# Acquiring educational access for neurodiverse learners through multisensory design principles

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## ABSTRACT
Educational interface designers are in an unprecedented position to facilitate autonomous learning in neurodiverse learners (children with special needs). These learners are particularly in need of special design, given the disproportionate impact it can have on their quality of life and the current vulnerability they experience due to changes in special education law. In response to the urgent conditions facing these students, we construct and define a set of design principles that are grounded in maximizing the potential of these learners by importing the meta-cognitive skills, algorithmic structures, and multiple sensory modalities that are both proven successful in their remediation and uniquely suited to technological design adaptation.

We draw from our main author's experience as a heavily remediated Dyslexic, a lifelong user of modified, adaptable and assistive technology, and a self-aware learner taught to understand why the methods behind her remediation worked. We additionally draw on our cumulative experience as users, teachers and developers of technology and on interviews with participants from a wide variety of sociocultural functions and pedagogical practices involved with special education. Based upon these and existing methods and applications, we present our insights in the form of guidelines for universal design that have the potential to not only embrace the differences of all learners but to maximize the potential of underserved neurodiverse learners so they can become self-sufficient masters of their own skills and interests across their lifetime.

## Categories and Subject Descriptors
H.5.2 [**Information Systems**]: H.5 Information Interfaces and Presentation. H.5.2. User Interfaces

## General Terms
Design, Human Factors, Legal Aspects

## Keywords
Educational technology, dyslexia, multisensory, special needs, neurodiversity, user interface design, universal design

## 1. INTRODUCTION
In this paper we set out to identify design principles for technology that could best help neurodiverse children maximize their potential. (We use the term "neurodiverse learners" because the term "special needs" has historically held negative connotations and to indicate that these learners are different but not inferior.) There is particular need in this arena because of recent developments in special education law and the outsized benefits these children would receive from such design. We draw from the experience of our main author, a dyslexic who experienced technological remediation firsthand and now teaches technology to children herself, who has seen the way technology has evolved -and failed to evolve -to meet new challenges. We believe that these principles, based on our insights into the efficacy of multisensory and multiple modality educational methodologies, will maximize the learning potential of all learners.


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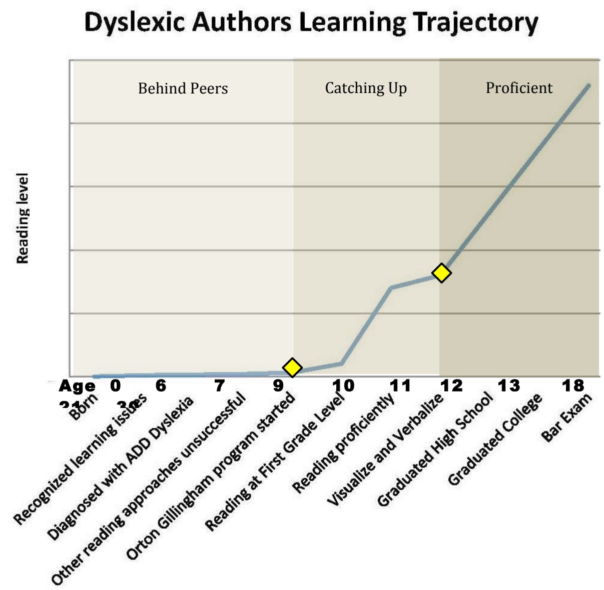


**Figure 1. Dyslexic Author's Learning Trajectory**

## 2. BACKGROUND
Our authors have extensive experience dealing with educational technology and strategies for neurodiverse learners, particularly dyslexics. The main author of this paper has Dyslexia and ADHD, along with a host of other learning disabilities, and experienced firsthand the failure of traditional classroom methods (Figure 1). Well into fourth grade, she was still unable to read and incapable of identifying the corresponding sounds to each letter of the alphabet to the point where her tutor said "it was as if she had never seen letters or phonics before — because functionally she had not." All remediation failed until she began multisensory programs, provided under the auspices of Massachusetts special education Law (**Table 1**). Orton Gillingham (OG), a multisensory phonics program which assumes no intuitive knowledge of language and breaks words down to their very core of phonemes,

finally taught her to read (albeit at the first grade level) at the age of twelve; Lindamood Bell's Visualize and Verbalize (VV), using multisensory data and mental imagery, helped increase her concept memory so she could retain what she read. These programs, complemented by technological solutions including exposure to immersive technology at the Center for Applied Special Technology, had her up to speed with her peer group within two years, though she continued to lack the basic knowledge her peers had accumulated from their years of literacy.

