

STUDENTS AT THE CENTER

TEACHING AND LEARNING
IN THE ERA OF THE COMMON CORE

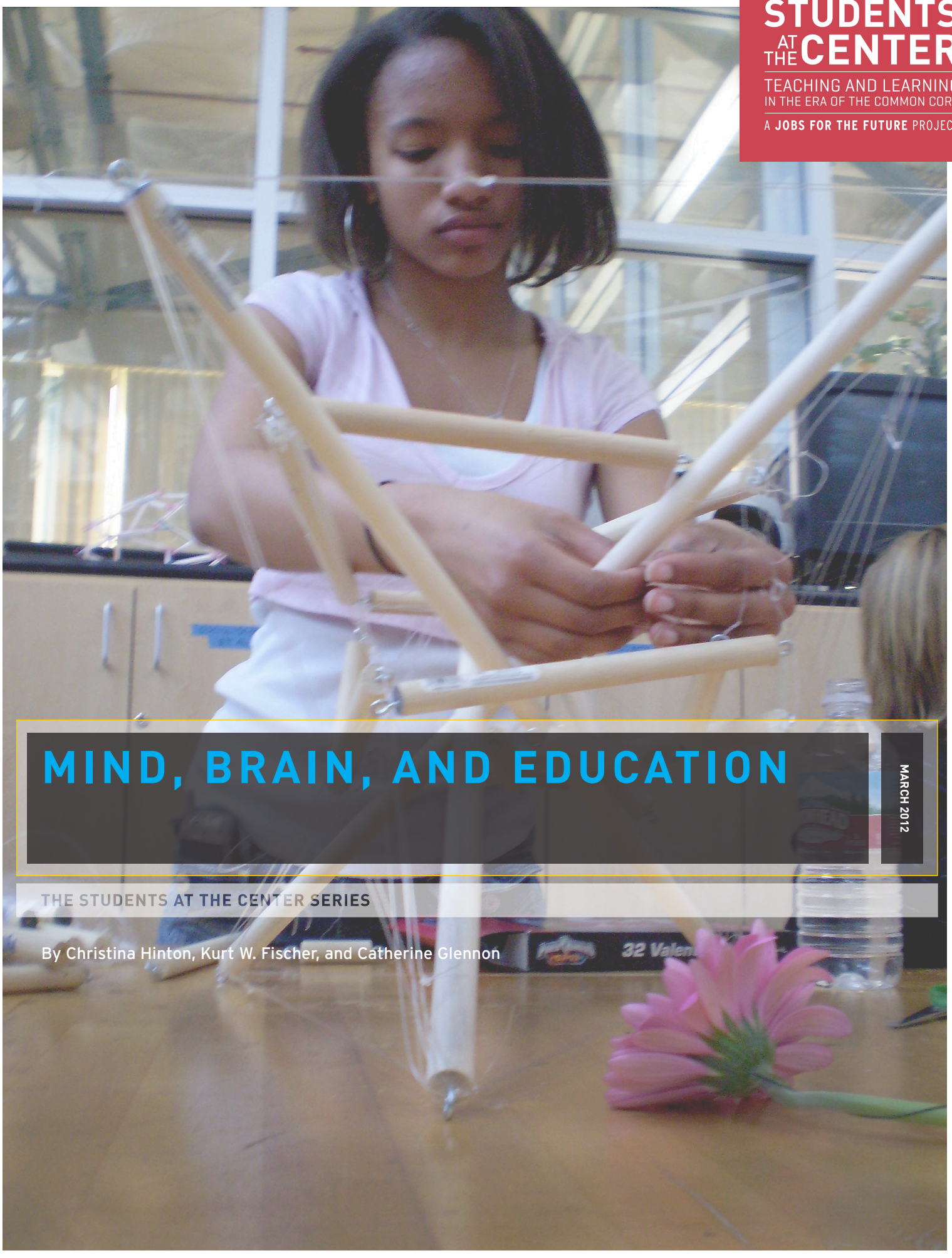
A JOBS FOR THE FUTURE PROJECT

MIND, BRAIN, AND EDUCATION

MARCH 2012

THE STUDENTS AT THE CENTER SERIES

By Christina Hinton, Kurt W. Fischer, and Catherine Glennon



EDITORS' INTRODUCTION TO THE STUDENTS AT THE CENTER SERIES

Students at the Center explores the role that student-centered approaches can play to deepen learning and prepare young people to meet the demands and engage the opportunities of the 21st century. *Students at the Center* synthesizes existing research on key components of student-centered approaches to learning. The papers that launch this project renew attention to the importance of engaging each student in acquiring the skills, knowledge, and expertise needed for success in college and a career. Student-centered approaches to learning, while recognizing that learning is a social activity, pay particular attention to the importance of customizing education to respond to each student's needs and interests, making use of new tools for doing so.

The broad application of student-centered approaches to learning has much in common with other education reform movements including closing the achievement gaps and providing equitable access to a high-quality education, especially for underserved youth. Student-centered approaches also align with emerging work to attain the promise and meet the demands of the Common Core State Standards.

However, critical and distinct elements of student-centered approaches to learning challenge the current schooling and education paradigm:

- > Embracing the student's experience and learning theory as the starting point of education;
- > Harnessing the full range of learning experiences at all times of the day, week, and year;
- > Expanding and reshaping the role of the educator; and
- > Determining progression based upon mastery.

Despite growing interest in student-centered approaches to learning, educators have few places to which they can turn for a comprehensive accounting of the key components of this emerging field. With funding from the Nellie Mae Education Foundation, Jobs for the Future asked nine noted research teams to synthesize existing research in order to build the knowledge base for student-centered approaches to learning and make the findings more widely available.

The topic of this paper, as with each in the series, was selected to foster a deeper, more cohesive, research-based understanding of one or more core elements of student-centered approaches to learning. The authors in this series: synthesize and analyze existing research in their areas; identify what is known and where gaps remain related to student-centered approaches to learning; and discuss implications, opportunities, and challenges for education stakeholders who put students at the center. The authors were asked to consider the above definition of student-centered approaches, but were also encouraged to add, subtract, or critique it as they wished.

The authors were not asked explicitly to address the Common Core State Standards. Nevertheless, the research proceeded as discussions of the Common Core were unfolding, and several papers draw connections with that work. The thinking, learning, and teaching required for all students to reach the promised outcomes of the Common Core provide a backdrop for this project. The introductory essay looks across this paper and its companion pieces to lift up the key findings and implications for a new phase in the country's quest to raise achievement levels for all young people.

The nine research papers are loosely organized around three major areas of inquiry—learning theory; applying student-centered approaches; and scaling student-centered learning—although many of the papers necessarily cross more than one area:

- 1. LEARNING THEORY:** What does foundational and emerging research, particularly in the cognitive and behavioral sciences, tell us about how students learn and about what motivates them to learn?

Mind, Brain, and Education

Christina Hinton, Kurt W. Fischer, Catherine Glennon

Motivation, Engagement, and Student Voice

Eric Toshalis, Michael J. Nakkula

2. APPLYING STUDENT-CENTERED APPROACHES: How are student-centered approaches to learning implemented? What is the nature of teaching in student-centered learning environments? How can students who are underrepresented in postsecondary education be engaged earlier and perform well in the math and reading activities that scaffold learning? How are advances in technology customizing curriculum and changing modes of learning to meet the needs of each student?

Teachers at Work—Six Exemplars of Everyday Practice

Barbara Cervone, Kathleen Cushman

Literacy Practices for African-American Male Adolescents

Alfred W. Tatum

Latino/a and Black Students and Mathematics

Rochelle Gutierrez, Sonya E. Irving

Curricular Opportunities in the Digital Age

David H. Rose, Jenna W. Gravel

3. SCALING UP STUDENT-CENTERED APPROACHES TO LEARNING: How have schools sought to increase personalization and with what outcomes for learning? What is the relationship between assessment and student-centered approaches? What can districts do to support student-centered approaches to learning?

Personalization in Schools

Susan Yonezawa, Larry McClure, Makeba Jones

Assessing Learning

Heidi Andrade, Kristen Huff, Georgia Brooke

Changing School District Practices

Ben Levin, Amanda Datnow, Nathalie Carrier

A number of distinguished researchers and practitioners serve as advisors to *Students at the Center* including Scott Evenbeck, founding president of the New Community College, City University of New York; Charles Fadel, Visiting Scholar, Harvard Graduate School of Education, MIT ESG/IAP, and Wharton/Penn CLO; Ronald Ferguson, Senior Lecturer in Education and Public Policy, Harvard Graduate School of Education and the Harvard Kennedy School; Louis Gomez, Professor and the John D. and Catherine T. MacArthur Foundation Chair in Digital Media and Learning, Graduate School of Education and Information Studies, UCLA; Susan Moore Johnson, Professor and the Jerome T. Murphy Professor of Education, Harvard Graduate School of Education; Jim Liebman, Simon H. Rifkind Professor of Law, Columbia University School of Law; Miren Uriarte, Professor, College of Public and Community Service, University of Massachusetts, Boston; and Arthur VanderVeen, Vice President, Business Strategy and Development at Compass Learning.

To download the papers, introductory essay, executive summaries, and additional resources, please visit the project website: www.studentsatthecenter.org.

Over the coming months, Jobs for the Future and the Nellie Mae Education Foundation will craft opportunities to engage a broad audience in the conversation sparked by these papers. We look forward to building a shared understanding and language with you for this important undertaking.



Nancy Hoffman, Adria Steinberg, Rebecca Wolfe

Jobs for the Future



JOBS FOR THE FUTURE

Jobs for the Future identifies, develops, and promotes education and workforce strategies that expand opportunity for youth and adults who are struggling to advance in America today. In more than 200 communities across 43 states, JFF improves the pathways leading from high school to college to family-sustaining careers.

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The **Nellie Mae Education Foundation** is the largest charitable organization in New England that focuses exclusively on education. The Foundation supports the promotion and integration of student-centered approaches to learning at the high school level across New England. To elevate student-centered approaches, the Foundation utilizes a strategy that focuses on: developing and enhancing models of practice; reshaping education policies; increasing the body of evidenced-based knowledge about student-centered approaches and increasing public understanding and demand for high-quality educational experiences. The Foundation's initiative and strategy areas are: District Level Systems Change; State Level Systems Change; Research and Development; and Public Understanding. Since 1998, the Foundation has distributed over \$210 million in grants.

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INTRODUCTION

Recent technological breakthroughs make research in biology and cognitive science more relevant for education than ever before. Powerful brain imaging tools enable neuroscientists to study the learning brain in action for the first time. New technologies in genetics allow researchers to explore complex gene-environment interactions. Innovative cognitive science methods for analyzing learning enable researchers to track alternative learning pathways. These and other advancements have led to a global emergence of the field of mind, brain, and education (Fischer, Immordino-Yang, & Waber 2007; Fischer et al. 2007; OECD 2007; Stern 2005). This field aims to synthesize research in biology, cognitive science, and education to create a trans-disciplinary learning science that can inform education policy and practice.

This paper considers student-centered learning approaches in light of mind, brain, and education research.¹ Student-centered approaches to learning comprise a research-based framework for education that aims to help students from a wide range of backgrounds master the skills necessary for college and the 21st-century knowledge economy (JFF 2011). In particular, it is intended to support underserved youth who are often excluded from higher education. The approaches begin with a common set of rigorous standards. Students can reach these standards through learning experiences tailored to their needs and interests, which may include informal learning outside of school. Students are empowered to take responsibility for their own learning, with teachers and other professionals as facilitators.

