Bread and Brain, Education and Poverty
Pontifical Academy of Sciences, Scripta Varia 125, Vatican City 2014
www.pas.va/content/dam/accademia/pdf/sv125/sv125-wolf.pdf

The Reading Brain, Global Literacy, and the Eradication of Poverty

Maryanne Wolf[1], Stephanie Gottwald[1], Tinsley Galyean[2,4], Robin Morris[3], Cynthia Breazeal[2]

Reading represents one of the most powerful, cultural inventions that humans have ever created. The importance of this achievement for the advancement of our global society cannot be exaggerated. The acquisition of reading changes the brain, propels the individual reader's intelligence, and advances the species' collective intelligence (Wolf, 2007). When a child acquires literacy, the life of the child is transformed, and so is the life of the surrounding society. That almost 200 million children, through no fault of their own, will never learn to read (either proficiently or at all) means that a huge segment of our species will never reach their potential for cognitive and social transformation. It is an incalculable and, we believe, preventable loss.

This chapter will be comprised of four parts, each of which will describe different theoretical and applied dimensions of our work. In the first more theoretical and historical section of the chapter, our goal is to describe – cortically, cognitively, and ethically – what it means to be literate for a child, and by implication, what it means to be illiterate. The second section will describe a bold, innovative set of efforts by our group to promote global literacy in remote regions of Ethiopia. This radical initiative combines advances in technology, cognitive neuroscience, and child development to develop an advanced form of digital learning. As will be detailed, our ultimate goal is to create an open-source platform that supports literacy development over the next decade that can reach millions of children who would otherwise never become literate. The third section provides more specific details on the methods, evaluation, and preliminary results of our efforts to date. Finally, in our last section we will argue that work on global literacy represents one of the most hopeful applications of theoretical knowledge to one of the world's most intractable sources of poverty.

[1] Tufts University, Center for Reading and Language Research.
[2] MIT Media Lab.
[3] Georgia State University.
[4] The Dalai Lama Center for Ethics and Transformative Values at MIT.

I. Theoretical Background

The Origins of the Reading Brain

Let us begin with a very simple, but profound insight: Human beings were never meant to read. We were biologically programmed to speak, see, think, and remember, but not to read. These other, more basic critical processes require vast neuronal networks that are genetically given. More pertinent to literacy, they are also the essential component parts for the development of a new *reading circuit* in the brain of every literate person. The reading circuit represents one of the most powerful examples of the brain's semi-miraculous ability to form new circuits from the neuronal networks used for older, genetically programmed processes. Numeracy (see Dehaene, 2011) and writing represent other examples. In the case of reading, the networks for vision, language, cognition, affect, memory, and attention are all brought together for something outside our basic repertoire of abilities. Pascal once wrote that there is nothing new under this earth, but that there is "rearrangement". The reading brain circuit is, from our perspective, the physiological instantiation of Pascal's principle of *rearrangement*.

But how does this rearrangement begin in a child? Although there remains much we have to learn about the development of any of the "new circuits", the combination of decades of work in child development and more recent brain imaging allows us to follow the formation of this circuit with increasing accuracy. It begins at the very start of life, as young children slowly develop each of the genetically preprogrammed parts of the circuit, particularly processes underlying language, hearing, cognition, and vision. For most individuals about five years are required for the development of each of these individual component parts before children gradually learn how to integrate the separate parts into one wholly new circuit for the purpose of reading. This integration, which is the basis for the reading circuit, never simply emerges without exposure to a writing system, and the nurturance of the environment or culture around the child.

Given the brain's *rearranging* capacity, most children learn to associate what they see, hear, and know with symbolic characters through varying amounts of teaching assistance. Although some children might be able to induce the alphabetic principle themselves (see Sartre's unusual account of his auto-didactic learning, in Sartre, 1963), the alphabetic principle requires demanding cognitive insights into the nature of a symbolic function. Whether the child is learning the alphabetic principle or other writing systems like Chinese and Japanese Kanji, the child must learn that a visual symbol corresponds to a specific sound, syllable, word, or concept.

Indeed the perceptual, linguistic, and cognitive hoops that every child has to move through to learn what it means to decode letters and words into meaningful units can be likened to a three-ring cognitive circus. In the first ring, the language system must be developed in multiple ways: from the outset, children must be exquisitely attuned to the unique individual "phonemes" or sounds of their language, that make up the sound structure of each word. Equally importantly, they must know the meanings and grammatical functions of hundreds and ultimately thousands of words, so that when they eventually read the word, they know what it means in a sentence.

The second ring is comprised of the fine-tuned perceptual processes that allow the child to detect the often subtle visual features of individual letters or characters. There are very specific groups of neurons responsible for the particular features that letters are comprised of, and indeed Dehaene (2009) writes eloquently about the "neuronal niche" that letters inhabit. In similar fashion, with sufficient exposures, other "working groups" of neurons become specialists for recognizing the particular letter patterns, and highly used words in any writing system.

The third ring involves the increasingly sophisticated and abstract cognitive processes that allow the child first to learn that a letter (or character) symbolizes a sound; second, that in an alphabetic system these sounds are blended to make words; and third, that words come together to give meaningful thoughts and information that ultimately propel their own thoughts. This last accomplishment requires ever more complex processes over time like inference, analogical and deductive thinking which all contribute to what we call "deep reading" (Wolf & Barzillai, 2009).