**Table 1. Multisensory Learning Methods for Remediating Dyslexia**

| Learning Method | Multisensory Linkage |
|---|---|
| Orton-Gillingham Phonics | Sound, touch, smell to letter awareness and recognition |
| Lindamood-Bell's Visualize and Verbalize | Sound and visual memory to aid conceptual development |

She became an attorney, an active member of the International Dyslexia Association, and a champion for legal educational reform, who volunteers teaching technology to elementary students. Aware of the role that both law and technology played in her own successful remediation, she became interested in how advances in technology could supplement a special education law that had been vastly weakened since her own experiences. One coauthor on this paper is also an attorney who has been a part of the dyslexic's ecosystem as a family support member and has experience with the legal aspects of disability. The third author is a media designer who has worked closely engaging in participatory design with sight-and hearing-impaired people for over a decade. The three met through co-participatory design of software to support multisensory learning outside of the classroom.

## 2.1 Sensory Modalities for Learning

Through our cumulative experience, we observe that multisensory techniques that incorporate multiple modalities often work well for teaching neurodiverse learners. The first barriers to remediation have commonly been issues of information retention and recall. Many neurodiverse children have deficits in working and short term memory, which are necessary for children to hold information in order to perform tasks like reading [14]. While a traditional learner can hold up to seven items in his or her working memory, on average, a dyslexic child can only hold three. One way to circumvent this problem and essentially "trick" the brain into holding information is through multisensory learning, whereby a children obtains information through multiple modalities (among the most common: visual, auditory, and kinesthetic) [8].

For example, a child learning to count might be presented with three marbles. The child will count to three aloud, engaging the auditory sense, but also touch each marble as he or she does so, engaging the kinesthetic sense. By engaging different modalities, children strengthen connection to the material and increase retention. Another example is teaching literacy by associating words with the sound of the word and pictorial representation [4]. Because each modality creates its own pathway in the brain to the information, the child is more easily able to recall it [13]. Since even traditional learners have unique strengths and weaknesses across modalities, the use of multiple modalities is advantageous to all children, ensuring they will have the opportunity to use the modalities best suited to their learning styles [2].

## 2.2 Ed Tech is the Ideal Venue for Multisensory Learning

For a variety of reasons, educational technology is the ideal venue for multiple modalities and multisensory learning.

### *2.2.1 Legal entitlement and access*

In the United States, neurodiverse children who meet the criteria of the federal Individuals with Disabilities Education Act have a right to demand that school systems consider assistive technology as a part of the plan of services that they receive [7]. Today, school districts have identified a higher number of eligible students than ever before, creating a need for technology specifically aimed at these populations [12].

Given the current financial climate, school districts may balk at the purchase of technology designed specifically for neurodiverse children. Schools may instead prefer to classify technology that serves the mainstream classroom as assistive technology. This means that instead of receiving technology aimed at remediating their issues, neurodiverse children may receive technology created solely with the traditional learner in mind. This practice, which fails to address the needs of this population, is legally accepted due to a Supreme Court decision which held that schools have no need "to afford [a neurodiverse learner] the same opportunity to meet her potential as afforded to her non-disabled peers" or to provide an "equal educational opportunity"; they must only do the minimum required for her to receive passing marks [3]. Any educational technology for the classroom should therefore be designed to be of equal use to both traditional and neurodiverse learners, as it may be the only technology available to either.

Current price points for mobile educational apps make them ideal for use by parents and schools already stretched thin meeting the needs of neurodiverse children. In order to access the services to which they are entitled by law, neurodiverse students must undergo a battery of tests proving their diagnosis, paid for by the school district. Parents also have a host of costs associated with their children, including fees for doctors, therapists, and tutors, as well as any testing that must be paid for out-of-pocket. The relatively low cost of mobile technology makes it an attractive supplement to these services.

### *2.2.2 Portability and personalized learning*

Because multisensory learning is not traditionally prioritized in curricula, teachers seeking to use it may have to independently seek out multisensory activities. Not all such activities are appropriate for the classroom, as they may be too loud or messy. Even when a teacher feels he or she would be able to carry out the activity in a school setting, the activity may use unorthodox materials that may be inconvenient or expensive to obtain. For example, one multisensory activity for the classroom is painting letters with spices, which engages senses of smell and sight, but requires the purchase of outside materials [10].