While many student-centered learning approaches are well grounded in education research, this paper is the first to consider student-centered learning from the perspective of trans-disciplinary research in mind, brain, and education. This paper begins with a brief description of the student-centered learning concept. It then discusses research in mind, brain, and education that is most relevant to student-centered learning. It first explains the

neurological mechanism underlying learning. As students learn in both formal and informal contexts, these experiences shape the physical architecture of their brains (Squire & Kandel 2009). The chapter then presents neuroscience research on individual differences, which are central to the student-centered learning concept. Since students have different genetic predispositions and experience continuously shapes their brains, each student's brain has a unique profile of strengths and limitations (Fischer & Bidell 2006). The paper then describes how the brain learns certain academic content, including language, literacy, and mathematics. Language learning is discussed because one in four low-income students is an immigrant (NCSL 2004), and proficiency in the language of instruction strongly influences academic achievement among immigrants (OECD 2003). Literacy and mathematics are core academic subjects, highly relevant for all students. Research on how these academic abilities are created in the brain illustrates how learning experiences shape the brain and give rise to individual differences. Finally, the paper explores the fundamental role of emotions in learning. As part of this, it elucidates the influence of stress on the brain, which has important implications for education, especially education of underserved youth who are under the chronic stress of poverty (Shonkoff & Phillips 2000). After this mind, brain, and education research is presented, the paper considers the implications of this work for student-centered learning approaches, with a particular focus on using these approaches to educate underserved youth.

STUDENT-CENTERED LEARNING

The student-centered learning model aims to help students from all backgrounds master the skills needed for postsecondary education and the 21st-century knowledge economy (JFF 2011). In this approach, education provides flexible learning experiences that enable students at various levels to build toward mastery of a common set of core skills. A commitment to addressing the individual needs and goals of each student is at the core of the model. Therefore, students are empowered to follow customized learning pathways that meet their particular needs and interests as they build their expertise. As students progress, educators use formative assessment to guide learning and teaching. Formative assessment involves using ongoing assessment throughout the learning process to tailor instruction to meet each student's current needs (OECD 2005). Student-centered learning approaches recognize each student's emotional needs as well. Such approaches work to help students build self-confidence and motivation through learning experiences that match their abilities and interests, with the ultimate goal of supporting them to become self-directed learners.

Another fundamental element of student-centered learning approaches is that learning can take place in both formal and informal contexts. Learning is not restricted to the confines of a traditional classroom or school hours; rather, it transpires in multiple dimensions of a student's life. Learning can occur in settings ranging from internships to community

centers to cyberspace. Likewise, educators can include teachers, parents, community members, and professionals. The approaches resonate with the Nigerian proverb: It takes a village to raise a child. Student learning can—and should—be supported by a range of adults in multiple contexts. Moreover, with this approach, all learning experiences that build core skills are formally credited.

In addition, student-centered models call for advancement upon mastery. Students advance when they have reached proficiency in particular skills, rather than when they have accumulated a certain number of hours in a classroom. Students therefore do not necessarily progress with their peers in a cohort. Instead, each student is challenged based on her or his skill levels and graduates a program when he or she meets that program's established standards. Overall, student-centered learning approaches compose a flexible system designed to help students from all backgrounds succeed academically.

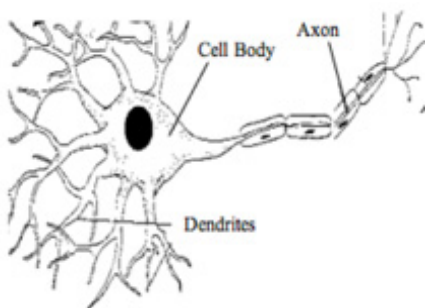


Student-centered learning approaches work to help students build self-confidence and motivation through learning experiences that match their abilities and interests, with the ultimate goal of supporting them to become self-directed learners.

HOW THE BRAIN LEARNS

Arguably the most important insight for education from the field of neuroscience is that the brain is highly adaptive, a property called plasticity (Singer 1995; Squire & Kandel 2009). Students' brains continuously adapt to the environments where they live and work, including school, home, workplaces, community centers, and so forth. As students learn in these places—mastering reading, playing online chess, or practicing typing—these experiences gradually sculpt the architecture of the brain. The brain is made up of networks of interconnecting nerve cells called neurons and supportive glial cells. Learning experiences are translated into electrical and chemical signals that gradually modify connections among neurons in certain areas of the brain. Over time, these changes in neuronal connectivity can aggregate to significant reorganization of brain areas involved in certain types of learning.

FIGURE 1
A NEURON



Source: Adapted from OECD (2007)

Each neuron has three main parts: dendrites; a cell body; and an axon (Kaczmarek & Levitan 2002) (see *Figure 1*). When a student has a learning experience, such as looking at a painting in an art museum, certain neurons are activated. The dendrites of each activated neuron receive chemical signals in response to this experience. Dendrites then relay these signals to the cell body, and if the signal is above a certain threshold, it triggers an electrical signal called an action potential. The action potential then travels along the axon, a long process covered by a fatty myelin sheath. When an action potential reaches the end of the axon, it prompts the release of chemical signals into the synaptic cleft, a small space between neurons. These signals then bind to receptors on the dendrites of downstream neurons. This leads to the series of intercellular signaling described above in these neurons, which in turn stimulates other neurons, and so forth. Therefore, a learning experience elicits a cascade of signaling among many neurons in many areas of the brain. In fact, reading just the words in this sentence activates millions of neurons in the brain.

Learning experiences modify connections among neurons in certain areas of the brain, which gradually reorganize these areas (Squire & Kandel 2009). Each neuron has many inputs from other neurons. When students have learning experiences, certain connections are activated, while others are not. Over time, connections that are most active relative to other inputs are strengthened, while those that are relatively less active are weakened or eliminated (Hebb 1949; Squire & Kandel 2009). In this way,



Students' brains continuously adapt to the environments where they live and work. As students learn in these places, these experiences gradually sculpt the architecture of the brain.

connections are gradually modified in response to learning experiences following a “use it or lose it” rule. These experience-dependent changes in the efficacy of neuronal connections are thought to be the biological substrate of memory. Over time, they aggregate to significant reorganization in certain brain structures, which reflects learning in domains associated with those structures.

This plasticity is most well researched in the domain of music. Seminal work by Thomas Elbert, Christo Pantev, and their colleagues demonstrated that learning to play the violin leads to changes in the organization of certain areas of the cortex, a brain area involved in many types of learning (Elbert et al. 1995; Pantev et al. 1998). Elbert et al. (1995) showed that the area of the somatosensory cortex representing the fingers of the left hand is larger in violinists than in non-musicians. Moreover, this area of the brain is also larger for violinists’ left hands than for their right hands. This suggests that this area is enlarged as a result of practicing the violin, rather than, for example, a genetic predisposition for a large somatosensory cortex that could predispose individuals to become violinists. As a student practices the violin, neuronal connections in the somatosensory cortex underlying finger dexterity in the left hand are activated, which strengthens them. Over time, this likely accounts for the differences in the somatosensory cortex observed by Elbert and colleagues.

Learning to play the violin influences the auditory cortex as well. Pantev et al. (1998) found that the area of the auditory cortex representing musical tones is larger in violinists than in non-musicians. This is true only for tones of the musical scale, not pure tones, suggesting that this area became enlarged through musical practice. Moreover, later research showed that short-term musical training led to strengthening of neuronal connections in the auditory cortex (Pantev et al. 2003). This result supports the notion that as students practice the violin, neuronal connections in the auditory cortex are strengthened, which eventually leads to large-scale reorganization. Research has demonstrated this type of plasticity in the cortex as a result of other types of learning as well, including learning other instruments (Lappe et al. 2008; Pantev et al. 2003), motor learning (Ungerleider, Doyon, & Karni 2002), language learning

(Li Voti et al. 2011; McCandliss, Posner, & Givo’n 1997; Ostry, et al. 2010; Shtyrov, Nikulin, & Pulvermüller 2010), and learning Braille (Hamilton & Pascual-Leone 1998).

Eleanor A. Maguire and colleagues (2000) revealed plasticity in response to learning in the hippocampus. The hippocampus is an area of the brain known to play a central role in spatial learning (Maguire, Burgess, & O’Keefe 1999; Smith & Milner 1981). Maguire and colleagues found that London taxi drivers have an enlarged hippocampus relative to control subjects who are not taxi drivers (Maguire et al. 2000; Woollett, Spiers, & Maguire 2009). Moreover, the degree of hippocampal enlargement is correlated with the amount of time spent as a taxi driver, which suggests that the enlargement is as result of experience as a taxi driver, rather than a preexisting condition that biases certain individuals to become taxi drivers. As London taxi drivers learn to navigate the twists and turns of the city’s streets, this presumably strengthens connections among neurons involved in spatial processing in the hippocampus, leading to the observed enlargement.

As students learn—in both formal and informal contexts—these experiences shape the architecture of their brains. Therefore, abilities are not fixed but rather continuously developing. In essence, the more a student learns in a particular area, the more intelligent the brain becomes in that area. This plasticity enables students to overcome many learning challenges. For example, some students have dyslexia, a reading difficulty commonly involving impaired phonological processing (Lyon, Shaywitz, & Shaywitz 2003). While this presents a clear learning challenge, brain plasticity enables many dyslexic students develop alternative neural circuitry to support reading when given appropriate educational support (Shaywitz 2003). In fact, brain plasticity can enable students to overcome even severe learning challenges. A case study of a student who had half of his brain removed due to severe epilepsy reveals the incredible plasticity of the brain (Immordino-Yang 2008). A hemisphere of this student’s brain was removed when he was in preschool, severely impairing a slew of functions. However, the remaining brain hemisphere gradually developed to compensate for the missing one to a significant degree. Now in high school, this student is cognitively normal, performing

above average in school, maintaining friendships, and is an aspiring artist. Crucially, this student received extensive educational support that was tailored to support his weakness and capitalize on his abilities.

The educational environment plays a crucial role in shaping the brain's abilities and determining students' academic achievement. Education should therefore strive to provide learning experiences that enable students at all levels to build toward mastery of a common set of skills, which is a principle of student-centered learning approaches. Research on brain plasticity also indicates that the brain is learning virtually all of the time, in both formal and informal contexts (Squire & Kandel 2009; OECD 2007). Education can therefore take advantage of nontraditional learning experiences in addition to school, such as afterschool enrichment, internships, and community programs. This approach is integral to student-centered learning, which formally credits these types of informal learning experiences.

ACTIVE LEARNING

Neuroscience research suggests that active engagement is necessary for learning. The changes in neuronal connections that underlie learning in the brain do not seem to occur when learning experiences are not active. In a seminal experiment, Gregg H. Recanzone and his colleagues (1992) found that when monkeys actively attended to finger stimulation because it was relevant to their goals, they learned the association between the stimulation and their goals, and the area of the somatosensory cortex representing the stimulated finger became enlarged. However, when monkeys received the same finger stimulation passively, it did not lead to changes in the somatosensory cortex. Researchers found the same pattern in plasticity of the auditory cortex (Recanzone et al. 1993). When monkeys were actively engaged in learning auditory information because

they earned rewards, it led to the expansion of the areas of the auditory cortex involved in processing that information. However, when the same auditory stimulation occurred and monkeys passively heard it, it did not lead to changes in the auditory cortex.