Finally, each ring's "acts" must be learned individually till they can be ultimately performed in tandem – flawlessly and synchronously – as a group of seemingly effortless performances. What we do when we read is very much like what a ringmaster does while conducting a three-ring performance. Quite literally, huge portions of the brain's visual, linguistic, cognitive and motoric areas are activated when first reading a single word or sentence. From a physiological perspective, it is one of the most impressive displays of activated cortex. Those who believe that human beings use only part of their brains have never seen images of the young reading brain at work! It is an extraordinary and impressive performance, that may be the most difficult the brain is ever called upon to perform at so young an age.

Understanding exactly what specific processes and underlying areas of the brain are activated at different stages of reading's development has been one of the foci of our work for many years, along with MIT colleagues, John and Susan Gabrieli and their research team. This systematic examination of the reading brain's formation in childhood has been and continues to be the basis for our group's efforts to create new approaches for helping children learn to read.

More specifically, we have created innovative reading methodologies that systematically target each component part of the developing reading circuit (Wolf, Bowers, & Biddle, 2000; Wolf, Barzillai, Gottwald, *et al.*, 2009; Wolf, Ullman-Shade, & Gottwald, 2000). Along with colleagues Robin Morris in Atlanta and Maureen Lovett in Toronto, we demonstrated through more than a decade of systematic, randomized treatment – control design studies how carefully targeted emphases in reading methods can help young and particularly young, struggling readers with dyslexia, learn to read with significantly more fluency and comprehension than other methods (see Morris, Lovett, Wolf *et al.*, 2012). From these studies, and related studies by other researchers, we have learned how to model the reading brain and to apply this knowledge to the teaching of the young in traditional school settings.

History of the Project

In the process of our work on intervention with struggling readers, we became increasingly aware of literacy issues outside our traditional research base in classrooms in the United States. A little over two years ago Nicholas Negroponte, the founder of the MIT Media Lab and the One Laptop Per Child initiative, approached the first and last authors with questions concerning literacy in remote regions around the globe – that is, places where there are neither schools nor teachers. Negroponte had become concerned about these issues because of what he discovered during his leadership of the One Laptop Per Child initiative, in which 2.4 million laptops were distributed to children in varied regions of the world. Although there were successes in countries like Uruguay, laptops in some other places could not be effectively used, because the children were simply unable to read. Negroponte, Breazeal, and Wolf began to discuss whether a digital learning experience, based on their different areas of expertise in reading and technology, could be created to help children learn to read on their own who had no access to school or teacher.

The facts then and now were and are overwhelming and more compelling than the multiple hurdles: 72 million children worldwide can never really become literate because they have no school. At least another 100 million children have such insufficient resources in their schools that they will never become functionally literate. The realities of these 172 million illiterate children pose staggering challenges and questions. We asked: Can our insights into the formation of the young reading brain and our research on methods for teaching children with dyslexia and other learning differences provide the basis for a completely new application of this knowledge base? Can we find and/or create apps and activities that target all the important areas in the reading brain circuit? Will children be able to teach themselves and each other with no adult instruction or help? Can our mobile technologies prove capable of delivering these apps and also assessment tools to ensure the efficacy of the approach? How can we implement these technologies and evaluate the children in the remote regions where most of these 172 million children live? In other words, we asked ourselves *whether it is possible to create a digital learning experience capable of combating illiteracy through mobile technology devices like tablets and smart phones in places and situations where schools and teachers are either unavailable or insufficient.*

Three factors convinced us that we have a unique opportunity to achieve massive inroads on illiteracy on a global scale. First, our increased understanding of the young reading brain and how to teach it makes the curation and development of innovative digital content a conceivable goal. Second, within technology there are increasing breakthroughs that make new mobile computer technologies affordable and available around the world, thus making the financial basis of digital learning possible for large numbers of children, something that would have been heretofore impossible. Moreover, wirelessly connected mobile computing devices have become a cost-effective platform for delivering learning content through multiple experiences (e.g., apps, videos, e-books, games, and online communities) to children across varied knowledge bases and skill domains.

Third, the growing ubiquity of connectivity, along with cloud computing and big data analytics, enable completely new forms of assessment both of children's individual progress and also of the performance of large populations (e.g., from the village to the country to the global levels). More specifically, by creating a tightly iterative design in which a child's performance can be immediately assessed, we could provide ever more targeted individualized instruction on the specific areas of need for a given individual. Such a design could provide one of the most important means for advancing learning on digital technologies, particularly in remote areas of the world.

These three factors became the context for our research consortium. Members of the Tufts Center for Reading and Language Research, MIT Media Lab, Georgia State University, and most recently the Dalai Lama Center for Ethics and Transformative Values came together to work towards one overarching goal: to investigate whether our evolving knowledge of the young reading brain, big data analytics, child development (particularly child-driven learning), and new technologies can be applied on mobile technologies.

Specifically, we sought to understand whether theoretically based content on affordable tablets could help children learn to read by helping themselves and each other, even in the absence of a teacher or literate adult. Nicholas Negroponte and the One Laptop per Child Foundation provided both the funding and infrastructure for the first deployments in Africa, and also the assistance of OLPC Matt Keller in negotiations with government officials. More recently, Negroponte went on to become director of a different, but analogous literacy-related initiative within the X Prize.

