Reading and the Brain: What Early Childhood Educators Need to Know

Article *in* Early Childhood Education Journal · August 2010

DOI: 10.1007/s10643-010-0387-z

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Early Childhood Educ J (2010) 38:103–110
DOI 10.1007/s10643-010-0387-z

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Published online: 13 April 2010

Abstract This manuscript focuses on neuroscience research that may have applicability for early childhood educators. Beginning with cautions about the usefulness of neurosciences, we offer reviews of several ideas that can inform the practice of early childhood educators. We begin with the understanding that reading is not innate, meaning that every brain must be taught to read. We continue with the idea that language learning physically changes the brain to remind early childhood educators that their instruction can be powerful. We note the research focused on repetition that leads to automaticity, a key finding from reading research that results in skilled readers. We also discuss the importance that visuals play in learning and then note that children are hardwired to imitate others, which is why teacher modeling is so important. We conclude the article with future research needs and implications for educators.

Keywords Reading · Brain · Neuroscience · Learning

Introduction

The education field is awash in findings about brain development and its implications for the classroom. In addition to dozens of new books, there are national conferences dedicated to helping teachers understand so-called "brain-based education." We are both fascinated by and skeptical of the evidence collected thus far concerning the significance of brain research for teaching. Fascinated because a better understanding of the very organ we're trying to influence could transform teaching and answer many of the questions educators have; skeptical due to the generalizations and leaps of faith some people are making based on limited data collected in clinical settings. However, in a decade where "scientifically based reading instruction" has become increasingly valued, we are interested in locating neuroscience research that validates and extends our understanding of quality reading instruction for young children. This article draws from neuroscientific research regarding how reading acquisition occurs and some possible explanations for why it doesn't happen for some children. Accordingly, our hope is that readers become informed consumers of the research in this field. In addition, we make recommendations for future research that could extend knowledge in both the educational and neuroscientific fields, as well as expand the knowledge base regarding developmentally appropriate practice for children in preschool and primary education (National Association for the Education of Young Children 2009).

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The Emerging Field of Neuroscience: What is Its Role in Early Childhood Education?

Neuroscience is a loose collection of specialties and includes neurobiology, neuroimaging, neuropsychology, neuropharmocology, and even neuroeconomics (the study of why you buy things). Language arts, on the other hand, has more defined fields such as reading, vocabulary, writing, and oral language development. Current findings emanating from neuroscientific fields can inform, but also confuse. Neuroscientists readily acknowledge that the field of reading research is much more advanced in its study of reading behaviors. Eden et al. (2004) cautions, "it should be noted that brain imaging studies… have not yet employed the reading-level matched design that is prevalent in behavioral studies of reading disabilities" (p. 417). However, cognitive neurosciences can serve the useful purpose of informing biologically what we understand behaviorally. And just as importantly, the reading research field must understand the clinical work of the neurosciences community in order to contribute insights at the applied level.

There is debate about the application of neuroscience research in education, and it is complicated by the diversity of specialties within the neurosciences. In 1997, Bruer argued that linking neuroscience to education was "a bridge too far" (p. 4). An emergent field of research, called neuroeducational studies, focuses on bridging the fields of psychology, neuroscience, and education to create a set of methodological, ethical, and empirical practices for conducting and reporting findings (Howard-Jones 2009). The Harvard School of Education introduced an interdisciplinary master's degree program in Mind, Brain, and Education earlier in the decade to address practice and public policy issues related to this emergent field, especially as it applies to reading and reading disorders (Fischer et al. 2007). Related programs are offered at Dartmouth College and Cambridge University.

The rapid changes in the technological tools available in the neurosciences mean that as educators we should not fail to revisit the possibilities that lie in the educational neurosciences (Varma et al. 2008). There are ideas from the neurosciences that are important for teachers to understand. In the same regard, there are ideas in reading research that are important for neuroscientists to understand. An analysis of the research suggests five topics worthy of attention. For each of the topics, we will make connections to reading acquisition research and practical guidelines for preschool and primary grade teachers.