Recent imaging work suggests that cortical plasticity is conditional upon active engagement in humans as well (Ruytjens et al. 2006; Weinberger 2008; Winer & Schreiner 2011). Complementary research shows that active engagement is also necessary for the strengthening of neuronal connections in the cortex thought to underlie large-scale cortical reorganization (Ahissar et al. 1992; Recanzone et al. 1993; Recanzone & Wurtz 2000). Taken together, this research suggests that active engagement is a prerequisite for the changes in brain circuitry that are thought to underlie learning. In educational terms, this suggests that passively sitting in a classroom hearing a teacher lecture will not necessarily lead to learning. Conversely, active engagement with educational material within or outside of school will support learning.²

Related Paper in the *Students at the Center Series*³

For a more detailed discussion of research on active engagement and learning theory, see *Motivation, Engagement, and Student Voice*, by Eric Toshalis and Michael J. Nakkula.



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INDIVIDUAL DIFFERENCES

Why do some students whiz through chemistry while others struggle? Why do certain students show an uncommon resilience in the face of adversity? Why are some students passionate about literature and others drawn to mathematics? These variations are grounded in individual differences in the brain. Students' genetic predispositions interact with learning experiences to give rise to a wide range of individual differences (Fischer & Bidell 2006; Hinton & Fischer 2011; Shonkoff & Phillips 2000; Ridley 2003). Students are born with certain genetic tendencies. As they interact with the world around them, these experiences can reinforce or counteract their genetic inclinations. For example, a student may have a genetic predisposition for shyness (Arbelle et al. 2003), yet grow into a gregarious person despite that because of supportive social experiences at home, in school, or in the community.

Since genetics and experience interact to shape the brain, each student's brain is unique. Students have a collection of different abilities, and a student may struggle in one area, such as mathematics, and yet thrive in another, such as interpersonal intelligence (Gardner 1983). Moreover, within each of these domains, students can have both talents and limitations. For example, in the musical domain, students who have perfect pitch typically struggle with transposing, which is singing a melody in a key that is different from the one it was written in. Mind, brain, and education research does not support the simplistic notion that each student is either intelligent

or not; rather, it points to a more nuanced perspective that recognizes that each student has a complex profile of strengths and limitations.

In fact, recent research suggests that it may be a misnomer to label dyslexia as a disability. Students with dyslexia have reading difficulty that results from atypical cortical organization (Shaywitz 2003). However, recent research suggests that the atypical cortical organization of dyslexics is also associated with specific visual talents (Schnepps, Rose, & Fischer 2007). Different brain circuitry underlies the central and peripheral visual fields. While most students process visual stimuli most easily in the central visual field, which is used for reading, dyslexic students favor the peripheral visual field.

It turns out that this difference leads to certain visual talents. Dyslexics are better than non-dyslexics at integrating information across the visual field and quickly detecting anomalies or oddities in visual images (von Karolyi et al. 2003). This is not merely an interesting laboratory finding—it has real-world implications. These visual talents give dyslexics an advantage as astronomers (Schnepps, Rose, & Fischer 2007). Astronomers need to examine patterns of stars in the sky, as well as patterns of waves that come from stars and planets in the sky. The visual talents of dyslexic astronomers help them detect black holes, the mysterious places in the sky with gravitational fields so intense that even light cannot escape. Detecting black holes requires the capacity to integrate information across wide areas of the visual field, which calls upon the peripheral



Students' genetic predispositions interact with learning experiences to give rise to a wide range of individual differences.

visual field. Therefore, students with dyslexia do not have a “less intelligent” brain, but rather atypical brain organization that brings a specific profile of disadvantages, which are evident in reading, and talents, such as an enhanced capacity to integrate information across the visual field.

The standard curriculum and traditional pedagogical techniques often do not accommodate individual differences. Research on reading instruction illuminates the shortcomings of this approach. Most students in the United States learn to read words, linking sounds with letters to form words. However, few students master the skill of learning from text (Snow, Burns, & Griffin 1998; Snow, Griffin, & Burns 2005). That is, they do not learn to extract meaning effectively from text they read. This educational failure means that most students’ brains never become fully literate. Much of the problem is that students follow different learning pathways when learning to read, and the standard curriculum is structured as if all students follow the same pathway (Fischer & Bidell 2006; Fischer, Bernstein, & Immordino-Yang 2007; Knight & Fischer 1992). This uniform curriculum loses a host of students because it does not take into account the different ways students learn or the different languages, cultures, values, goals, and interests they bring to school (Fischer & Bidell 2006; Fink & Samuels 2007).

Student achievement arises from an interaction of a student’s profile with instructional techniques.⁴

For example, research shows that the performance of students with a gene that is linked to anxiety can vary significantly based on instructional technique (Kegel et al. 2011). When students with this anxiety-linked gene engage in a computer literacy instruction program without feedback, they perform lower than students without this gene. However, when the program is adjusted to include positive feedback that motivates and informs students as they work, those with the anxiety-linked gene have higher outcomes than those without it. Adjusting instruction to meet each student’s particular needs can often move students from failure to proficiency.

Much more research is needed on how to accommodate a wide variety of individual differences. Education literature is overwhelmingly based on studies of middle-class individuals of European-American ancestry (Shonkoff & Phillips 2000). Given that instructional methods can be differentially effective for different subgroups, it is problematic that evidence-based practice is, by and large, based on evidence from this particular subgroup. Recent research suggests that studies with this subgroup are unlikely to generalize to other populations (Henrich, Heine, & Norenzayan 2010). For example, the degree to which Intelligence Quotient is influenced by genetics and the environment seems to vary dramatically depending on students’ socioeconomic status, which is an indicator of social position that takes into account their familial income, education level, and occupations (National Center for Educational Statistics 2008; Turkheimer et al. 2003).⁵ In students from high socioeconomic backgrounds, genetic difference accounts for 70 to 80 percent of the variation in IQ, with shared environment accounting for less than 10 percent.⁶ However, in students from low socioeconomic backgrounds, shared environment accounts for about 60 percent, and genetic variation contributes from 0 to 10 percent. This is likely because there is more variability in the environments of students from low-income backgrounds. As another example, there are robust gender differences in spatial reasoning in students of high and middle socioeconomic status but not in low-SES students (Levine et al. 2005). More research is needed with subpopulations from low-income and minority backgrounds to ensure that instructional techniques can be tailored to their needs and interests.

LANGUAGE LEARNING

The brain is genetically primed to acquire language. Noam Chomsky (1959) proposed that the brain is predisposed to process certain stimuli according to universal language rules. Indeed, recent research confirms that there are brain structures that are genetically specialized for language (Neville & Bruer 2001). Broca's area is involved in a broad range of linguistic functions, including language production (Bookheimer 2002). Wernicke's area plays a key role in semantics (Bookheimer et al. 1998; Thompson-Schill et al. 1999).

Although certain brain structures are biologically primed for language, experience acts as a catalyst to initiate the process of language acquisition. There are sensitive periods in certain areas of the brain during which they are most receptive to particular aspects of language learning (Bruer 2008; Neville & Bruer 2001; Kuhl 2010). There is a sensitive period for acquiring the accent of a language, which is learned most effectively between birth and about 12 years of age (Neville & Bruer 2001). There is also a sensitive period for learning the grammar of a language (Neville & Bruer 2001). If the brain is exposed to a non-native language between one and three years of age, grammar is processed by the left hemisphere, as it is in native speakers. However, when initial exposure occurs at the ages of 11, 12, or 13 years, corresponding to early secondary school, brain imaging studies reveal an alternative processing strategy, involving both hemispheres. The brain circuits genetically primed to learn grammar are most plastic early in life. Therefore, when foreign language exposure occurs later in life, the brain must rely partially on other circuits that are not genetically specified for learning grammar. This may account for the deficits in grammatical processing often found in students who were first exposed to non-native language instruction late in their schooling (Fledge & Fletcher 1992). Given these sensitive periods, education should begin non-

native language instruction, including English Second Language (ESL) instruction, as early as possible.

However, although early non-native language instruction seems to bring certain biological advantages, it is certainly possible to learn language throughout the lifespan (Worden, Hinton, & Fischer 2011). If adolescents and adults are immersed in a non-native language, they can learn it very well, although particular aspects, such as accent, may never develop as completely as they could have if the language had been learned earlier. Additionally, there are individual differences such that the degree and duration of sensitive periods can vary from one student to the next. Some individuals are able to master almost all aspects of a non-native language into adulthood.

LITERACY IN THE BRAIN

Cultural evolution has vastly outpaced biological evolution. Biological evolution occurred over billions of years, and has endowed the brain with certain genetic predispositions, such as the predisposition for language learning. Cultural evolution has taken place comparably much more rapidly, over many generations (Tomasello 1999). As a result, cultural inventions such as literacy and formal mathematics are not built into the genetic blueprint of the brain. However, because of the brain's incredible plasticity, it can adapt to create complex networks that can support this cultural knowledge (Hinton 2011).

Literacy is a prime example of this. While the brain is genetically primed to learn language, literacy arises through cumulative experience-dependent changes in brain architecture (Hinton, Miyamoto, & della Chiesa 2008; OECD 2007). The brain structures genetically predisposed to support language, including Broca's area and Wernike's area, are at the core of reading networks. As a student learns to read, these areas connect with additional areas that were not genetically destined for literacy but rather recycled to fit this function (Dehaene 2009). There are biological constraints on which areas can be recycled for this purpose. However, the degree to which certain areas are involved and the recruitment of supplemental areas can vary based on experience. Neuroscientists are only just beginning to delineate the complex networks underlying literacy.

Neuroscience research to date has focused on reading at the level of the word. The dual-route theory provides an overview of what happens in the brain when an English native reader reads a word (Jobard, Crivello, & Tzourio-Mazoyer 2003; Levy et al. 2009). As you look at a word on this page, this stimulus is first processed by the primary visual cortex. The dual-

route theory posits that processing then follows one of two complementary pathways. One pathway has an intermediate step of converting letters into sounds, which involves Broca's area. The other pathway consists of a direct transfer from word to meaning, and seems to involve the visual word form area (Cohen et al. 2002; Gaillard et al. 2006). Since there are genetically specified language areas in the brain and biological constraints on which brain areas will fit a literacy function well, many of the areas involved in reading are shared across languages (Dehaene 2009).

However, learning to read in different languages does produce some differences in the brain network that supports reading. These differences reflect the properties of each language. English has an inconsistent match between letters and sounds. For example, consider the pronunciation of the letter *g* in the words "girl" and "tough"; the English language is riddled with these types of inconsistencies. Therefore, it is most efficient for the brain to read English using a combination of phonetic decoding and whole-word recognition. Italian, by contrast, has a highly consistent match between letters and sounds. As a result, it is most efficient for the brain to rely primarily on phonetic decoding when reading in Italian. Indeed, a seminal study revealed that learning to read in Italian creates a brain network for reading that is less heavily dependent upon the visual word form area, which is central to whole-word recognition (Paulesu et al. 2001). Italian native readers use this brain network even when reading in English, indicating that the skill of reading has been built somewhat differently as a result of experience learning to read in Italian. Further research has established that a similar brain network is used for reading in other languages, including Spanish and Hindi, which have a highly consistent match between letters and sounds as well (Dasa et al. 2011).