The responsibilities of the current members in the consortium are multiple: Tinsley Galyean, a member of both the MIT Media Lab and also the Dalai Lama Center for Ethics and Transformative Values, coordinates technological development and multiple dimensions of open-source platform development. Georgia State University's Robin Morris directs study design and statistical methods for the use of big data analytics in our evaluations; in addition, he coordinates new deployments in the rural South of the United States where literacy development also lags. Venerable Tenzin Priyardarshi from the Dalai Lama Center of Ethics and Transformative Values helps with future deployments in India and elsewhere, and also to spur the next phases of curricular offerings to include principles of ethical development in the overall project. MIT Media Lab Professor Cynthia Breazeal directs varied assets of software design and technological implementation, along with David Nunez, who is creating a mentoring engine for the tablet, in which children's choices of apps lead to more (or, in some cases, less) sophisticated content based on their performances. Finally, cognitive neuroscientist Maryanne Wolf and linguist Stephanie Gottwald and members of the Tufts Center for Reading and Language Research provide the basis for content curation and new content design, based on their research on the reading brain and early language and reading development.

II. First Deployment: Ethiopia

Overview and Background

In the fall of 2011, our consortium began an extraordinary, ongoing study in two remote regions of Ethiopia. Ethiopia represents one of the ten countries with the highest rates of illiteracy. Over half of its population of 91,196,000 people are illiterate. Two thirds of the women are not literate. The government spends approximately $86 per person a year on education, making it one of the lowest rates in the world. These particular sites were selected because of the infrastructure provided by the earlier OLPC initiative. Through these existing contacts with the Ethiopian government, and the critical support of the government and local leadership, the particular villages were chosen as representative of most of Ethiopia's inaccessible populations. The government refers to children in these regions as "pastoral children" who will have almost no opportunity for any form of traditional education in their area. The first village, Wonchi, is found on the rim of a volcanic crater at 11,000 feet and is an agrarian community with relatively good access to well water, but little access to main roads. To reach the village requires transportation by foot or animal in the last segments.

The second village, Wolenchiti, is located at the edge of the Great Rift Valley, which anthropologists believe may be our species' ancestral "cradle of humanity". There is no easy access to water in this second, tiny village, where children and adults walk daily five hours to and from the nearest source of water for their village. There is little vegetation in the arid, harsh living conditions surrounding Wolenchiti, and access to the village is extremely difficult. To assure that the investigators could reach their village by overland vehicle, the elders of the village removed almost one-half mile of large volcanic rocks to allow passage from the nearest road to their settlement.

Children and the adults in these two villages live "off the radar": they have neither electricity nor running water nor sanitation nor easy access to any form of transportation or communication. To the best of our knowledge, the children have not seen books or paper or pencils; they have not seen any form of technology, although this has not been independently confirmed. Perhaps most importantly for this work, the children speak Oromo, one of several languages in Ethiopia, and have never, or very rarely, heard English, or seen written language in either Oromo (which uses a Latin script) or English.

The four major hurdles that the children face are individually and collectively massive. First, they have had no exposure to any technology and must become computer literate at a basic level for any digital learning to occur. Second, many of the concepts that would appear on any of the varied apps and activities would be unknown by the children (for example, even the verb "swim" is a foreign concept to children who have no easy access to water). Third, the children have no exposure to the English language, and there were no appropriate apps or digital activities available in the children's native Oromo language. Fourth, although Oromo possesses a writing system, the children have had no exposure to it or to any other form of symbolic representation. No adults in these villages have had formal education or read in any language. Any one of these hurdles, much less all four, could prove insurmountable. The reason, however, for such a radical choice for our first deployment was that if we are able to demonstrate that children in these most difficult of conditions can make progress towards literacy, then there is a considerable rationale to believe that the millions of children in similar, seemingly impossible conditions for learning can also learn to read, using digital devices with carefully curated and/or designed learning applications.

In addition, there were two additional, powerful forces that mitigate against the acknowledgedly difficult hurdles these children face. The first was what we refer to as "Child-Driven learning". We believe that children everywhere around the world learn best when motivated by their own curiosity and desire to understand and "figure things out" for themselves. Child-Driven Learning involves learning that occurs alongside one's peers, almost all of whom share similar interests and have a drive to discover together. We believe that this additional factor is a key aide in education in areas where children do not have access to teachers. This form of learning has been the focus of some ground-breaking work in India by Sugata Mitra, who served as a consultant to our project in its earliest conceptualization. We sought from the start to study whether children would share their knowledge (which we conceptualize as a form of "teaching") with each other in this intrinsically peer-learning setting.

The second powerful force that we encountered from the outset involves the desire of the children's parents for their children to learn English. Indeed it was more important to the parents that the children would be learning English than literacy, because they knew that their children would have more opportunities for future employment if they knew English. The parents feel that the ability to speak English in Ethiopia is a virtual pass to higher paying jobs. From the perspective of the Ethiopian government, if the children begin to learn English, this factor might enhance some of the children's chances for future educational opportunities in Ethiopian schools, where English is typically taught. Based on these reasons, in our sites to this point, we have focused on the deployment of an English language-based literacy curriculum. There were good reasons for this initial choice in our sites, but it is one that we now hope to shift to include the native Oromo language as described below.