Reading is Not Innate

Oral language and written language are fundamentally different. This can best be demonstrated by two recurrent findings; first, that even though most young children without disabilities learn to speak or listen, not all become fluent readers and writers (Schultz 2003). One finding from neuroscience confirms the complex nature of reading acquisition and forwards the theory of neuronal recycling (Dehaene and Cohen 2007). Unlike speech, which develops uniformly across languages and cultures and is directly associated with specific brain and motor structures (Tomasello 2008), reading occurs only through the intentional appropriation of existing structures within the brain. While many thousands of spoken languages have existed during the course of human history, not all have a written language component. Reading is a complex, rule-based system that must be imposed on biological structures that were designed or evolved for other reasons. Most children are born with the right structures, but these structures do not inherently know how to read.

The brain has evolved for hundreds of thousands of years as a speaking and listening brain, while written language as only existed for 6,000 years (Wolf 2007). Pinker observed, "children are wired for sound, but print is an optional accessory that must be bolted on" (Pinker 1999, p. ix). The human brain is able to accomplish this through the repurposing of brain structures, through the process of neuronal recycling. For example, the reading brain must figure out a way to convert the occipital region of the brain, which is designed to recognize objects, into one that recognizes letters and words. Letter and word recognition must be further coordinated with the auditory areas of the brain that process the sounds of language and assemble them into meaningful strings. This loop between the occipital lobe, Broca's area in the left frontal lobe (language processing), and Wernicke's area in the left temporal lobe (language comprehension) must be trained to coordinate efficiently. Any disruption in this pathway can potentially interfere with reading comprehension (e.g., Perfetti 1985). A portion of this coordinated system, called the dorsal stream, links the visual cortex with a spatial attention area that locates objects in space. In a study of entering kindergarten students that used reading behavior measures and functional magnetic resonance imaging (*f*MRI), Kevan and Pammer (2009) found that difficulty within this pathway was a predictor of reading problems 18 months later.

The behavioral reading literature confirms the importance of early experiences with print to prepare young children for reading instruction. These serve as a means for establishing and strengthening the coordination of the phonological loop, which perceives and produces the sounds of meaningful language, with the long term memory systems needs to acquire and sustain reading behaviors (Cunningham and Stanovich 1997; Swanson 1999). Young children need to be read to and talked with, even before they enter formal schooling (e.g., Hart and Risley 1999). As Duursma et al. (2008) note, bedtime reading stimulates a wide range of a child's development, from language to motor skills to memory. Children require a rich set of experiences that ensure that they hear, process, and produce language. In addition to advocating for family reading time, early childhood teachers must implement intentional instruction that ensures students have lots of opportunities to engage with oral and written language in ways that allow them to explore the sounds, sights, and meanings of words. This is consistent with the NAEYC position statement's advice that "language interactions throughout the day" offer a "linguistic payoff [through] extended discourse" (2009, p. 7).

Wolf adds, "The more young children are read to, the more them will understand the language of books and increase their vocabulary, their knowledge of grammar, and their awareness of the tiny but very important sounds inside words" (2007, p. 223). Being read to builds the neural pathways critical to written language comprehension and production. By connecting these reading experiences with reinforcing activities such as eating, being held, and receiving attention, a pleasure pathway is formed that connects reading with enjoyment in the brain.

Language Learning Physically Changes the Brain

The second implication from neurosciences is that experience changes neural connections. When we experience something, neurons fire. Repeated firings lead to physical changes that, over time and with repetition, become more permanent. The functional organization of an individual's brain is the result of intense and relentless competition for space on the cortical map. Because the brain is not as hardwired as was previously thought, these brain maps can be noticeably altered in days or weeks. For example, Mark et al. (2006) summarized a number of transcranial magnetic stimulation (TMS), (*f*MRI), and other neuroimaging approaches that document the changes that occur in a stroke-damaged brain due to therapy.