Learning to read in non-alphabetic languages gives rise to a brain network underlying reading that is similar to that created by learning to read in alphabetic languages, but partially distinct. The neural network underlying reading in Chinese native readers seems to involve both Broca's area and the visual word form area, which are both central to reading in alphabetic languages (Lee et al. 2004; Tan et al. 2003; Wang et al. 2008). However, the neural network underlying reading in Chinese native readers also involves certain brain areas associated with spatial information processing that are not part of the reading network of English native readers (Tan et al. 2003). These spatial areas likely become a part of the reading network because of the spatial complexity of Chinese ideograms. Even among non-alphabetic languages such as Chinese and Japanese, the brain networks underlying reading are partially distinct (Matsuo et al. 2010).

Together, research on reading in the brain illustrates that there are individual differences in reading networks based on experience learning to read in a particular language. One implication of this work is that ESL students are processing written information in somewhat different ways than native English speakers so standard reading instruction techniques may not be the right fit for their needs. More broadly, it illustrates how the brain is shaped by experience to give rise to individual differences.



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MATHEMATICS IN THE BRAIN

Like literacy, mathematics is created in the brain through a synergy of biology and experience (Dehaene 2011; Hinton, Miyamoto & della Chiesa 2008; OECD 2007). Just as there are brain structures that have been designed through evolution for language, there are analogous structures for a quantitative sense. As students learn mathematics, these structures connect with other brain areas that were not genetically destined for number but are sufficiently plastic to be gradually shaped for this function through experience. Therefore, mathematics draw on a complex network of genetically determined brain structures and experience-dependent brain areas.

Recent research has characterized students' genetically endowed basic quantitative sense (Wynn 1998; Ferigenson, Dehaene, & Spelke 2004). This quantitative sense includes a concept of one, two, and three. Infants can already precisely discriminate these quantities from one another and from larger quantities. Moreover, the concept of these numbers seems to be abstract since they are insensitive to modality, with infants connecting the quality of "two-ness" across two sounds and two objects (Izard et al. 2009; Starkey, Spelke, & Gelman 1990). This initial quantitative sense includes the ability to approximately discriminate among larger numbers. There is also evidence that this quantitative sense includes intuitions about simple mathematical operations. Karen Wynn (1992) found that when one object is placed behind a screen followed by a second object, infants expect to see two objects when the screen is removed, suggesting that they know that 1 plus 1 should equal 2. In addition, Koleen McCrink and Wynn (2004) found that infants can also perform approximate calculations with larger numbers, such as computing that 5 plus 5 equals about 10. Students therefore have an intuitive inclination to use numbers to understand the world around them.

The parietal cortex is likely the site of this genetically endowed quantitative sense and seems to play a central role in developing many mathematical skills (Dehaene 2011). Damage to the parietal cortex has devastating effects on mathematical abilities. For example, patients with parietal damage sometimes cannot answer a question as simple as which number falls between 3 and 5. However, they often have no difficulty solving analogous serial tasks across other domains, such as identifying which month falls between June and August or which musical note is between do and mi. They can also sometimes solve concrete problems that they cannot solve abstractly. For example, they sometimes know that there are two hours between 9 a.m. and 11 a.m. but still cannot subtract 9 from 11 in symbolic notation.

This pattern of results reveals two principles about mathematics in the brain. First, mathematics is at least partially dissociable from other cognitive domains, which supports the notion of multiple abilities (Gardner 1983). Talents or deficits in mathematics do not generally predict talents or deficits in other domains. A student may, for example, struggle with mathematics but have excellent linguistic abilities. Second, abilities within the domain of mathematics can be dissociable from one another. That is, a talent or weakness in a certain mathematical skill is not necessarily predictive of ability in another mathematical skill. This casts doubt on the validity of tracking students based on performance of basic mathematics skills, which may not necessarily relate to their abilities in advanced mathematics skills. In fact, research suggests that higher-level operations rely on partially distinct neural circuitry; the brain areas underlying algebra are largely independent of those used in mental calculation (Hittmair-Delazer, Sailer, & Benke 1995).

As students learn mathematics, the parietal cortex links with other brain areas to give rise to a rich array of mathematical skills (Dehaene 2011). As in the case of literacy, which areas are connected depends partially on experience. Different instructional methods can result in a different underlying neural circuit. For example, Margarete Hittmair-Delazer and colleagues (2005) found that that learning by drill, which involved learning to associate a specific result with two operands, was encoded in a different neural substrate than learning by strategy, which consisted of applying a sequence of arithmetic operations. This means that two students may both answer that 15 plus 15 equals 30, but if one student learned this fact through memorization while the other learned to calculate this answer using double-digit addition, the students are using distinct neural circuitries. Teaching by strategy seems to lead to a more robust neural encoding of mathematical information than teaching by drill, resulting in greater accuracy and transferability. More neuroscience research is needed to explore how different instructional methods influence mathematics in the brain.

EMOTION AND LEARNING

Over 2,000 years ago, Plato declared, “All learning has an emotional base.” Modern neuroscientists also argue that emotion is fundamental to learning (Damasio 1994, 1998; Dagleish 2004; Grindal, Hinton, & Shonkoff 2011; Immordino-Yang et al. 2007, 2009; LeDoux 2002; Rolla, Hinton, & Shonkoff 2011). In the words of Mary Helen Immordino-Yang and Antonio R. Damasio (2007), “We feel, therefore we learn.” Emotion recruits a complex network of brain regions, many of which are involved in learning. These areas include the prefrontal cortex, hippocampus, amygdala, hypothalamus, and many others (Dangleish 2004; Davidson 2003; Lang & Davis 2006; LeDoux 2002; MacLean 1949; Morgane et al. 2005). When a student has a learning experience, emotion and cognition operate seamlessly in the brain.

Emotion acts as a rudder to guide learning. The emotions students feel during an experience become salient labels that steer future learning and decision making. For example, consider the following scenario: A student decides to skip studying for a science exam to go to a baseball game. She enjoys the game, but does not feel particularly strongly about it. Since she did not study for her science exam, she fails it. As a result, she is scolded by her parents, feels embarrassed to tell the other students her grade, and bursts into tears whenever she thinks about the exam. What is this student likely to choose the next time she decides between studying and going to a sporting event? Emotions direct students’ learning processes, helping them gravitate toward positive situations and away from negative ones.

Some of the strongest neuroscience evidence that emotion guides cognition and learning arises from patients with lesions in areas of the brain involved in emotion. The case study of Phineas Gage, who had lesions in cortical areas involved in emotion, provides a classic example (Damasio et al. 1994). Before the accident that damaged his brain, Gage was responsible, intelligent, and well liked. After the accident, he remained intelligent in the conventional sense. However, he was unable to use emotional cues to guide his learning and decision making. As a result, he struggled to distinguish between successes and mistakes, and his learning and work suffered dramatically. Patients with this type of brain damage can reason logically using factual information (Saver & Damasio 1991). However, this reasoning is insufficient to produce good decisions because, without salient emotional tags, various pieces of information are not weighted properly. As a result, these individuals tend to make poor choices that lead them off track from learning goals. The brain uses emotion to effectively guide learning, tagging experiences as either positive and worth approaching or as aversive and worth avoiding.

Brain-imaging studies are beginning to elucidate the neural substrate of this system. When students encounter a situation, the brain quickly and automatically appraises it (Frijda 2006). The prefrontal cortex is the site of this appraisal, marking whether the situation brings positive or negative feelings (Davidson & Fox 1989). When events are positive, the left prefrontal cortex shows more activity, with higher-frequency brain waves. By



Emotions direct students’ learning processes, helping them gravitate toward positive situations and away from negative ones.



Education should give students opportunities to practice setting goals, tracking progress toward them, adjusting strategies along the way, and assessing outcomes.

contrast, when events are negative, activation in the prefrontal cortex occurs dominantly in the right.

The prefrontal cortex is also the seat of executive functioning, which involves goal setting, appropriately selecting learning strategies, monitoring progress, and assessing outcomes (Fuster 2008). Therefore, emotion and executive function are physically integrated in the brain. The prefrontal cortex is still maturing in adolescence so executive functioning skills are still developing (Luna & Sweeney 2004). Education should therefore support the development of these skills by giving students opportunities to practice setting goals, tracking progress toward them, adjusting strategies along the way, and assessing outcomes.

Since cognition and emotion are interrelated in the brain, individuals can cognitively regulate their emotions (Luan Phan et al. 2005; Ochsner et al. 2002; Ochsner et al. 2004; Phillips et al. 2003). For example, one study shows that individuals can down-regulate the emotional impact of negative experiences (Ochsner et al. 2004). This mollifying effect manifested in both reduced subjective affect and decreased amygdala activation. Effective strategies included reinterpretation and depersonalization. For example, participants reported depicting a sick woman as receiving a life-saving treatment (reinterpretation) and considered her with the clinical detachment of patient (depersonalization). The employment of these regulatory strategies recruited areas of the prefrontal cortex. Since the prefrontal cortex is still maturing in childhood and adolescence, students in primary and secondary school are still developing their emotional regulation skills (Gabrieli 2004; Luna & Sweeney 2004). In fact, one study showed that students who are between 8 and 12 years old were virtually unable to reduce negative

affect, and students who are between 13 and 17 years old demonstrated only half the regulatory control of adults (Gabrieli 2004).

Education can support the development of emotional regulation skills, and this should be a priority as emotional regulation skills strongly predict academic achievement (Hinton, Miyamoto, & della Chiesa 2008; OECD 2007). This is particularly important for students from underprivileged backgrounds: Recent research suggests that one of the main differences between disadvantaged students who succeed in school and those who do not is their ability to regulate emotions (OECD 2011).

Neuroscience evidence of the fundamental role of emotion in learning settles long-standing ideological debates about whether educators should be responsible for emotional development (Hinton, Miyamoto, & della Chiesa 2008). If educators are involved in intellectual development, they are inherently involved in emotional development as well. Student-centered learning approaches recognize the importance of emotion. Such approaches call for each student to be surrounded by a supportive community of educators. In addition, these approaches are designed to increase student motivation.⁷

Related Paper in the *Students at the Center Series*⁸

For an illustration of the role of emotion in the classroom and a discussion of the social-emotional aspects of learning, see “Element 4. Supporting Social and Emotional Growth and Identity Development” in *Teachers at Work—Six Exemplars of Everyday Practice*, by Barbara Cervone and Kathleen Cushman.



series



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MOTIVATION

Motivation in the brain is driven by emotion: Individuals are motivated to engage in situations with an emotionally positive valence and avoid those with an emotionally negative valence (Cain & LeDoux 2008; Lang 2010; Lang & Davis 2006; OECD 2007). Motivation recruits brain areas involved in emotion, including the prefrontal cortex and amygdala (Robbins & Everitt 1996). Much more research is needed to explore the brain mechanisms underlying the complex and varied motivations of students in educational contexts. Most neuroscience research on motivation to date focuses on animal studies that cannot capture the subjective experience of humans or basic motivations such as desire for food (Cain & LeDoux 2008; Robbins & Everitt 1996). However, there is extensive education psychology research on student motivation.⁹

Pioneering work by Carol Dweck (2006) is beginning to connect neuroscience with this established body of education psychology research on motivation. Extensive research has shown that many students hold one of two distinct attitudes toward intelligence (Dweck 2006).¹⁰ In one attitude, called entity, students treat intelligence as if it is fixed: A student is either smart or not. In the other attitude, called incremental, students believe that intelligence is achieved: A student can become more intelligent by working hard to learn. Students with an incremental theory of intelligence are more likely to persist in the face of challenge and use mistakes as opportunities to develop understanding.