Directly corresponding to the four seemingly insurmountable hurdles that the children embody, we set four seemingly impossible goals for our work with them. The first goal of the project was to propel the children to a level of computer literacy, without human direction or instruction, that enables digital learning to occur. Without it, the rest of our work would be meaningless. The second goal involved helping the children to understand basic concepts of child development that may not be known in their culture, for example, basic categories around time, nature, colors, number knowledge (etc.) are not necessarily known in remote villages like Wonchi or Wolenchiti. Because our apps employ many of the basic concepts in their content, it was important to ensure sufficient exposure to these categories of conceptual knowledge so that the apps could be effective in teaching more abstract pre-literacy skills.

Our third goal comprised activities to help the children begin an understanding of oral English. For example, we have begun to create the first Oromo-English vocabulary apps that are based on the principle that children learn words most easily when they represent things (animate and inanimate) in their immediate environments. Thus, we asked our Ethiopian counterparts to take pictures of the children holding their own personal objects with the words *spoken and written* in both Oromo, the children's language, and English. For example, a boy from Wonchi held up a very thin chicken, while a girl from Wolinchite pointed to a very dusty, furry donkey. In the newest app, the words for the objects will appear on the side in both English and Oromo, and are audible when the viewer touches the word on the screen, a technique they have mastered already from other existing apps on the tablet .

Ultimately, we seek to build a more *universal template* for learning to read across various languages and writing systems. Towards that end, we are attempting to construct principles for the choice and/or creation of all apps, regardless of language. For example, from a linguistic viewpoint, we want children to know the full repertoire of the phonemes in whatever language they are learning to read, as well as the meanings of the basic concepts in early child development, regardless of culture. We want to provide apps, therefore, that present the more universal perceptual, linguistic, and cognitive principles that are needed for the development of the reading circuit, whatever language is being read. Similarly, we want all apps embedded within a design that arouses children's intrinsic curiosity and allows them to learn on their own initiative. This design will be agnostic of content and curriculum and even mobile device.

Our fourth and most difficult goal was to introduce the children to the *precursors of literacy*. These included the important elements of alphabetic knowledge, such as 1) learning the alphabet and being able to "recite the alphabet" in a group or as an individual; 2) learning to identify letters by pointing to a letter that is heard; 3) learning to give the name of the letters in both serial and mixed arrays of letters; 4) knowledge of letter-sound correspondences (e.g., being able to give the sound or sounds associated with each letter of the alphabet); 5) writing letters to dictation; and 6) acquiring very basic sight word recognition (e.g., reading – though *not yet decoding* – the most common early words like *mother, father, baby*).

Our thinking throughout this early phase of our deployment is that if we can someday achieve all of the first four goals, the immediately subsequent goals will involve basic decoding of simple words and basic reading comprehension of brief passages. We would then be able to introduce several other curricular domains, such as numeracy, health and hygiene, and ethical development. For example, plans are currently underway to use student seminars at Tufts, MIT, and the Rochester Institute for Technology to create apps that will begin to extend learning into these domains.

An old maxim in reading research, often quoted, by the late renowned reading researcher Jeanne Chall, is that children must learn to read, so that they can "read to learn" (Chall, 1983). Our ultimate objective for these children is to enable them to move along a continuum of literacy pre-reading precursors to reading acquisition to that critical reading transition from learning to read to reading to learn. If we can propel them to this stage, we can also introduce them to a whole world of learning across multiple domains.

If, over time, we can help the children in the two tremendously challenging Ethiopian environments to attain first or even second grade levels of reading comprehension, this level of early reading development is sufficient to serve as a platform for true literacy in the children. Such a level involves fluent decoding and what we are calling "deep reading" (Wolf & Barzillai, 2009). The latter form of reading represents a hierarchy of skills that are necessary for more sophisticated forms of thought including: inference, analogy, inductive and deductive reasoning, and finally insight and novel thought. These skills, in turn, become the foundation for the equally abstract thought necessary to develop more heightened understanding of concepts like empathy, perspective-taking, and moral problem-solving.

By the time we reach the stage of learning in which children are reading fluently across varied domains, our very largest goal is to have developed a global open-source platform that is a repository of many different apps from around that world that can introduce children to multiple areas of learning and whole different cultures and languages. We are already receiving requests from Ethiopia for content in health and hygiene. We wish to ensure the opportunity for all types of learning to occur on our platform, particularly in numeracy, math, science, and ethical development. We envision that such a platform will also include data collection and data analytics to be able to measure and assess what children are doing with the tablets or other devices, their level of engagement, and their level of mastery of the materials and activities.

A key dimension of this platform involves harnessing the power of Child-Driven Learning as a social force that propels how children explore, discover, share and learn together. Our vision is not only to support child-driven learning within each local community of children, but also to connect these learning communities across the globe. In this way, children from different deployment sites will be able to discover, share and communicate through specially designed apps that support children's desire to create, communicate, and share with one another. For instance, something as simple as a dictionary of culturally relevant concepts (e.g., the concept of "home") could be co-created with children in different locations via a specially designed app that grows as children add contributions. Children can take pictures or videos of what constitutes a "home" in their culture, describe it with written words, recorded voices, or their personal drawings, and then share them with each other. Over time, children all over the globe could contribute what "home" means to them. This not only serves to build children's conceptual knowledge and vocabulary in a rich multi-modal format, it also helps to build empathy and understanding across different cultures, a parallel goal of our work.