While strokes in early childhood are rare, the evidence that learning leads to changes at the biological level expands our understanding the effect of teaching on the learner. In an *f*MRI study of elementary students with reading difficulties before and after 100 h of sentence comprehension instruction, Meyler et al. (2008) found brain activation changes that persisted when analyzed 1 year later. Neuroplasticity, the brain's ability to physically change, is an important consideration given that our actions can permanently alter the learner's brain.

Neuroplasticity is an important concept in early childhood education because of the role of background knowledge and wide reading in learning. As background knowledge is built through direct and indirect experiences and wide reading experiences, physical changes occur in the brain. These new neural pathways are used in later reading-related tasks, such as making connections and visualizing. Engaging instruction that reinforces specific pathways makes it easier for new knowledge to be acquired, learned, and recalled (Draganski et al. 2006).

Even among learners who have more significant issues that may impede their reading acquisition, it can and does occur. Over the past decade, education researchers have come to understand that many children with disabilities did not learn how to read because they did not receive instruction in how to do so (Kliewer et al. 2006). The implication for early childhood educators is that students with significant disabilities should not be excluded from reading instruction, as a growing body of evidence is demonstrating that those who are taught well do in fact acquire knowledge in how to read. This should serve as a confirmation to classroom teachers who may wonder whether the time doing so is well spent. The good news is that it is.

Repetition Leads to Automaticity

Squire and Kandel (2000) demonstrated that there are three areas of the brain involved in the early stages of learning a new skill or procedure: the prefrontal cortex, the parietal cortex, and the cerebellum. These three areas allow the learner to pay attention, execute the correct movements, and sequence steps. Their research, and the research of others they summarize, suggests that as a task or procedure is learned, these brain areas become *less* involved as the sensory-motor cortex takes over. In other words, more cognitive space is needed when learning a new skill, and needed space is reduced over time as the skill becomes more automatic.

Hebb (1949) suggested that as neuronal pathways are used repeatedly, they begin to change physically and form steadily faster networks. Hebb's principle that "neurons that fire together, wire together" is echoed in the theory of automaticity (LaBerge and Samuels 1974). As these pathways are used in ever-increasing efficiency, the reader becomes more fluent, creating the necessary "think time" to form new connections. Fluent reading is also associated with an expanding working memory (WM), believed to be key in growth from novice to expert (Ericsson and Kintsch 1995). In other words, as specific tasks become automatic, working memory is available for meaning making or comprehension.

Automaticity is an important tool for teachers because of its relationship to fluency and understanding. Fluent reading is positively associated with comprehension and is thought to contribute to the learner's ability to process the meaning of the text because less effort is required to recognize symbols, decode, and assign meaning to words (e.g., Bell and Perfetti 1994). Consistent with the idea of automaticity, reading teachers know from experience that just getting students to read faster does not lead directly to higher levels of understanding or engagement. Automaticity is not about speed reading; it's about creating pathways that fire consistently so that the reader's working memory can focus on meaning making.

This explains why some weak readers can comprehend well in spite of their poor reading speed. Walczyk and Griffith-Ross (2007) propose that when less able readers are taught other tasks such as slowing down, pausing, and looking back, they are able to compensate and thus comprehend. The Compensatory-Encoding Theory (C-ET), which is based in neuropsychology, suggests less fluent readers can be taught to use compensatory reading strategies to enhance their understanding of the text. In a large-scale study of C-ET, "less fluent readers compensated more often, and older readers compensated most efficiently" (Walczyk et al. 2007, p. 867). These findings merge with current discussions of skilled versus strategic readers, led by Afflerbach et al. (2008), who place emphasis on the reader's actions, and whether they are automatic or deliberate. In their words, "reading skills operate without the reader's deliberate control or conscious awareness … [t]his has important, positive consequences for each reader's limited working memory" (p. 368). Strategies, on the other hand, are "effortful and deliberate" and occur during initial learning, and when the text becomes more difficult for the reader to understand (p. 369). The findings on the use of compensatory reading strategies by Walczyk et al. (2007) support this stance of shifting attention from the labeling of strategies to one that emphasizes how and when a reader applies them automatically.