Dweck (2006) connects these attitudes with brain research. One brain region (frontal) responds strongly to negative feedback about performance, and another region (temporal) activates with efforts to correct mistakes in performance. Students with an entity attitude show a stronger frontal response to the negative feedback they receive when they make a mistake than students with an incremental attitude. Brain processes closely follow students' attitudes about learning. Students with an entity attitude react strongly to errors but do not take advantage of the opportunity to learn more effectively, while students with an incremental attitude react less strongly to errors and work more effectively to learn from their mistakes. Understanding these types of individual

difference in motivation can help educators adapt pedagogy to be congruent with each student's emotional needs.¹¹

STRESS

Another emotion that is highly relevant in an education context is stress. Low levels of stress can be positive or tolerable and may even contribute to motivation. However, high levels of frequent or prolonged stress can be toxic to the brain (Grindal, Hinton, & Shonkoff 2011; McEwen & Sapolsky 1995; Shonkoff & Phillips 2000). Positive stress involves short-lived stress responses, including brief increases in heart rate or mild changes in stress hormones such as cortisol. Examples of positive stress include giving a class presentation, feeling challenged by a mathematics problem, or trying out for a sports team. This kind of stress is a normal part of life, and learning to adjust to it is an essential feature of healthy development. Tolerable stress refers to stress responses that could affect brain architecture but occur for brief periods or in the presence of support so that the brain can recover. Tolerable stress can range from taking a high-stakes exam to experiencing the death of a loved one with the support of a parent, teacher, or school psychologist. Toxic stress refers to strong, frequent, or prolonged activation of the body stress management system in the absence of support. Toxic stressors include chronic poverty, abuse, bullying, and trauma without support.

Toxic stress impacts the physical architecture of the brain. It leads to quantifiable changes in areas of the brain that are centrally involved in learning, such as the hippocampus, which can result in learning problems (McEwen & Sapolsky 1995; Shonkoff & Phillips 2000). Furthermore, toxic stress can change the stress system so that it responds at lower thresholds (Shonkoff & Phillips 2000). This means that a situation that would not seem threatening to most students may trigger a stress response in students who have experienced toxic stress. This stress response can interrupt learning. Moreover, it can manifest in a problematic aggressive attitude that damages students' relationships with teachers and peers.



When students from disadvantaged backgrounds are in high-quality schools, their cortisol levels decrease throughout the day. The better the school, the more the cortisol levels decrease. Therefore, a quality learning environment can help students reach healthy cortisol levels, which lead to better emotional regulation and more favorable learning outcomes.

Fortunately, recent research shows that supportive school environments can buffer students' brains from the impacts of unhealthy levels of stress (Rappolt-Schlichtmann Ayoub, & Gravel 2009; Rappolt-Schlichtmann et al. 2009; Rappolt-Schlichtmann & Watamura 2010). Rappolt-Schlichtmann and colleagues (2009) studied the level of the stress hormone cortisol in students of low and middle socioeconomic status. Results reveal that low-SES students typically come to school with higher levels of cortisol than their middle-SES counterparts. However, when students from disadvantaged backgrounds are in high-quality schools, their cortisol levels decrease throughout the day. The better the school, the more the cortisol levels decrease. Therefore, a quality learning environment can help students reach healthy cortisol levels, which lead to better emotional regulation and more favorable learning outcomes (Mangels 2011; Shonkoff & Phillips 2000; OECD 2007). This research underscores the need for child-friendly learning spaces that promote students' intellectual, emotional, and physical well-being and shelter students from toxic stress both during and outside of regular school hours (UNICEF 2009).

RELATIONSHIPS

Learning and emotions take place in an environment of relationships, and the human brain is primed for emotional bonding, which supports learning (Hinton 2011; Hinton & Fischer 2011; Immordino-Yang & Damasio 2007; National Scientific Council on the Developing Child 2004). The brain is tuned to experience empathy, which intimately connects individuals to one another's experiences. Mirror neurons fire to simulate others' experiences (Dobbs 2006). When a student sees a coach swing a baseball bat, some of the same neurons in the student's brain

fire as when the student swings the bat himself or herself. Similarly, when a teacher sees a student cry, some of the same neurons in the teacher's brain fire as when the teacher cries himself or herself. This mirror neuron system is thought to be the neurological basis for empathy and supports bonding and learning.

The mirror neuron system biologically primes students to attune to others and bond with them, which sustains interactions with adults and peers that support learning. Adults and more-expert peers provide scaffolding that enables children and adolescents to grapple with advanced knowledge, which leads to richer and more rapid learning than would be possible through individual exploration (Vygotsky 1978). For example, as a student struggles to understand why a wooden block floats in water despite its large size, a parent can guide the student toward understanding by strategically suggesting other objects to test. The bond between the student and the parent facilitates this interaction, with the student attuning to the parent and trusting his or her suggestions. These types of social interactions are fundamental to learning. Environments that promote positive relationships and a sense of community therefore promote learning.¹²



Environments that promote positive relationships and a sense of community promote learning.

IMPLICATIONS FOR STUDENT-CENTERED LEARNING APPROACHES

The mind, brain, and education research discussed here supports many aspects of a student-centered learning approach. Research on brain plasticity, language learning, literacy, and mathematics all show that the brain is continually shaped by learning experiences (Squire & Kandel 2009; OECD 2007). This underscores that abilities are not fixed, but rather always developing. **Sorting students into rigid tracks based on current ability could therefore deny students in lower tracks the learning experiences their brains need to reach their full potential. By contrast, providing meaningful learning experiences with ongoing guidance can enable students at all levels to build toward mastery of a common set of skills, which is keeping with a student-centered learning approach. One powerful tool for guiding students toward mastery of skills is formative assessment (OECD 2005).**¹³ Formative assessment, an integral part of student-centered learning approaches, involves ongoing assessment throughout the learning process for the purpose of shaping teaching and learning. Educators use formative assessment to tailor instruction to meet each student's current needs. In tandem, students use it to inform how to approach continued learning.

Research on brain plasticity also indicates that the brain is learning virtually all the time, in both formal and informal contexts (Squire & Kandel 2009; OECD 2007). Traditional schooling with a teacher standing in front of a classroom is therefore only one of many potential learning experiences (OECD 2011). Since informal learning also shapes the brain, education can take advantage of nontraditional learning experiences in addition to school, such as afterschool enrichment, internships, or community programs. In a student-centered approach to learning, informal education experiences with nontraditional educators would be formally recognized and credited.¹⁴

Neuroscience research shows that the changes in the brain that underlie learning occur when experiences are active (Recanzone et al. 1992, 1993; Ruytjens et al. 2006; Weinberger 2008; Winer & Schreiner 2011). With student-centered learning approaches, students are empowered to engage in active learning experiences that are relevant to their lives and goals. When a student is passively sitting in a classroom where the teacher is presenting decontextualized information that he or she is not paying attention to, the brain is not learning. **On the other hand, the brain is learning when a student is actively engaged in learning relevant knowledge in an informal context.** Therefore, research on how the brain learns is consistent with the student-centered learning principle of giving credit for mastery of core skills in formal and informal contexts, rather than giving credit for mere time spent in a classroom.

Related Paper in the *Student at the Center* Series

Assessing Learning, by Heidi Andrade, Kristen Huff, and Georgia Brooke



series

» Providing meaningful learning experiences with ongoing guidance can enable students at all levels to build toward mastery of a common set of skills.

Mind, brain, and education research on individual differences, language learning, literacy, and mathematics suggests that students learn most effectively through experiences that are tailored to their needs and interests (Fischer & Bidell 2006; Fischer, Immordino-Yang, & Waber 2007; Hinton & Fischer 2011). Historically, education consisted of learning a sacred text, such as the Bible, the Koran, or the writings of Confucius (Gardner 2004). This history is evident in the current education system, which often asks students to memorize information from textbooks in a rigid way. **While content knowledge is important, students best learn this knowledge, as well as more advanced skills, through active learning experiences in a flexible educational context.** Mind, brain, and education research on individual differences, language learning, literacy, and mathematics indicates that students can follow different learning pathways (Fischer, Immordino-Yang, & Waber 2007). **A flexible education system that differentiates instruction to accommodate individual differences will therefore meet the needs of a wider variety of students.**¹⁵ Technology can provide a powerful means of differentiating instruction if it is designed for that pedagogical purpose (Rose & Meyer 2000, 2002; Wilson et al. 2006). Student-centered learning approaches allow students to follow different pathways to core skills and standards. Students can progress at their own pace through learning experiences that meet their particular needs and interests.

Neuroscience research also suggests that each student has a unique profile of strengths and limitations, and a student's ability in one domain does not predict his or her ability in another (Gardner 1983). This underscores the need for multiple pathways to core knowledge (Rose & Strangman 2007; Rose & Dalton 2009). **Without such flexibility, difficulties in a certain domain may unnecessarily interfere with learning in another domain.** Consider, for example, students with limited English proficiency who are learning mathematics. In a traditional

classroom, these students would have difficulties accessing mathematical knowledge from printed English textbooks and would struggle to demonstrate their understanding on paper-and-pencil exams. These types of avoidable problems impede learning and mask mathematical abilities. **If students with limited English proficiency are given alternative means of instruction and assessment, such as a computer program that can translate English instructions into their native language, they would not fall behind in mathematics while their language skills were developing. A student-centered learning approach can provide this type of flexibility.**

Related Paper in the *Students at the Center Series*¹⁶

For a more detailed discussion of how technology facilitates differentiating instruction and meeting different learning styles, see *Curricular Opportunities in the Digital Age*, by David H. Rose and Jenna W. Gravel.



Neuroscience research indicates that emotion and learning are biologically interdependent (Damasio 1994, 1998; Dalglish 2004; Grindal, Hinton, & Shonkoff 2011; Immordino-Yang et al. 2007, 2009; LeDoux 2002; Rolla, Hinton, & Shonkoff 2011). This scientific evidence that emotion is fundamental to learning settles long-standing ideological debates concerning whether educators should be responsible for emotional development—**if educators are responsible for intellectual development, they are inherently involved in emotional development as well** (Hinton, Miyamoto, & della Chiesa 2008). **Students are more likely to thrive academically if educators provide a positive learning environment, encourage a sense of community, teach emotional regulation strategies, and shelter students from toxic stress. Student-centered approaches to learning recognize the central role of emotion in learning.**

Student-centered approaches to learning require students to be self-directed and responsible for their own learning, which requires executive functioning skills such as goal setting, planning, and monitoring

» This scientific evidence that emotion is fundamental to learning settles long-standing ideological debates concerning whether educators should be responsible for emotional development—if educators are responsible for intellectual development, they are inherently involved in emotional development as well.



Student-centered approaches to learning require students to be self-directed and responsible for their own learning, which requires executive functioning skills such as goal setting, planning, and monitoring progress.

progress. Since the prefrontal cortex is still maturing in adolescence, executive functioning skills are still developing (Luna & Sweeney 2004). Educators can support the development of executive functioning skills by explicitly teaching metacognitive skills of “learning how to learn,” including how to set appropriate goals, track progress toward them, appropriately adjust learning strategies, and accurately assess outcomes (Schoenfeld 1987; White & Frederiksen 1998). When students first begin learning these skills, educators can provide a good amount of targeted support, or scaffolding. Educators can then gradually remove this scaffolding as students become more self-directed in their learning.¹⁷

UNDERSERVED YOUTH

Mind, brain, and education research on individual differences suggests that underserved students may sometimes thrive with different instructional techniques than their middle-class peers (Henrich, Heine, & Norenzayan 2010). For example, neuroscience research on literacy shows that ESL students are using a somewhat different brain network for reading than native English readers (OECD 2007). That suggests that ESL students may require alternative means of reading instruction. Many of the practices associated with student-centered learning provide a flexible framework for education that can accommodate individual differences through differentiated instruction.