III. Methods, Design, and Results of First Deployment Study

Tablet Description and Usage

In this section we present more detailed information about our efforts to date. At the most general level, we pioneered a tightly-iterative, evidence-based approach to global literacy in which we a) collected data (cross-sectionally and longitudinally) through android tablets to track how children use the tablet and apps; b) assessed their learning via the tablet; and then c) used these data to improve, adapt and revise our custom apps and tablet experience.

The devices used in this first deployment were android Motorola Xoom tablets. The tablets required a solar-charging system that was provided to each village. The villagers built a small structure for the solar-charging units. The structure served almost immediately as a gathering place for the children. Two computer engineers from the University of Addis Ababa, Michael Girma and Markos Lemma, who were part of the original OLPC infrastructure, taught adults in the village to use the solar power units so that the tablets could be recharged every night. The computer engineers were the first to give the tablets to each of the forty children (twenty in each village), but were instructed not to teach the children how to use them or problem solve for them. They developed strong relationships with the children and their families in the villages. Twice a month, the two computer engineers visited the villages, maintained the equipment, and swapped memory cards so that researchers in the consortium were able to study how the tablet contents were used from minute to minute by the children.

The MIT team developed an automated method for data collection and remote app updates via a cloud backend where wifi is accessible. Such a system is currently working with new deployments in the US, with plans to provide this capability with other communities in other countries, often where there is a school or a community place where a wifi access and a place to charge the tablets is available.

Tablet Content Principles

As described, the components of the reading brain circuit for written English comprised the template for what we called the essential "app map". This template involved what we conceptualize as the ideal set of components necessary for the formation of pre-reading, with emphases on the well-known and not-so well-known language, perceptual, and attentional processes in the young reading brain circuitry. For example, some skills included in the app map are those commonly associated with learning to read: i.e., phoneme knowledge or sound awareness, vocabulary growth, conceptual knowledge, letter-naming and letter-sound knowledge, sight word recognition, decoding and comprehension skills. Other skills, less commonly emphasized, involve auditory perception of phonemes and rhythmic patterns known to foster phoneme awareness; knowledge of the multiple meanings of words; learning syntactic functions of words (e.g., action verbs), etc. This more comprehensive ideal template for apps was used as the basis for selection of the digital learning activities included on the software in Ethiopia, each of which are in English.

It is important to note, however, that what we selected and what we sought were not the same. At the time of our first curation, there was a paucity of high-quality apps and activities for the android tablet that target the multiple components of our ideal app map. We chose, therefore, a group of apps which were approximations of the apps we hope someday to use; a large group of E-books of well-known children's stories; videos of topics that taught early conceptual development; and selected segments of educational television devised for young pre-readers through the cooperation of our public television colleagues in WBGH in Boston. Altogether there were over 325 apps, videos, and activities for the children to select from on the tablets. The basic processes that were addressed at least in part with these apps and activities included: alphabetic knowledge, letter name knowledge, letter-sound correspondence principles, early conceptual knowledge, early language learning in the English language, some basic decoding principles, and some sight word recognition.

What we found during our curation was that while there has been much work in developing educational apps, the skills and abilities that they promote represent a relatively small portion of the entire app map that we envision. Further, there were very few apps that targeted some of the most important precursors like phoneme awareness and blending. One app which we consider a prototype for future development of apps for concept development was particularly engaging to the children in both villages. Called a TinkrBook, this app represents a new kind of interactive story that supports and invites children to "tinker" with text and graphics to explore how these changes impact the narrative (See Chang and Breazeal, 2013). One key design principle is called "textual tinkerability", where an interactively reinforced association links the written word, the spoken word, and the graphical depiction of the concept.

For instance, in the version of TinkrBook used in Ethiopia, the child follows the story of the hatching of a baby duck. More importantly, through the interactive features of the app, the child *guides* the duck through its very first day of life. First, the child helps the duck hatch out of the egg by being " invited" to tap on an egg that is wiggling and obviously about to hatch. The words on the first page are "Tap, tap, tap. Pop!" Second, each time the child taps the egg with his or her finger, the egg cracks a bit more. Each successive "tap" of the child's finger highlights the word, as it is spoken. The child can touch the word "tap", and hear the word, as well as see the egg crack a bit. Thus, there is a consistent multi-modal reinforcement of the concept "tap", even in the first word of the Tinkrbook. Third, once the egg is tapped three times, the egg pops open, and the word "Pop!" is highlighted and spoken. From this point on the child helps to guide the baby duck through the rest of its memorable "first day". The child bathes the duck with colored soaps and, in the process, can experiment and learn about colors and mixing colors creates new shades of color.

With each new concept that is introduced in the TinkrBook to the child, there is an in-built assessment component for the child to demonstrate his or her knowledge on the next page of the story. Importantly, the TinkrBook records all the data for how the child explores the story and the concepts within it. For instance, we know how many times the child has touched a particular word, has heard a word spoken, or has interacted with a graphic that illustrates the word. In the case of the frog scene, we know which color words the child has explored. As a result, the TinkrBook will only present the child with a "probe" for those colors the child has in fact engaged. Over repeated exposures to the TinkrBook, we can aggregate how many times children have been exposed to specific color concepts over weeks or months. This is another important kind of longitudinal data that can also be leveraged to evaluate the children's understanding of color in other apps. For instance, we designed a simple matching app to examine children's ability to match the words within the TinkrBook and other apps to pictures of those words. We specifically designed the matching game app to test those concepts we knew the children had many encounters with through the data we collected via the tablet.

