://www.cboard.io/ |
| Coughdrop | Y | https://www.mycoughdrop.com/ |
| Livox | N | https://livox.com.br/en/ |
| Daisy Book Reader | Y | https://sourceforge.net/projects/dbr/ |
| Kota Reader | N | https://play.google.com/store/apps/details?id=com.daisy.reader&hl=en_GB |
| Robobraille | N | https://www.robobraille.org/ |
| DHchat | N | https://fordeaf.blogspot.com/ |
| Oviichat | N | https://appadvice.com/app/ovii-chat-real-time-communiction/1071931133 |
| AVA | N | https://www.ava.me/ |
| UBIDUO | N | https://www.scomm.com/ |
| NVDA | Y | https://www.nvaccess.org/ |
| Voiceover | N | https://www.apple.com/voiceover/info/guide/_1121.html |
| Talkback | Y | https://support.google.com/accessibility/android/answer/6283655?hl=en |
| Project Ray | N | https://project-ray.com/ |
| Global Public Inclusive Infrastructure (GPII) | Y | https://gpii.net/ |
| Big Launcher | N | http://biglauncher.com/ |

| PRODUCT | OPEN SOURCE | DEVELOPER LINK |
|---|---|---|
| Office 365 Accessibility Checker | N | https://support.microsoft.com/en-us/office/improve-accessibility-with-the-accessibility-checker-a16f6de0-2f39-4a2b-8bd8-5ad801426c7f |
| Google Suite Tools | Y | https://support.google.com/a/answer/2821355?hl=en |
| Easy Converter Express | N | https://yourdolphin.com/products/education/easyconverter-express |
| Grammarly | N | https://www.grammarly.com/?q=brand&utm_source=google&utm_medium=cpc&utm_campaign=brand_f1&utm_content=329885936576&utm_term=grammarly%2com&matchtype=e&placement=&network=g&gclid=EAIaIQobChMI6pPSyqXd6gIVCaGzCh2F5gMhEAAYASAAEgJINfD_BwE |
| Global Symbols | Y | https://globalsymbols.com/ |
| Clarifai | N | https://contentclarifier.mybluemix.net/ |
| Speech Recognition | Y | https://www.ibm.com/cloud/watson-speech-to-text?p1=Search&p4=43700051010024068&p5=b&cm_mmc=Search_Google-_-1S_1S-_-WW_NA-_-%2Bspeech%20%2Bto%20%2Btext_b&cm_mmca7=71700000062156796&cm_mmca8=kwd-18392003896&cmmmca9=EAIaIQobChMIkeus8KXd6gIVweDICh3DsgPQEAAYASAAEgJdZPD_BwE&cm_mmca10=412803415405&cm_mmca11=b&gclsrc=awds&&gclid=EAIaIQobChMIkeus8KXd6gIVweDICh3DsgPQEAAYASAAEgJdZPD_BwE |
| Project DeepSpeech | Unclear | https://github.com/mozilla/DeepSpeech |
| Kaldi | Unclear | http://kaldi-asr.org/doc/ |
| Julius | Unclear | https://github.com/julius-speech/julius |
| Wav2letter | Unclear | https://ai.facebook.com/tools/wav2letter |
| DeepSpeech2 | Unclear | https://github.com/PaddlePaddle/DeepSpeech |
| Alternative Keyboards | Y | https://www.thingiverse.com/darthrtfm/collections/keyboard |

| INITIATIVE | DESCRIPTION | URL |
|---|---|---|
| Project Vive | Project Vive works with open hardware designs to make speech generating devices accessible to everyone. They offer a range of devices and peripherals based on open hardware specifications. | https://www.projectvive.com/ |
| Open Assistive | Open Assistive is a collection of major open source assistive technology projects from across the world. The listed projects can be downloaded for use, and there are links to source code | www.openassistive.org |
| AT Makers | AT Makers is a group of engineers and designers who distribute instructions and designs for assistive technologies that can be fabricated locally. | www.atmakers.org |
| BeneTech Bookshare | Benetech and Bookshare support a range of projects to design tools and content that support literacy and education for children with a disability. | https://benetech.org/tag/assistive-technology/ |
| Voice Banking | Voice banking is a technology that allows users to record and segment their speech to be saved and provided as the basis of a personal text to speech solution where they are likely to lose the ability to speak in the future. | https://www.cereproc.com/en/products/cerevoiceme<br>https://www.callscotland.org.uk/blog/what-voice-banking-options-are-currently-available/ |
| UNICEF Innovation Fund (AAC) | The Unicef Innovation Fund projects develop, design, and distribute technologies to benefit children with disabilities, including ebook readers and communication tools. | https://www.unicef.org/innovation/ |
| Microsoft Accessibility | Microsoft's accessibility initiative includes integrated solutions within their products, specific products designed to meet the needs of people with a disability, global development programs including AI for accessibility, and a broad portfolio of research and development activities. | https://www.microsoft.com/en-us/accessibility |
| Google Accessibility | Google's accessibility efforts extend beyond accessibility tools to include both external and internal research efforts like the Google Impact Challenge: Disabilities, which seeks to advance ideas and emerging technologies that increase the independence and opportunity for people with disabilities. | https://www.google.co.uk/accessibility/ |
| Amazon Accessibility | Amazon accessibility initiatives include increasing access to devices and contents including their eBook readers, tablets, and smart speakers. | https://www.amazon.com/b?ie=UTF8&node=15701038011 |
| Apple Accessibility | Apple offers a wide range of functions and tools within their products to support the needs of people with a disability. They also offer information and resources to encourage developers to make best use of these features. | https://www.apple.com/uk/accessibility/ |

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