Recent research indicates that a key difference between disadvantaged students who succeed in school and those who do not is their emotional skills (OECD 2011). Resilient disadvantaged students tend to have more self-confidence and higher motivation than their non-resilient peers. Therefore, using an educational approach that nurtures emotional development is especially important for underserved students. In addition, research suggests that students from disadvantaged backgrounds are more likely to experience toxic stress, which can disrupt brain

circuitry that is central to learning (Shonkoff & Phillips 2000; Rappolt-Schlichtmann et al. 2009).

Since student-centered learning is not confined to the traditional school calendar and schedule, it can provide child-friendly learning spaces that shelter students from toxic stress when they are away from school, such as over the summer or after regular school hours (UNICEF 2009).

Proficiency in the language of instruction strongly predicts academic achievement among immigrants (OECD 2003). Neuroscience research indicates that there are sensitive periods for certain aspects of language learning early in life (Bruer 2008; Neville & Bruer 2001; Kuhl 2010). Because of these sensitive periods, students who receive non-native language instruction in preschool or primary school have a biological advantage for mastering certain aspects of that language. Therefore, teaching ESL students the language of instruction as early as possible gives them a biological advantage for learning that language, which ultimately supports their academic achievement. Much more mind, brain, and education research is needed on education of underserved youth.

CHALLENGES AND FUTURE DIRECTIONS

Research in mind, brain, and education suggests that student-centered approaches to learning are consistent with how students learn. However, there are major logistical challenges in implementing these approaches. First, student-centered learning approaches call for evidence-based pedagogy. The current education system lacks an infrastructure that supports a sustainable interaction between researchers and practitioners. Without this infrastructure, there is a gap between research and practice, and practices are often based on history or ideology rather than evidence. A related challenge is that implementing student-centered learning requires extensive professional development for educators,

who would need to be skilled in understanding research, using multiple forms of pedagogy, effectively differentiating instruction, carrying out formative assessments, and connecting with community members. One solution to both of these challenges is to create research schools, which are living laboratories where researchers work alongside teachers to carry out research, train educators, and disseminate research results (Hinton 2008; Hinton & Fischer 2008, 2010).¹⁸

Other challenges of student-centered learning approaches arise from students following their own pathways to proficiency, often through informal learning experiences. How can educators ensure accountability in a system with permeable borders between schools, homes, communities, and professional institutions? How can educators measure progress toward common standards across a wide variety of informal learning contexts? How will educators' performances be evaluated in a system that distributes responsibilities among teachers, parents, community members, and others? In addition to these accountability issues, students following different learning pathways bring an even more troubling challenge: namely, a system that treats students differently risks creating further inequity. If the system is not regulated properly, it could lead to unintentional tracking or widening of the achievement gap.

Additional challenges involve issues with funding and political will. For example, it will likely be expensive to fund professional development programs that can create teams of educators in various facets of students' lives who are capable of differentiating instruction, supporting emotional regulation skills, teaching metacognitive skills, and so forth. Moreover, gaining political will for certain aspects of these approaches may also be challenging. For example, students from disadvantaged backgrounds will likely require more resources to reach a common set of core standards than students from more privileged backgrounds. How can educators gain political support for this unequal distribution of resources?

Research in mind, brain, and education suggests that student-centered learning approaches could lead to a more effective and equitable education system, but there are many serious logistical challenges that need to be dealt with before such practices can be effectively and holistically implemented. In reference to progress in education, Howard Gardner (2004) notes, "This task may take one hundred years or more; but as a French military leader once famously remarked when facing an especially daunting task, in that case, we had better begin today."

ENDNOTES

¹ The purpose of this chapter is not to review all cognitive science or neuroscience research on learning but rather to discuss mind, brain, and education research that is most relevant to student-centered learning approaches, with a particular focus on neuroscience research.

² For more information, see “Universal Design for Learning” in *Curricular Opportunities in the Digital Age*, by David H. Rose and Jenna W. Gravel. <http://www.studentsatthecenter.org/papers/curricular-opportunities-digital-age>

³ See series paper: <http://www.studentsatthecenter.org/papers/motivation-engagement-and-student-voice>

⁴ For more information, see series paper: *Curricular Opportunities in the Digital Age*, by David H. Rose and Jenna W. Gravel. <http://www.studentsatthecenter.org/papers/curricular-opportunities-digital-age>

⁵ Since Howard Gardner (1987, 2006, 2008) revolutionized our concept of intelligence, educational researchers understand that intelligence is more multifaceted and dynamic than the notion of IQ suggests. Nonetheless, the considerable difference in genetic and environmental contributions to IQ in different subgroups is an interesting finding.

⁶ Shared environment refers to the environmental factors shared among siblings living in the same household. Other factors that contribute to variability in IQ include non-shared environmental factors, those that are different among siblings living in the same household such as experiences with peers and random chance.

⁷ For more information, see series paper: *Motivation, Engagement, and Student Voice*, by Eric Toshalis and Michael J. Nakkula. <http://www.studentsatthecenter.org/papers/motivation-engagement-and-student-voice>

⁸ See series paper: <http://www.studentsatthecenter.org/papers/teachers-work>

⁹ For more information, see: *Motivation, Engagement, and Student Voice*, by Eric Toshalis and Michael J. Nakkula.

¹⁰ For more information, see series paper: *Curricular Opportunities in the Digital Age*, by David H. Rose and Jenna W. Gravel. <http://www.studentsatthecenter.org/papers/curricular-opportunities-digital-age>

¹¹ For an illustration of how teachers can use feedback to motivate students, see “Element 7. Clear, Timely Assessment and Support” in *Teachers at Work—Six Exemplars of Everyday Practice*, by Barbara Cervone and Kathleen Cushman. <http://www.studentsatthecenter.org/papers/teachers-work>

¹² For more information, see series paper: *Motivation, Engagement, and Student Voice*, by Eric Toshalis and Michael J. Nakkula. <http://www.studentsatthecenter.org/papers/motivation-engagement-and-student-voice>

¹³ See series paper: <http://www.studentsatthecenter.org/papers/assessing-learning>

¹⁴ For examples and a discussion of connecting informal learning to schools, see “Element 5. Anywhere, Anytime, and Real-world Learning” in *Teachers at Work—Six Exemplars of Everyday Practice*, by Barbara Cervone and Kathleen Cushman. <http://www.studentsatthecenter.org/papers/teachers-work>

¹⁵ For more information, see series paper: *Motivation, Engagement, and Student Voice*, by Eric Toshalis and Michael J. Nakkula. <http://www.studentsatthecenter.org/papers/motivation-engagement-and-student-voice>

¹⁶ See series paper: <http://www.studentsatthecenter.org/papers/curricular-opportunities-digital-age>

¹⁷ For examples of how educators scaffold learning and foster self-directed learners, see Elements 3, 4, and 8 in *Teachers at Work—Six Exemplars of Everyday Practice*, by Barbara Cervone and Kathleen Cushman. <http://www.studentsatthecenter.org/papers/teachers-work>

¹⁸ For a detailed discussion of other means of supporting professional development to foster student-centered approaches to learning, see “Professional Learning in Student-centered Environments” in *Teachers at Work—Six Exemplars of Everyday Practice*, by Barbara Cervone and Kathleen Cushman. <http://www.studentsatthecenter.org/papers/teachers-work>

REFERENCES

- Ahissar, E., Vaadia, E., Ahissar, M., Bergman, H., Arieli, A., & Abeles, M. 1992. "Dependence of Cortical Plasticity on Correlated Activity of Single Neurons and on Behavioral Context." *Science*. Vol. 257, No. 5057.
- Arbelle, S. Benjamin, J., Golin, M., Kremer, I., Belmaker, R.H., & Ebstein, R.P. 2003. "Relation of Shyness in Grade School Children to the Genotype for the Long Form of the Serotonin Transporter Promoter Region Polymorphism." *The American Journal of Psychiatry*. Vol. 160, No. 4.
- Bookheimer, S.Y. 2002. "Functional MRI of Language: New Approaches to Understanding the Cortical Organization of Semantic Processing." *Annual Review of Neuroscience*. Vol. 25.
- Bookheimer, S.Y., Zeffiro, T.A., Blaxton, T., Gaillard, W.D., Malow, B., & Theodore, W.H. 1998. "Regional Cerebral Blood Flow During Auditory Responsive Naming: Evidence for Cross-modality Neural Activation." *NeuroReport*. Vol. 9, No. 10.
- Bruer, J.T. 2008. "Critical Periods in Second Language Learning: Distinguishing Phenomena from Explanation." In M. Mody & E. Silliman, eds. *Brain, Behavior and Learning in Language and Reading Disorders*. New York, NY: The Guilford Press.
- Cain, C.K. & LeDoux, J.E. 2008. "Emotional Processing and Motivation: In Search of Brain Mechanisms." In A.J. Elliot, ed. *Handbook of Approach and Avoidance Motivation*. New York, NY: Taylor and Francis Group.
- Cohen, L. et al. 2002. "Language-specific Tuning of Visual Cortex? Functional Properties of the Visual Word Form Area." *Brain*. Vol. 125, No. 5.
- Dalgleish, T. 2004. "The Emotional Brain." *Nature Reviews Neuroscience*. Vol. 5.
- Damasio, A.R. 1994. *Descartes' Error: Emotion, Reason, and the Human Brain*. New York, NY: Grosset/Putnam.
- Damasio, A.R. 1998. "Emotion in the Perspective of an Integrated Nervous System." *Brain Research Reviews*. Vol. 26.
- Damasio, H., Grabowski, T., Frank, R., Galaburda, A.M., & Damasio, A.R. 1994. "The Return of Phineas Gage: Clues about the Brain from the Skull of a Famous Patient." *Science*. Vol. 264, No. 5162.
- Das, T., Padakannaya, P., Pugh, K.R., & Singh, N.C. 2011. "Neuroimaging Reveals Dual Routes to Reading in Simultaneous Proficient Readers of Two Orthographies." *NeuroImage*. Vol. 54, No. 2.
- Davidson, R.J. 2003. "Seven Sins in the Study of Emotion: Correctives from Affective Neuroscience." *Brain and Cognition*. Vol. 52.
- Davidson, R.J. & Fox, N.A. 1989. "Frontal Brain Asymmetry Predicts Infants' Response to Maternal Separation." *Journal of Abnormal Psychology*. Vol. 98, No. 2.
- Dehaene, S. 2011. *The Number Sense: How the Mind Creates Mathematics*. Oxford, UK: Oxford University Press.
- Dehaene, S. 2009. *Reading in the Brain: The Science and Evolution of a Human Invention*. New York, NY: Penguin.
- Dobbs, D. 2006. "A Revealing Reflection: Mirror Neurons Seem to Effect Everything from How We Learn to Speak to How We Build Culture." *Scientific American Mind*. May/June.
- Dweck, C.S. 2006. *Mindset*. New York, NY: Random House.
- Elbert, T. et al. 1995. "Increased Cortical Representation of the Fingers of the Left Hand in String Players." *Science*. Vol. 270, No. 5234.
- Ferigenson, L., Dehaene, S., & Spelke, E.S. 2004. "Core Systems of Number." *Trends in Cognitive Neuroscience*. Vol. 8, No. 7.
- Fink, R.P. & Samuels, J., eds. 2007. *Inspiring Success: Reading Interest and Motivation in an Age of High-stakes Testing*. Newark, DE: International Reading Association.
- Fischer, K.W., Bernstein, J.H., & Immordino-Yang, M.H., eds. 2007. *Mind, Brain, and Education in Reading Disorders*. Cambridge, UK: Cambridge University Press.