This simple example of one app's construction illustrates how we can harness the flexibility of cloud-connected devices and app features to inform the design of new apps. But the process of curation for our first deployments also illustrated the need for far more, theoretically grounded apps for the android tablets.

Testing Measures

During this year, the first author collected the first preliminary behavioral data with the children in both villages. Both U.S.-standardized and non-standardized measures were used in these areas: receptive vocabulary; knowledge of the alphabet (through letter identification on serial and mixed letter arrays; alphabet recital; letter-sound correspondence rule knowledge; and letter-writing); and basic sight word recognition and decoding.

Receptive Vocabulary. The children were assessed using experimental versions of commonly-used U.S. standardized measures adapted for the harsh environment, fully acknowledging the many limits of such cross-cultural evaluations. For example, a common measure used in reading and language development research is the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007). The published version of this test would have been unsuitable for an environment in which testing the children could not take place in a quiet, one-on-one setting and had to be completed quickly. Moreover, we knew the children would only have the chance to know those vocabulary words to which they had been exposed on their tablets. Thus, we used a similar format – where the children hear a word and see four pictures and are asked which picture matches the word they heard – but only included a random sample of 20 words based on both conceptual categories and on the content available on their tablets.

Knowledge of the Alphabet. We tested the letter-naming and letter-sound knowledge of the children in several ways: 1) Letter Identification – a small selection of letters were to be pointed to when named by administrator; 2) if successful on (1), the subject was asked to point to a letter that could appear anywhere within a random array of the 26 letters in the alphabet; 3) Alphabet Recital –children were asked to recite alphabet orally; 4) Letter Naming – children were asked to name the sound that the letter represents in a limited selection of letters.; 5) Letter Writing – children were asked to write all the letters they knew on paper with pencil (note they had no experience with either).

Sight Word Recognition and Decoding. Finally, if children could perform at high levels (80% accuracy) on the vocabulary and alphabetic tasks, they were asked to read a short list of basic sight words that represented known concepts and were found in apps (e.g., *baby, mother, father, dog, cat).* If children could perform well on sight recognition words, they were asked to read a selection of easily decodable words, that were not common sight recognition words (e.g., *bat, tap*).

Summary of Behavioral Results and Engagement Data

Our first formal assessments of the four goals for the children in Ethiopia after one year are extremely promising (i.e., technological familiarity; basic conceptual growth and vocabulary development; and literacy precursor skills).

First, except for two children whose parent decided that children cannot learn without a teacher, all the children are completely "computer-literate" with the tablets. The earliest data indicated that in Wonchi, all the children were able to turn on their laptops within the first day without instruction or direction; in Wolenchiti, by the second day all were engaged. By the end of the first month every app had been activated. The children are totally "at home" with these technologies.

With regard to our second and third goals for growth in concepts and vocabulary, all of the children in Wonchi knew some of the tested English vocabulary words; over half of the children knew the meaning of over half of the words. This result is encouraging when one takes into account two facts: 1) the words on the assessment were randomly chosen from the apps on the tablet, and 2) the children had no environment to practice their knowledge of these words. Despite the fact they speak no English, most of the children learned many basic vocabulary words.

The "precursors of literacy" goal is both the most challenging and the most surprising. The children are achieving remarkable precursor literacy skills with the tablets even in this short time period. All of the children were able to recite all of the letters of the alphabet. Most of the children recognize most letters in any array – serial or mixed. Most were able to write their letters, despite not having had paper or pencil before the testing (although we have pictures of them writing letters in the dirt with sticks).

In other words, they were able to generalize motoric skills from tablet and ground (!) to paper. A smaller group knew letter-sound correspondence rules. This group can recognize almost all English letters in any array, can write letters from memory, and most importantly can read a group of sight words. These top performers, therefore, were and remain at this writing on the cusp of beginning to read. No child in either village was able to decode the words in the decoding task.

It was noteworthy that in both villages, the older girls were among the most advanced readers and were actively teaching the other children: the creation of a teacher from amidst a situation in which there had been no teacher before was an important emergence. It was akin to watching the emergence of the "first school".

This latter observation suggests at the present moment that with improvements to the platform and the applications and media that are to be delivered in the coming year, some portion of the children in the two villages will be able to make the next critical step to learn to decode and to comprehend what they are reading. To help them connect this textual knowledge to their own knowledge, we are presently creating stories and apps that are based on Ethiopian village life and also on our first analyses of the engagement data, described next.

Engagement Data

We have begun to analyze some of the massive data we have to date on multiple dimensions of the children's usage of the tablet. At the most general level, data collected over the last year indicate that children used the tablets about 6 hours a day, often sharing the multiple apps and educational media on the tablets with each other. More specifically, five findings in Wonchi during the first 12 months of the project are illustrative. First, over 325 apps (including ebooks, video stories, games, music videos, and related materials) were opened and explored. Second, based on the 20 tablets most used by children, over 85,000 app opening events occurred (Wolonchete had over 166,099!), with the most frequent being the TinkrBook app (described above) with 5882 initiations. Third, peak app use occurred during weeks 3 and 4 with over 9883 apps opened; lowest use occurred during the summer (averaging 405 apps opened during August). Fourth, children developed favorite apps, with only 20 apps accounting for 25 percent of all activities (over 20,000 app opening events), a majority of which were literacy-focused. Finally, as the year progressed, quantitatively, children opened less apps, but qualitatively spent much more time using a specific app, thus indicating more in-depth engagement with apps over time.