Automaticity is dependent on working memory. Despite attempts to cram lots of information into a brain all at once, neuroscience research confirms Miller's (1956) finding that humans can work with about seven new and previously unassociated bits of information at a time. Accordingly, teachers need to chunk information in ways that are consistent with working memory and long-term transfer. One of the ways to do this is through work with schemas, or mental structures that represent content. Importantly, schema are involved in background knowledge and vocabulary. Tools such as concept maps, word webs, and graphic organizers provide students with schemata that they can use to organize information (e.g., Guthrie et al. 2004).

LaBerge and Samuels (1974) suggested that a key to automaticity is in building reader's capacity to shift their attention from decoding to comprehension. This is accomplished through fluency development that frees up working memory (Kintsch 2004). The challenge, of course, with automaticity is to not allow repetition to turn into a rut. Samuels (1979) and others have advocated for repeated reading experiences that provide students with the necessary repetition with text passages. Readers Theater is one way to causing repeated readings because they are motivated to perform their scripts expressively for their audience (Martinez et al. 1999). Inexperienced students may want to memorize their scripts, which defeats the fluency-building intention of the activity. Therefore, the parameters of the activity must be clear:

- Performances conducted by groups of students
- Expressive reading, but little if any movement or use of props.
- Use of the script, even during the performance.
- Performance goal is to create an entertaining experience for the audience.

Nested within automaticity is the subskill of phonemic awareness. There has been an abundance of research in neurosciences in this area, one that most reading researchers would say has limited usefulness. While there has been considerable debate about how phonemic awareness should be taught, there is strong evidence from a neuroscience perspective that the sound system is important in learning to read (e.g., Eden et al. 2004; Sousa 2004). For example, Paulesu et al.'s (2001) study of English, French, and Italian children who were poor readers found commonalities across languages—a reduced activation in the superior temporal gyrus, which forms part of the phonological loop between Broca's and Wernicke's areas. Furthermore, when a person who once had phonemic awareness suddenly loses it, his or her reading ability is compromised. Conduction aphasia, which results when a stroke occurs in this region of the brain, leaves adult readers struggling, and many will transpose phonemes within a word (e.g., "pisghetti" for "spaghetti") (Schmahmann and Pandya 2006).

A contributory skill in automaticity is phonemic awareness, the ability to recognize and differentiate among the 44 sounds of the English language. There is evidence in the reading research that phonemic awareness instruction is important for young children (e.g., Snow et al. 1998). For example, in their study of 1509 first-grade students, Hoein et al. (1995) used regression analysis of reading achievement and found that the phonemic identification factor was the strongest predictor of reading achievement. While others have raised methodological questions about this study in terms of participants, length of study, and such, there appears to be a relationship between phonemic awareness and reading for young children. Having said that, we also recognize that phonemic awareness itself is nested within the larger reading picture. Paris (2005) calls phoneme identification a "constrained skill" because it has a finite range—once you know the sounds of a language, you know them (unless something occurs to cause conduction aphasia). In a meta-analysis of US studies, the findings of Bus and van IJzendoorn (1999) did not support the predictive nature of phonemic awareness on later reading achievement. Our point is not to engage in a debate about phonemic awareness *per se,* but rather to point out that as educators we need to apply the same kind of nuanced analysis to neuroscientific studies that we routinely do to educational ones. As early childhood educators, it is necessary to be sensitive to the acquisition of this constrained skill, acknowledging its importance during the years when phonemic awareness is critical, but also understanding that once fully acquired (typically around the age of seven) its predictive power rapidly diminishes.