- Fischer, K.W. & Bidell, T.R. 2006. "Dynamic Development of Action and Thought." In W. Damon & R.M. Lerner, eds. *Handbook of Child Psychology*. New York, NY: John Wiley & Sons, Inc.
- Fischer, K.W., Daniel, D., Immordino-Yang, M.H., Stern, E., Battro, A., & Koizumi, H. 2007. "Why Mind, Brain, and Education? Why Now?" *Mind, Brain, and Education*. Vol. 1, No. 1.
- Fischer, K.W., Immordino-Yang, M.H., & Waber, D.P. 2007. "Toward a Grounded Synthesis of Mind, Brain, and Education for Reading Disorders: An Introduction to the Field and this Book." In K.W. Fischer, J.H. Bernstein, & M.H. Immordino-Yang, eds. *Mind, Brain, and Education in Reading Disorders*. Cambridge, UK: Cambridge University Press.
- Fledge, J. & Fletcher, K. 1992. "Talker and Listener Effects on Degree of Perceived Foreign Accent." *Journal of the Acoustical Society of America*. Vol. 91, No. 1.
- Frijda, N.H. 2006. *The Laws of Emotions*. New York, NY: Erlbaum.
- Fuster, J.M. 2008. *The Prefrontal Cortex*. London, UK: Academic Press.
- Gabrieli, J.D.E. 2004. *Development of Emotions and Learning: A Cognitive Neuroscience Perspective*. Cambridge, MA: Building Usable Knowledge in Mind, Brain, and Education.
- Gaillard, R. et al. 2006. "Direct Intracranial, fMRI, and Lesion Evidence for the Causal Role of Left Inferotemporal Cortex in Reading." *Neuron*. Vol. 50, No. 2.
- Gardner, H. 1987. "Beyond the IQ: Education and Human Development." *Harvard Educational Review*. Vol. 57, No. 2.
- Gardner, H. 1983. *Frames of Mind: The Theory of Multiple Intelligences*. New York, NY: Basic Books.
- Gardner, H. 2004. "How Education Changes." In M. Suárez-Orozco & D.B. Qin-Hilliard, eds. *Globalization, Culture, and Education in the New Millennium*. Berkeley, CA: University of California Press.
- Gardner, H. 2006. *Multiple Intelligences: New Horizons*. New York, NY: Basic Books.
- Gardner, H. 2008. "Who Owns Intelligence." In K.W. Fischer & M.H. Immordino-Yang, eds. *The Jossey-Bass Reader on the Brain and Learning*. Long Beach, CA: John Wiley & Sons, Inc.
- Grindal, T., Hinton, C., & Shonkoff, J. 2011. "The Science of Early Childhood Development: Lessons for Teachers and Caregivers." In B. Falk, ed. *In Defense of Childhood*. New York, NY: Teachers College Press.
- Hamilton, R.H. & Pascual-Leone, A. 1998. "Cortical Plasticity Associated with Braille Learning." *Trends in Cognitive Sciences*. Vol. 2, No. 5.
- Hebb, D.O. 1949. *The Organization of Behavior*. New York, NY: Wiley & Sons.
- Henrich, J., Heine, S.J., & Norenzayan, A. 2010. "The Weirdest People in the World?" *Behavioral and Brain Sciences*. Vol. 33.
- Hinton, C. Forthcoming. "Cosmopolitan Education: Building on a Biological Inclination for Care in a Globalised World." In B. della Chiesa, C. Hinton, & J. Scott, eds. *Learning to Speak the World*. Paris, France: OECD.
- Hinton, C. 2008. Usable Knowledge. "From Lipstick to Learning: Research Goes to School." Harvard Graduate School of Education. Accessed on December 2, 2011. <http://www.uknow.gse.harvard.edu/decisions/DD308-408.html>
- Hinton, C. & Fischer, K.W. 2011. "Learning from a Developmental and Biological Perspective." In H. Dumont, D. Istance, & F. Benavides, eds. *The Nature of Learning: Using Research to Inspire Practice*. Paris, France: OECD.
- Hinton, C. & Fischer, K.W. 2010. "Research Schools: Connecting Research and Practice at the Ross School." In M. Suárez-Orozco & H. Gardner, eds. *Educating the Whole Child for the Whole World: The Ross Schools and the Promise of Education for the Global Era*. Berkeley, CA: University of California Press.
- Hinton, C. & Fischer, K.W. 2008. "Research Schools: Grounding Research in Practice." *Mind, Brain and Education*. Vol. 2, No. 4.
- Hinton, C., Miyamoto, K., & della-Chiesa, B. 2008. "Brain Research, Learning and Emotions: Implications for Education Research, Policy, and Practice." *European Journal of Education*. Vol. 43, No. 1.
- Hittmair-Delazer, M., Sailer, U., & Benke, T. 1995. "Impaired Arithmetic Facts but Intact Conceptual Knowledge—a Single Case Study of Dyscalculia." *Cortex*. Vol. 31, No. 1.
- Immordino-Yang, M.H. 2008. "The Stories of Nico and Brooke Revisited: Toward a Cross-disciplinary Dialogue about Teaching and Learning in Mind, Brain, and Education." *Mind, Brain, and Education*. Vol. 2, No. 2.
- Immordino-Yang, M.H. & Damasio, A.R. 2007. "We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education." *Mind, Brain, and Education*. Vol. 1, No. 1.

- Immordino-Yang, M.H., McColl, A., Damasio, H., & Damasio, A.R. 2009. "Neural Correlates of Admiration and Compassion." *Proceedings of the National Academy of Sciences*. Vol. 106, No. 19.
- Izard, V., Sann, C., Spelke, E.S., & Strerib, A. 2009. "Newborn Infants Perceive Abstract Numbers." *Proceedings of the National Academy of Sciences*. Vol. 106, No. 25.
- Jobard, G., Crivello, F., & Tzourio-Mazoyer, N. 2003. "Evaluation of the Dual Route Theory of Reading: A Metanalysis of 35 Neuroimaging Studies." *NeuroImage*. Vol. 20, No. 2.
- Kaczmarek, L. & Levitan, I.B. 2002. *The Neuron: Cell and Molecular Biology*. Oxford, UK: Oxford University Press.
- Kegel, C., Bus, A.G., & van IJzendoorn, M.H. 2011. "Differential Susceptibility in Early Literacy Instruction through Computer Games: The Role of the Dopamine D4 Receptor Gene (DRD4)." *Mind, Brain and Education*. Vol. 5, No. 2.
- Knight, C.C. & Fischer, K.W. 1992. "Learning to Read Words: Individual Differences in Developmental Sequences." *Journal of Applied Developmental Psychology*. Vol. 13.
- Kuhl, P.K. 2010. "Brain Mechanisms in Early Language Acquisition." *Neuron*. Vol. 67, No. 5.
- Lang, P.J. 2010. "Emotion and Motivation: Toward Consensus Definitions and a Common Research Purpose." *Emotion Review*. Vol. 2, No. 3.
- Lang, P.J. & Davis, M. 2006. "Emotion, Motivation and the Brain: Reflex Foundations in Animal and Human Research." *Progress in Brain Research*, Vol. 156.
- Lappe, C., Herholz, S.C., Trainor, L.J., & Pantev, C. 2008. "Cortical Plasticity Induced by Short-term Unimodal and Multimodal Musical Training." *The Journal of Neuroscience*. Vol. 28, No. 39.
- LeDoux, J.E. 2000. "Cognitive-emotional Interactions: Listen to the Brain." In R.D. Lane & L. Nadel, eds. *Cognitive Neuroscience of Emotion*. Oxford, UK: Oxford University Press.
- Lee, C. et al. 2004. "Neuronal Correlates of Consistency and Frequency Effects on Chinese Character Naming: An Event-related fMRI Study." *NeuroImage*. Vol. 23, Vol. 4.
- Levine, S.C., Vasilyeva, M., Lourenco, S.F., Newcombe, N.S., & Huttenlocher, J. 2005. "Socioeconomic Status Modifies the Sex Difference in Spatial Skill." *Psychological Science*. Vol. 16, No. 11.
- Levy, J. et al. 2009. "Testing for the Dual-route Cascade Reading Model in the Brain: An fMRI Effective Connectivity Account of an Efficient Reading Style." *PLoS One*. Vol. 4, No. 8.
- Li Voti, P. et al. 2011. "Correlation Between Cortical Plasticity, Motor Learning and BDNF Genotype in Healthy Subjects." *Experimental Brain Research*. Vol. 212, No. 1.
- Luan Phan, K., Fitzgerald, D.A., Nathan, P.J., Moore, G.J., Uhde, T.W., & Tancer, M.E. 2005. "Neural Substrates for Voluntary Suppression of Negative Affect: A Functional Magnetic Resonance Imaging Study." *Biology Psychiatry*. Vol. 57.
- Luna, B. & Sweeney, J.A. 2004. "The Emergence of Collaborative Brain Function: fMRI Studies of the Development of Response Inhibition." *Annals of the New York Academy of Science*. Vol. 1021.
- Lyon, G.R., Shaywitz, S.E., & Shaywitz, B.A. 2003. "A Definition of Dyslexia." *Annals of Dyslexia*. Vol. 53, No. 1.
- MacLean, P.D. 1949. "Psychosomatic Disease and the 'Visceral Brain': Recent Developments Bearing on the Papez Theory of Emotion." *Psychosomatic Medicine*. Vol. 11.
- Maguire, E.A. et al. 2000. "Navigation-related Structural Change in the Hippocampi of Taxi Drivers." *Proceedings of the National Academy of Sciences*. Vol. 97, No. 8.
- Maguire, E.A., Burgess, N., & O'Keefe, J. 1999. "The Human Hippocampus and Spatial and Episodic Memory." *Current Opinion Neurobiology*. Vol. 9.
- Mangels, J.A., Good, C., Whiteman, R.C., Maniscalco, B., & Dweck, C.S. 2011. "Emotion Blocks the Path to Learning Under Stereotype Threat." *Social Cognitive and Affective Neuroscience*. Vol. 6.
- Matsuo, K. et al. 2010. "Neural Substrates of Phonological Selection for Japanese Character Kanji Based on fMRI Investigations." *NeuroImage*. Vol. 50, No. 3.
- McCandliss, B.D., Posner, M.I., & Givo'n, T. 1997. "Brain Plasticity in Learning Visual Words." *Cognitive Psychology*. Vol. 33.
- McCrink, K. & Wynn, K. 2004. "Large-number Addition and Subtraction by 9-month-old Infants." *Psychological Science*. Vol. 15, No. 11.
- McEwen, B.S. & Sapolsky, R.M. 1995. "Stress and Cognitive Function." *Current Opinion Neurobiology*. Vol. 5.
- Morgane, P.J., Galler, J.R., & Mokler, D.J. 2005. "A Review of Systems and Networks of the Limbic Forebrain/Limbic Midbrain." *Progress in Neurobiology*. Vol. 75.
- National Center for Educational Statistics. 2008. "Socioeconomic Status." Accessed on August 22, 2011. <http://nces.ed.gov/help/sitemap.asp>