Overview of Preliminary Data

When taken as a whole, the behavioral data in the present deployment provide a vehicle for studying the emergence of literacy in a group of children who have never seen symbolic text. They also demonstrate a first proof of concept to show how mobile devices like the tablet can give children access to the precursors to literacy and to beginning to learn another language.

There are observational data that are less formal, but that require note. As described by both the first author and in the bi-weekly site visits by the two computer engineers, the child-driven learning dynamic that emerged in both groups of children in Ethiopia created a natural collaborative atmosphere in which kids of greater ability appeared compelled and excited to help the other children by taking a leadership role. If expanded and reinforced over time, we believe that such positive, collaborative exchanges among children will create a natural environment for the development of such interactional abilities as empathy, a sense of interconnectedness, and a stronger awareness of self and other. They may also contribute to facilitating heretofore unknown leadership capacities. Certainly the young boy who taught everyone how to use the tablets initially became the unlikely hero of the village and took on the role of teacher over the last year. Similarly the older girls were clear teachers for the younger children in both villages.

The collective pilot data and our insights into them are still ongoing in the deployments in Ethiopia. The children of Wonchi and Wolenchiti have given us a never expected petri dish for literacy and a still unfolding story. It is, we believe, a new chapter in our society's collective understanding of what literacy and child-driven learning mean in the life-course of a young human being, wherever and whatever the circumstances.

IV. Next Directions

The leitmotiv of this chapter, and indeed of all our work, is that literacy can open the mind of a person to a potential lifetime of knowledge in all its varieties, and, in the process, to creativity, personal growth, and critical thought. Such forms of thinking in a society can fuel discovery, productivity, and innovation, which, in turn, can drive economic growth, public health, and the well-being of that society. What we do not know is whether we can replicate the same early learning curve in children in different environments which may be equally difficult in some ways, but more hostile to learning itself. For example, the parents of the children in both villages could not have been more supportive. What of children in a Mumbai undercity, like those described so eloquently by Katherine Boo (2012), who have no such supportive families and whose basic goal must be to survive?

What of children who have schools, but schools which are so overpopulated and understaffed that 60 to 100 children may be taught in a single classroom by one insufficiently prepared teacher? And what of children in our own "backyard" in rural United States, where poverty and inadequate language environments render them at risk for school failure before they even enter the Kindergarten door?

To address these and related questions of generalizability, we plan or have begun new deployments in each of the above situations: in undercity populations in India; in settlement schools in South Africa; and in language-impoverished populations in rural Georgia and Alabama. Each of these deployments will bring unique challenges to our work and provide us with unique opportunities for increasing the utility of our platform for increased numbers of children.

To address the clear lacunae noted in app development, we are actively seeking funding towards the development of a more comprehensive set of new apps that will better target more components of the reading brain circuitry and that will also be more interconnected to each other. For example, we wish to be able to assess children's mastery of concepts and skills in the new and older apps and to help children move more seamlessly from one skill to the next with them. Towards those ends, we are working to combine the ideal app map with a new mentoring system that will connect the child's performance to a network of sequenced learning targets. This will allow for more dynamic learning by the child in a digital learning environment, and it will automatically connect one set of skills to multiple other related skills. In the process, the new system will highlight the relationships between lower-level knowledge like vocabulary learning with higher-level skills like comprehending written words, while still allowing the children to follow their own path to learning how to read. Thus, some children who spend less time in a particular area that represents a weakness (e.g., vocabulary), will be encouraged to select apps that provide a different form of interaction with vocabulary, one that can then lead to more progress in the more complex activity of decoding "harder" words. Other children may excel at learning vocabulary, but struggle to understand basic letter-sound relationships. They will be encouraged through the mentoring system along a different path with apps that enhance their weak areas, as they develop their strengths.

Such a system will allow us to monitor these children closely and ensure that the content remains engaging and fun for them, even though they may be having difficulty with some new skills. Ultimately, we want to be able to track children's use of every app, the amount of time engaged, and their performances, in order to build an adaptive, individualized learning system that will maximize their literacy development. .

A more global goal is to use our collective insights about apps to date to foster the development of more carefully constructed, language and literacy-relevant content on an international scale. This can be done by empowering app developers to work with experts in various domains on the creation of content directly related to language and reading development. Such a process, we believe, will enable teachers, researchers, and facilitators to contribute socially and culturally relevant material: For example, the development of photographs and picture collections that represent vocabulary in the local context, or the creation of local myths, fables, and stories that can be uploaded into interactive storybooks.

One can also imagine in some settings enlisting older literate children not only to interact with younger children on such apps as the TinkrBook, but also to write stories using particular vocabulary words that are automatically developed into apps for the younger children. This has several benefits beyond providing content that is contextualized and relevant to the local population. It creates a community of creators that keeps evolving the material over time, allowing the system to react to the growing and changing population of users. It also allows the project to cross-pollinate different populations.

As one present example in our most recent deployment, we hope to inspire children in the rural US to create material for vocabulary and stories that can be sent to Ethiopia, and vice versa in an exchange. This would not only expand and reinforce their understanding of the vocabulary by showing variations in new physical and social contexts, but, just as importantly, it fosters curiosity and understanding about another culture. We believe that these children will become far better prepared to understand and empathize with other children from all over the world, and will have a new perspective on who is "other". Thus the development of apps for literacy to us is, in fact, a potential vehicle for the conceptualization of a far broader learning experience that can embody principles of ethical and character development.