When multiple modalities are contained within mobile technology, concerns about inconvenience or inappropriateness for the classroom are easily resolved. Mobile technology has the additional advantage of being easily transported to wherever the lesson happens, which proves a boon for students whose learning difficulties mean they must continue to work even when school is out.

### *2.2.3 Stigmatization and social concerns*

Neurodiverse children are at higher risk for depression and social anxiety, even after they've transitioned out of the school environment [9]. Because diagnosing and dealing with their needs is time-consuming, they have less time for social interaction, causing them to lose the opportunity to learn social cues and customs that will benefit them going forward. They are further impacted by the need to travel to a special needs class or get special attention within the mainstream class, which singles them out in front of their peers.

Because technology has become so normalized, peers will not consider students strange if they have an iPad or mobile phone, removing one barrier to positive social interaction. Any help in remediation that doesn't stigmatize the student must be considered desirable, if not essential, to the student's mental health and their ability to dedicate themselves to their important work.

### *2.2.4 Self-sufficiency beyond the classroom*

The private nature of a student's interaction with mobile devices and applications allows the student freedom to experiment as to what methods work for him or her without concern for the social stigmas outlined above. For neurodiverse students, this freedom to learn how they learn is imperative. While traditional learners have little need to understand their process, neurodiverse learners must be able to consciously construct and facilitate the steps in learning that occur for others naturally and automatically. The right piece of technology can let students get things wrong without fear of stigma, without decimating already fractured self-esteem and lead them to powerful insights on understanding how they best learn. This is essential for self-confidence and self-sufficiency, especially once students have graduated into the wider world. Though the law ensures students will have some level of accommodation while within the classroom, once they're outside of the classroom environment, whether because school is out for the day or because they've graduated, students need to have independent strategies to fall back on. The dire nature of this need is evidenced by special education law's recent addition of "transition services," which seek to address self-sufficiency and life skills.

# 3. LESSONS FROM KNOWN METHODS AND UNIVERSAL DESIGN

Our approach to developing multisensory technology recognizes that there is much to be gained by a universal design for learning (UDL) approach [1]. A multisensory universal design learning approach that works well for neurodiverse learners can also benefit mainstream learners [11]. For these traditional learners, incorporating multisensory aspects can expand the appeal and efficacy of these programs as well as benefit those who happen to be tuned to different types of intelligences [6].

However, the mere presence of multisensory stimulation within an app by itself does not guarantee its educational benefit. OG and VV work because they help communicate core learning concepts through different modalities. The use of multisensory representation is designed to convey redundant and complementary representations of concepts that can broaden the student's experience of that concept. By invoking many direct and purposeful sensory experiences, a learner is able to understand the concept. In the OG and VV methods there are learning trajectories that involve multisensory engagement and rigid or algorithmic rules to help learners understand the relationships underlying phonics or deep reading. OG starts with a sensory appreciation for the components of text: for example, breaking down a word into constituent phonics is a rule that associates the phoneme to the syllables. The student can approach any word using the algorithm and map pieces of a word by combining the mappings between sounds to the letters.

In contrast, educational apps for mainstream audiences employ a more entertainment-based approach to multisensory stimuli [5]. For example, in letter-tracing or flash card apps, the multisensory avenues were often used as mere embellishment. In some cases, cute animations are given as rewards for correct answers. In other instances, arbitrary restrictions are imposed on the user's multisensory interactions (e.g. when tracing letters, requiring that the fingers approach and follow the line in a particular direction to create the letter). Some informal quotes from users we interviewed on these other programs give an idea of the pros and cons of existing multisensory technology:

*"He likes to start the letter 'O' from the bottom, but the program forces him to start his 'O' from the top."* – Parent

*It's easier to pay more attention when it's a viewframe with touching because it's part of a story. Better than copying down notes, just copying down and forgetting the next day.* – 4th grader

*"There are three choices, and he's memorized the right one, but I am not sure if he really recognizes the letters because they always appear in the same place."*--Parent

# 4. DESIGN PRINCIPLES

## 4.1 Fixed Content, Fluid Access

The first principle we propose is that educational technology should contain fixed content but fluid access. Apps or tech that allow children to reach the correct answers in only one way are no better than classroom methods that ignore modality strengths and the advantages of multisensory teaching. We therefore propose the idea of fluid access, meaning that multiple modalities should be available to get students to one unchanging truth or rule.