- National Scientific Council on the Developing Child. 2004. "Young Children Develop in an Environment of Relationships: Working paper no. 1." Accessed on August 6, 2011. <http://www.developingchild.harvard.edu>
- Neville, H.J. & Bruer, J.T. 2001. "Language Processing: How Experience Affects Brain Organization." In D.B. Bailer, J.T. Bruer, F.J. Symons, & J.W. Lichtman, eds. *Critical Thinking About Critical Periods*. Baltimore, MD: Paul H. Brookes Publishing.
- Ochsner, K.N., Bunge, S.A., Gross, J.J., & Gabrieli, J.D.E. 2002. "Rethinking Feelings: An fMRI Study of the Cognitive Regulation of Emotion." *Journal of Cognitive Neuroscience*. Vol. 14, No. 8.
- Ochsner, K.N., Ray, R.D., Robertson, E.R., Cooper, J.C., Chopra, S., Gabrieli, J.D.E., & Gross, J.J. 2004. "For Better or For Worse: Neural Systems Supporting the Cognitive Down- and Up-Regulation of Negative Emotion." *NeuroImage*. Vol. 23.
- Organisation for Economic Co-Operation and Development. 2011. *Against the Odds: Disadvantaged Students who Succeed in School*. Paris, France: Author.
- Organisation for Economic Co-operation and Development. 2005. *Formative Assessment: Improving Learning in Secondary Classrooms*. Paris, France: Author.
- Organisation for Economic Co-Operation and Development. 2007. *Understanding the Brain: The Birth of a Learning Science*. Paris, France: Author.
- Organisation for Economic Co-operation and Development (OECD). 2003. *Where Immigrant Students Succeed: A Comparative Review of Performance and Engagement in PISA*. Paris, France: Author.
- Ostry, D.J., Darainy, M., Mattar, A.A.G., Wong, J., & Gribble, P.L. 2010. "Somatosensory Plasticity and Motor Learning." *The Journal of Neuroscience*. Vol. 30, No. 15.
- Pantev, C. et al. 1998. "Increased Auditory Cortical Representation in Musicians." *Nature*. Vol. 23, No. 392.
- Pantev, C. et al. 2003. "Music and Learning-induced Cortical Plasticity." *Annals of the New York Academy of Sciences*. Vol. 999.
- Paulesu, E. et al. 2001. "Dyslexia: Cultural Diversity and Biological Unity." *Science*. Vol. 291, No. 5511.
- Phillips, M.L., Drevets, W.C., Rauch, S.L., & Lane, R. 2003. "The Neurobiology of Emotion Perception: The Neural Basis of Normal Emotion Perception." *Biological Psychiatry*. Vol. 54.
- Rappolt-Schlichtmann, G., Ayoub, C.C., & Gravel, J.W. 2009. "Examining the 'Whole Child' to Generate Usable Knowledge." *Mind, Brain, and Education*. Vol. 3, No. 4.
- Rappolt-Schlichtmann, G. & Watamura, S.E. 2010. "Inter- and Transdisciplinary Research on Hormones with Problems of Educational Practice." *Mind, Brain, and Education*. Vol. 4, No. 4.
- Rappolt-Schlichtmann, G., Willett, J.B., Ayoub, C.C., Lindsley, R., Hulette, A.C., & Fischer, K.W. 2009. "Poverty, Relationship Conflict, and the Regulation of Cortisol in Small and Large Group Contexts at Child Care." *Mind, Brain, and Education*. Vol. 3, No. 3.
- Recanzone, G.H. et al. 1992. "Topographic Reorganization of the Hand Representation in Cortical Area 3b of Owl Monkeys Trained in a Frequency-discrimination Task." *Journal of Neurophysiology*. Vol. 67, No. 5.
- Recanzone, G.H., Schreiner, C.E., & Nerzenich, M.M. 1993. "Plasticity in the Frequency Representation of Primary Auditory Cortex Following Discrimination Training in Adult Owl Monkeys." *The Journal of Neuroscience*. Vol. 13, No. 1.
- Recanzone, G.H. & Wurtz, R.H. 2000. "Effects of Attention on MT and MST Neuronal Activity During Pursuit Initiation." *Journal of Neurophysiology*. Vol. 83, No. 2.
- Ridley, M. 2003. *Nature via Nurture: Genes, Experience and What Makes Us Human*. New York, NY: HarperCollins.
- Robbins, T.W. & Everitt, B.J. 1996. "Neurobehavioural Mechanisms of Reward and Motivation." *Current Opinion in Neurobiology*. Vol. 6, No. 2.
- Rolla, A., Hinton, C., & Shonkoff, J. 2011. *The Science of Early Childhood Development. Hacia un Modelo Interdisciplinario: Biología, Interacción Social y Desarrollo Infantil Temprano*. Buenos Aires, Argentina: Jorge Baudino Ediciones.
- Rose, D. & Dalton, B. 2009. "Learning to Read in the Digital Age." *Mind, Brain, and Education*. Vol. 3, No. 2.
- Rose, D. & Meyer, A. 2002. *Teaching Every Student in the Digital Age: Universal Design for Learning*. Wakefield, MA: CAST.
- Rose, D. & Meyer, A. 2000. "Universal Design for Individual Differences." *Educational Leadership*. Vol. 58, No. 3.
- Rose, D. & Strangman, N. 2007. "Cognition and Learning: Meeting the Challenge of Individual Differences." *Universal Access in the Information Society*. Vol. 5, No. 4.
- Ruytjens, L., Albers, F., van Dijk, P., Wit, H., & Willemsen, A. 2006. "Neural Responses to Silent Lipreading in Normal

- Hearing Male and Female Subjects." *European Journal of Neuroscience*. Vol. 24, No. 6.
- Saver, J.L. & Damasio, A.R. 1991. "Preserved Access and Processing of Social Knowledge in a Patient with Acquired Sociopathy Due to Ventromedial Frontal Damage." *Neuropsychologia*. Vol. 29.
- Schnepps, M., Rose, T., & Fischer, K.W. 2007. "Visual Learning and the Brain: Implications for Dyslexia." *Mind, Brain and Education*. Vol. 1, No. 3.
- Schoenfeld, A. 1987. "What's All the Fuss About Metacognition?" In A. Schoenfeld, ed. *Cognitive Science and Mathematics Education*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Shaywitz, S.E. 2003. *Overcoming Dyslexia*. New York, NY: Random House, Inc.
- Shonkoff, J.P. & Phillips, D.A., eds.; Committee on Integrating the Science of Early Childhood Development; National Research Council and Institute of Medicine. 2000. *From Neurons to Neighborhoods: The Science of Early Childhood Development*. Washington, DC: National Academy Press.
- Shtyrov, Y., Nikulin, V., & Pulvermüller, F. 2010. "Rapid Cortical Plasticity Underlying Novel Word Learning." *The Journal of Neuroscience*. Vol. 30, No. 50.
- Singer, W. 1995. "Development and Plasticity of Cortical Processing Architectures." *Science*. Vol. 270, No. 5237.
- Smith, M.L. & Miller, B. 1981. "The Role of Right Hippocampus in the Recall of Spatial Location." *Neuropsychologia*. Vol. 19, No. 6.
- Snow, C.E., Burns, M.S., & Griffin, P., eds. 1998. *Preventing Reading Difficulties in Young Children*. Washington, DC: National Academy Press.
- Snow, C.E., Griffin, P., & Burns, M.S. 2005. *Knowledge to Support the Teaching of Reading: Preparing Teachers for a Changing World*. San Francisco, CA: Jossey-Bass.
- Squire, L.R. & Zola-Morgan, M. 1991. *Memory: From Mind to Molecules*. New York, NY: Scientific American Library.
- Starkey, P., Spelke, E.S., & Gelman, R. 1990. "Numerical Abstraction by Human Infants." *Cognition*. Vol. 36.
- Stern, E. 2005. "Pedagogy Meets Neuroscience." *Science*. Vol. 310, No. 5749. November 4.
- Tan, L.H. et al. 2003. "Neural Systems of Second Language Reading Are Shaped by Native Language." *Human Brain Mapping*. Vol. 18, No. 3.
- Thompson-Schill, S.L., Aguirre, G., D'Esposito, M., & Farah, M.J. 1999. "A Neural Basis for Category and Modality Specifics of Semantic Knowledge." *Neuropsychologia*. Vol. 37.
- Tomasello, M. 1999. *The Cultural Origins of Human Cognition*. Cambridge, MA: Harvard University Press.
- Turkheimer, E., Haley, A., Waldron, M., D'Onofrio, B., & Gottesman, I.I. 2003. "Socioeconomic Status Modifies Heritability of IQ in Young Children." *Psychological Science*. Vol. 14, No. 6.
- Ungerleider, L.G., Doyon, J., & Karni, A. 2002. "Imaging Brain Plasticity During Motor Skill Learning." *Neurobiology of Learning and Memory*. Vol. 78, No. 3.
- UNICEF. 2009. *Manual: Child Friendly Schools*. New York, NY: Author.
- von Karolyi, C., Winner, E., Gray, W., & Sherman, G. 2003. "Dyslexia Linked to Talent: Global Visual-Spatial Ability." *Brain and Language*. Vol. 85, No. 3. June.
- Vygotsky, L.S. 1978. *Mind in Society*. Cambridge, MA: Harvard University Press.
- Wang, S. et al. 2008. "Broca's Area Plays a Role in Syntactic Processing during Chinese Reading Comprehension." *Neuropsychologia*. Vol. 46, No. 5.
- Weinberger, N.M. 2008. "Cortical Plasticity in Associative Learning and Memory." In J.H. Byrne, ed. *Learning and Memory: A Comprehensive Reference*. Oxford, UK: Elsevier Ltd.
- White, B.Y. & Frederiksen, J.R. 1998. "Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students." *Cognition and Instruction*. Vol. 16, No. 1.
- Wilson, A.J., Dehaene, S., Pinel, P., Revkin, S.K., Cohen, L., & Cohen, D. 2006. "Principles Underlying the Design of 'The Number Race,' an Adaptive Computer Game for Remediation of Dyscalculia." *Behavioral and Brain Functions*. Vol. 2, No. 19.
- Winer, J.A. & Schreiner, C.E., eds. 2011. *The Auditory Cortex*. New York, NY: Springer.
- Wolfe, R.E., Hoffman, N., & Steinberg, A. 2011. *Building the Knowledge Base of Student-Centered Learning*. Boston, MA: Jobs for the Future. Unpublished manuscript.
- Woollett, K., Spiers, H.J., & Maguire, E.A. 2009. "Talent in the Taxi: A Model System for Exploring Expertise." *Philosophical Transactions of the Royal Society B*. Vol. 364, No. 1522.
- Worden, J., Hinton, C., & Fischer, K.W. 2011. "What Does the Brain Have to do with Learning?" *Phi Beta Kappa*. Vol. 92, No. 8.

Wynn, K. 1992. "Addition and Subtraction by Human Infants."
Nature. Vol. 358.

Wynn, K. 1998. "Numerical Competence in Infants." In C.D.
Donlan, ed. *The Development of Mathematical Skills*. East
Sussex, UK: Psychology Press.



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