Indeed, based on our ongoing work to date, we envision three primary vehicles for how ethical development curriculum could be extended within the present platform in the near future: 1) weaving aspects of character and ethical development into future language-literacy curricula through stories that portray empathy and leadership qualities among characters, as well as that provide moral problems and dilemmas to solve; 2) leveraging the connections between different learning communities to inspire greater understanding and connectedness with people outside children's immediate environs; and 3) adapting and/or developing specific apps in ethics curricula for older ages (Note: an ongoing area of work in the Dalai Lama Center for Ethics and Transformative Values) for use with younger populations.

The ultimately envisioned platform is conceptualized as a global hub to foster a new, intellectual/technological movement in which an international community of users, developers, technologists, scientists, education practitioners, policy makers, and families work together to create a place where the digital assets, findings, and methods of best practice can be shared by all to help all children have their best chances to reach their potential. We think of this future entity as a kind of place where "Wikipedia" meets "Grameen Bank" – where interactive educational content can be deployed on mobile devices to any corner of the globe, and become an investment in all the individuals and communities reached

.

Summary

If our combination of a theoretically based, digital-learning experience and child-driven learning can be successful across such diverse cultures and settings, we estimate that 100 million children could have the potential to become literate in the next generation. The implications of such an advance in literacy and its sequelae would be extraordinary, beginning with decreasing poverty and mortality rates, and extending to increased understanding and connections across vastly different cultures. Literacy does not insure a conflict-free world; but its absence almost assures the existence of conflicts between the literate and the non-literate.

At the most basic level, literacy changes the brain of every literate person through new circuitry, which allows new forms of thinking and learning. At the level of society, literacy rates translate into greater community involvement and civic participation. Further, each new generation of readers passes these skills and their accompanying expectations on to their children and grandchildren, thus potentially ending the cycle of illiteracy and, very importantly, changing its insidious correlate – poverty. Higher rates of literacy empower young women to seek greater educational, economic, and even entrepreneurial challenges, which, in turn, make them more likely to raise healthy, literate, economically independent children. With the most basic of tools, individuals with an adequate to advanced level of literacy can become full-fledged members of society and can become involved on an equal basis in social and political discourse. As the world around us changes the way information can become available to anyone with access and the ability to read and understand it, there is a potentially revolutionary leap forward possible for the citizens of our world, wherever and whoever they are. There has never been a time in human history when literacy has been more important to a child's future, or more possible.

Until we demonstrate that children in our villages can learn to read, our acknowledgedly bold hope at the time of this chapter's writing is that the unfolding story of a literacy initiative in two tiny villages in remote Ethiopia will inspire us all. We hope to bring to the collective consciousness around the world the profound, intellectual generativity that lies at the heart of reading and the great waste when children never enter the worlds of knowledge opened for them by literacy. From the start of our work to the still distant moment when we can give this work to others, our constant goal is to elicit in children everywhere a desire to use literacy to go beyond their own knowledge. We want the next generation to learn to read and to think in ways that render the new readers capable of the highest forms of creativity and reflective thought.

In so doing, we seek to release the potential of children who might otherwise be exploited, underutilized, or completely excluded from the ever-changing societies in our own world. If we achieve even some part of our goals, we predict that whole new forms of literacy will emerge that will increase connectedness among children and individuals around the world and, in the process, usher in new dimensions of empathy and compassion for human beings they would never otherwise have encountered in their lives in Mumbai, Wonchi, Wolenchiti, Bangladesh, Uganda, urban Los Angeles, and towns in our own rural backyards, like Blakely, Georgia and Roanoke City, Alabama.

References

Boo, Katherine. (2012). *Behind the Beautiful Forevers: Life, Death, and Hope in a Mumbai Undercity*. New York: Random House.

Chall, J (1983). *Stages of Reading Development*. New York: McGraw-Hill.

Dehaene, S. (2009). *Reading in the Brain*. New York: Viking.

Dehaene, S. (2011). *The number sense (2nd edition)*. New York: Oxford University Press.

Dunn, L., & Dunn, L. (2007). *Peabody Picture Vocabulary Test (4th ed.)*. Circle Pines, MN: American Guidance Service.

Morris, R., Lovett, M., Wolf, M. *et al.* (2012). Multi-component approaches to reading intervention. *Journal of Learning Disabilities. 45 (2)*, 99-127.

Sartre, Jean-Paul. (1963). *The Words: The Autobiography of Jean-Paul Sartre:* Amereon Limited.

Wolf, M., & Barzillai, M. (2009). The importance of deep reading. *Educational Leadership*, 131-140.

Wolf, M. (2007) *Proust and the Squid: The Story and Science of the Reading Brain*. New York: Harper Collins.

Wolf, M., Barzillai, M., Gottwald S., Miller, L., Spencer, K., Norton E., Lovett, M., & Morris, R., (2009) The RAVE-O Intervention: Connecting Neuroscience to the Classroom. *Mind, Brain, and Education*, 3(2), 84-93.

Wolf, M., Ullman-Shade, C., & Gottwald, S. (2012). The emerging, evolving reading brain in a digital culture: Implications for new readers, children with reading difficulties, and children without schools. *Journal of Cognitive Education and Psychology,* 11 (3).