Visuals Play an Important Role in Learning

A fourth area of neuroscientific research that has implications for early childhood education concerns the role of visual information in learning. Medina (2008) argues that vision trumps all other senses and is "probably the best single tool we have for learning anything" (p. 233). In other words, visual stimuli will be attended to over other stimuli most of the time, especially when the visual stimulus moves. Medina argues that attending to visual information is a survival mechanism, which is why it takes up so much neural real estate and resources (about 50% according to Medina).

But all visual information isn't equal. Pictures consistently trump text or oral presentations. This is so common that cognitive scientists have a name for it: pictorial superiority effect (Stenberg 2006). For example, there is evidence that people can remember 2,500 pictures with about 90 percent accuracy several days after seeing them (Standing et al. 1970). In another study, adults were able to recognize pictures of Dick and Jane (from the readers) decades after they completed elementary school (Read and Barnsley 1977). It's not just that pictures are easier to remember, they're significantly more likely to be stored and much more likely to be retrieved.

This has profound implications for a print-based society. Could we really improve student achievement with the addition of visual/pictorial information? Might the work on comics, the Internet, videos, and other highly visual representations confirm the neuroscience research on the primacy of images? As teachers consider the multiple and new literacies of their students, they recognize that they are accountable for their students' traditional literacy achievement.

Given that research in this area is relatively new, it seems prudent to ensure that students have access to visual information paired with text and are taught how to interpret visual stimuli. For example, Sipe (1998) identified five scaffolds that preschool and primary teachers use to focus students on meaning making of print and visual information (reading the text, managing/encouraging, clarifying/probing, speculating/wondering, and extending/refining).

It is also possible that people may process visual information differently. There is preliminary evidence that adults with reading difficulties take in more visual information peripherally and less at the fovea (focus area), which may interfere with their ability to process print information, but may be an incredible boon in other fields (Schneps et al. 2007). For example, there are a disproportionate number of astronomers and astrophysicists labeled as dyslexic, a discipline that demands pattern recognition across wide star fields (Schneps et al. 2007).

As brain researchers focus on the human visual system (e.g., Tovée 2008) a growing body of evidence suggests that text should be paired with illustrations. This has implications for the Internet, picture books, and the comprehension strategy of visualizing. Again, combining reading and neuroscience research could yield instructional implications we can all use, and can assist us in recognizing the skills and strengths of our students. However, the necessary voices of reading researchers who are leading the way in how digital media are understood from a learning standpoint must collaborate with neuroscientists to explore this nexus.

Hardwired to Imitate

A final subfield of neuroscientific research concerns the role of imitation in learning. An aspect of intentional instruction is teacher modeling, demonstration, and thinking aloud. These teaching acts form the core of what occurs in early childhood education, especially in the use of speculative and observational language made public and apparent to learners. From the time we are born, we learn by imitating and mimicking. The brain makes use of specialized cells called mirror neuron systems (Cattaneo and Rizzolati 2009). These unique cells are active when we do something *or* when we watch someone do something. In terms of reading and language acquisition, students' neurons are firing as they watch teachers perform or think through information, such as reading for meaning. The way that students experience modeling affects how they perform and execute human actions from imitation to empathy to language learning and use. New evidence shows a similar phenomenon occurs as a reader reads text about an action a character in a story. Speer et al. (2009) offer intriguing new evidence that the pathways that fire while reading about an action are nearly identical to those that are fired in the commission of the action.

Research on mirror neuron systems, while still in its infancy, adds further evidence to support teacher modeling. Beginning with the work of Holdaway (1979, 1983), who developed big books as a way for teachers to model while young students watched, teacher modeling has become a staple in most literacy frameworks. Simply said, teacher modeling is one of the best ways to introduce skills and strategies for readers (Fisher et al. 2008). The use of these transactional strategies that allow students to witness and participate in making meaning has been demonstrated to be an effective means for fostering reading comprehension among primary-aged students, especially for those who are struggling (Brown 2008).