For example, a counting app that gives children an opportunity to learn through multiple modalities might show an image of the appropriate number of objects, speak the number aloud, and/or buzz the equivalent number of times in their hands. By keeping the method of accessing the answer fluid, the app ensures that children can learn whether through multisensory application or through a modality in which they have a particular strength. By providing multiple modalities, students can tailor their use of the app to their best learning style. An app that instead teaches counting only by showing the number will not be as universally helpful.

However, because fluid access provides so much freedom, it's essential that the underlying content remain unchanging and highly structured, anchoring the learning. The most successful programs for dyslexic children teach content that is rule-based and/or algorithmic. The highly organized nature of the programs helps cement the concepts. In math apps, this is easily accomplished as two plus two will always equal four. In literacy or subject apps, designers should keep in mind that the steps to teach about the content must remain structured and algorithmic. For example, while an application may provide for multiple means to write a narrative (such as speech-to-text, bluetooth-enabled keyboarding, or even use of a smartphone camera to gather images to write about), the initial steps to facilitate the process of writing must remain step-by-step, clear and omnipresent. Reliance upon constant review of old information even when learning more complex information is essential.

## 4.2 Continuous and Iterative Feedback

Once students use the app, they should be able to access data on which modalities were most successful for them. As mentioned above, learners and their support system, whether parents or teachers, succeed by understanding how learning works for them. Technology that provides multiple modalities should provide easily accessible data on a student's success with those modalities, whether that is information on success rate when using one modality over another or the time it took to come to the correct answer in each modality. Once that information is given, students are able to better understand how they might learn successfully, a lesson they can take and apply more broadly in all areas of learning. Self-awareness is essential to self-sufficiency.

This view is a contrast to monitoring mere success or failure in learning tasks. While we understand the need for assessing a student's success based on standardized criteria, we feel that information that helps student (and their caregivers) understand how best to maximize their learning potential is equally useful.

# 5. IMPLICATIONS

## 5.1 For Designers

We believe these principles will benefit designers as well as learners. Fixed content provides clear guideposts for them to follow, while the feedback practice provides ample data for quality assurance. Universal design practices also ensure that designers are pitching their products at the largest possible market to users who will reap the maximum possible benefits. While the best outlet at the moment is for mobile technology, designers can apply these principles to emerging technologies as well.

It is imperative that designers remain cognizant of the unique position they are in. At this point in the intersection of special education law and technology, designers have the ability to do justice that has normally been the purview of the law. Though this paper addresses only American law, its lessons emphasize why the legal framework for access should be kept in mind no matter what country is the primary audience for design.

## 5.2 For Learners

In the past, neurodiverse learners could count on two basic truths: that the special education law would provide them with an unequivocal right to meet their maximum potential and that this would likely necessitate a form of technology designed with them specifically in mind, as educational technology, still in its incipient phase, was not generally found in the classroom.

Now, as anyone who's ever seen video of a baby confusing a paper magazine with an iPad knows, technology is ubiquitous, even for children – and this is true even in the classroom. While this development may be a net positive, it coincides with a change in the legal interpretation of special education law that has cut the ground out from beneath neurodiverse children. No longer is the law interested in their maximum potential; instead, the court outright states that these children are not entitled to equal educational opportunity but only "some benefit" that lets them pass their classes [3]. Because of this weakened standard, schools have little incentive to purchase technology designed for neurodiverse children. This means that technology created for the mainstream learner may be the only technology neurodiverse learners ever see in the classroom.

This is especially dangerous because the impact that this tech can have on neurodiverse children cannot be understated; though these learners will one day reach the point where their services disappear, they will never reach the point where their disabilities do.

It's critical that neurodiverse children have access to technology that can teach them strategies while still under the protective umbrella of IDEA. Once a child assimilates how he or she learns, he or she can become an independent learner, able to succeed even once he or she has left school and entered the workplace and adulthood. If properly designed, ed tech can not only teach these children content areas like math or reading but the unique ways in which their brains work, helping them form learning strategies that will see them through the rest of their lives.

By this simple truth, designers can ensure that even as neurodiverse learners' disabilities survive the classroom, so will their autonomy.

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