From Lab to Classroom

The relevance of neuroscientific knowledge is likely to increase in the coming decade, and therefore it is critical to be informed about the current state of the field and where early childhood education research can contribute to their knowledge base (Dehaene 2009). In the same regard, neuroscientific findings can be applied to the education field to confirm or disconfirm teaching practices, as well as to expand and strengthen them. As we have noted, there is an explosion of research related to the human brain. Not all of it will be helpful nor will all of it be confirmed. The relationship between neuroscience and education is a tenuous one, and researchers in both fields caution that findings should not be extrapolated beyond the limitations of any one study (Varma et al. 2008). Becoming an informed consumer of this growing body of knowledge is an important role of the language arts teacher. Having said that, there are particular areas of future research that we can recommend, in light of the many unanswered questions and intriguing findings in the fields of reading and the neurosciences:

1. *Develop imaging techniques that allow for studies that involving reading longer passages.* The early (1990s) brain imaging studies were limited to very brief events of less than 1-s. Therefore, much of the reading research in the neurosciences involved reading single words in isolation. As educators, we know that this is insufficient for our purposes—reading in the classroom is far more complex. With the development of newer imaging techniques, particularly Transcranial Magnetic Stimulation (TMS), this window is expanding. However, further development of technologies that address this issue, as well as very real limitations regarding the size of the machinery and the high cost, must be addressed if neuroscientific results are to be useful in education.
2. *Create collaborative partnerships to create cross-disciplinary research.* The neuroscience community readily acknowledges that their lack of expertise in understanding reading behaviors limits the scope of their work. Innovative partnerships such as the Mind, Brain, and Education graduate program at Harvard are creating a new field of research that draws on the cognition research of psychology, neuroscience, and education to reach new understandings. Education research is notable for its history of consolidating many fields of study. No educator could imagine being prepared for the profession without being grounded in child development, psychology, communication, sociology, as well as specific disciplines such as mathematics and the sciences. These collaborations have come about because education researchers have reached out to other fields to utilize and apply what has been learned. In the same regard, educational applications inform and enrich these disciplines. Early childhood reading researchers like Wolf are formally collaborating with neuroscientists to inform and extend knowledge by asking questions of one another.
3. *Focus research on new literacies.* This is perhaps the most exciting area of emerging research. Just as notable researchers in the reading field are building our understanding of how digital environments change the act of reading, so can the neurosciences. For example, does the brain process print-based and digital based texts differently? Does age and experience affect these changes? What are the effects of near-constant exposure to screen-based literacies on reading acquisition? How does learning occur in a virtual environment? None of these questions can be solely answered by behavioral or neuroscientific research alone—they are dependent on one another.

While not directly controlled by the early childhood classroom teacher, our collective voices influence the development and funding of such neuroscientific research. As attention in our society has shifted from viewing preschool experiences as a caretaking one, to a view of early educational experiences as foundational to later academic achievement, so have research monies. For instance, the work of Petitto and colleagues at the University of Toronto focuses on early childhood language acquisition and development and includes implications for making policy and programmatic decisions (see Petitto 2005; Petitto and Dunbar 2004 for examples of this line of cross-disciplinary research.) In addition, the reported findings from clinical settings must be further examined in the applied environment. Early childhood educators play a vital role in testing, challenging, and confirming laboratory results in vivo—the living organism that is the preschool and primary classroom.

Conclusion

Regardless of the age of child we teach, we're all "brain workers." Teachers spend their days trying to influence that which is stored in students' brains. It's really quite simple. There are a limited number of inputs that the brain accepts and a limited number of outputs that the brain can produce. Inputs can come in the form of sight, hearing, taste, smell, and touch. Outputs include such modes as speaking, writing, and moving, but reading teachers have known that for decades. Where brain research might help us is in how information is stored and retrieved. Understanding the neural basis of reading will likely validate many of the instructional routines and cognitive strategies teacher and students already use as well as provide guidance on effective and less-than-effective approaches to reading and language acquisition.

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