Connecting Cognitive Science and Neuroscience to Education

Potentials and Pitfalls in Inferring Executive Processes

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Scientific understanding of mind and brain is advancing quickly and energetically, and society's need to improve the quality of education makes headlines every day. Naturally, these two trends create a broad interest in using research about the brain and mind to guide educational practice. Knowing how our minds/brains function, how we use the brain and body to process and store new information, how our minds/brains change and develop, and how damage to our brains contributes to disabilities and other problems—all these research efforts have great potential for moving forward the science and practice of learning.

This move to make educational practice more scientific has properties that are similar to the history of medical practice. Medicine once relied on the collected wisdom of culture but had no systematic procedure for testing which medical practices were actually effective. In the last 200 years, especially since the innovations of Louis Pasteur in France, medicine has established a powerful base in research in the biological sciences. Medical practice is now guided by what the biological sciences know about the body, and the biological sciences conduct

research that is informed by what is important to medicine. This process is interactive and reciprocal. Scientists do not dictate medical practice, but they contribute to investigating and understanding innovative treatments and techniques that often derive from the clinical skills and experiences of practitioners. In parallel fashion, education must clarify and strengthen its relationship with the research disciplines that study development, learning, and the brain. This relationship should be a reciprocal one in which educational practice and scientific research inform and learn from each other, as medicine and biology act symbiotically.

Although this relationship is still emerging, the growth in knowledge of development, learning, and the brain already provides potentially productive connections between educational practice and scientific research. One particularly promising arena is analysis of possible general abilities that are proposed as an important focus for educational practice, such as the teaching of executive function, the topic of this book. Based on both research and practice—scientific knowledge about how children learn and develop and the history of efforts in education to teach a broad, general ability—we will argue that there is no tightly organized executive function but only loosely coupled, diverse executive skills. A closer relationship between educational practice and research can provide a more accurate and practically useful view of executive function and other candidates for general abilities, such as metamemory, metacognition, and theory of mind (Fischer & Immordino-Yang, 2002; Fischer, Immordino-Yang, & Waber, 2006).

Commonly in human development and in learning in schools, researchers and teachers observe the regular occurrence of similar behaviors and changes that suggest a unified entity, such as executive function. Careful research and practical observation typically find that these behaviors are more diverse than unified. This widely occurring pattern pervades all aspects of human learning and development, including motor functioning, cognitive development, and brain development, as well as executive function. We argue that, like the other cases, executive function has important general characteristics that make it seem to be a unified entity, but at the level of detail important for educational practice it is diverse and variable, not unified. The practical implications of such an interpretation are many.

A RECIPROCAL PARTNERSHIP: DEVELOPMENT, NEUROSCIENCE, AND EDUCATION

Over the last two centuries, the biological sciences have come to form a natural partner for the improvement of medical practice. What fields might play a similar role in relation to education? The complex nature of
educational practice means that several types of research can produce educationally usable knowledge (Fischer & Katzir, in press). In this chapter, we focus particularly on knowledge about human development, the learning process, and brain functioning.

The study of how human beings develop and learn falls under the umbrella of the discipline of human development and its sibling, developmental psychology. This is the field of research that investigates how learning takes place and how people change as they grow from infancy through adulthood. Its research methods have traditionally involved controlled experiments in laboratories as well as studies of naturally occurring changes in behavior with age and setting. Research questions have often focused on narrow inquiries related to (1) normative patterns for particular ages or social groups and (2) species-general human characteristics of thought, memory, attention, emotion, and learning. The field is now experiencing major efforts to move it toward a broader framework that examines development as a function of the many components that affect human behavior, including biology, context, culture, and individual variation. Indeed, the first volume of the influential Handbook of Child Psychology highlights this important shift in emphasis (Damon & Lerner, 2006).

Neuroscience involves the study of the brain, especially its organization, functioning, and underlying physiology, including the neurons, synapses, and neural networks that it comprises. Neuroscience emphasizes brain functioning but not necessarily outwardly noticeable behavior. Most questions in neuroscience focus on specific, experimentally tractable hypotheses about the brain's response to simple stimuli (Turk et al., 2002). Study of the brain often requires combinations of fields in permutations such as cognitive neuroscience, behavior genetics, and behavioral neurochemistry. Our focus in this chapter is on research that makes connections between the brain's activity and people's actions and thoughts.

Education is different from development and neuroscience, as it is not only an academic area of study, but also a practical field. We consider education broadly to include traditional classroom learning, adult learning, and informal learning activities.

Education, human development, and neuroscience have yet to establish a truly reciprocal partnership despite continually increasing interactions tending in that direction. A handful of cases show the enormous potential of reciprocal interactions for benefiting educational practice. For example, research in dyslexia has led to major advances not only in understanding the bases of specific reading disabilities, but also in the design of interventions to help students with dyslexia learn to read and write effectively. Maryanne Wolf and her colleagues (Wolf & Bowers, 1999; Wolf & Katzir-Cohen, 2001; Wolf, Miller, & Donnelly, 2000) have developed a curriculum to support students with dyslexia
that integrates knowledge from neuroscience, development, cognitive science, and education in innovative and meaningful ways. David Rose and his colleagues use principles from these disciplines to inform the development of software and other educational tools that support reading, writing, and instruction that is flexible enough for a variety of learners, following the principles of what they call "universal design" (Rose, Meyer, Strangman, & Rappolt, 2002; Rose, Chapter 13, this volume). These are but two examples that show what is possible when expert scientists and educators from different disciplines work together to study and inform educational activities.

Such efforts move forward the reciprocal relationships of education with cognitive developmental science and neuroscience, producing major advances and innovations in educational practice. Yet caution remains imperative in basing education-related decisions on basic research, especially when there are one-sided relationships rather than reciprocal partnerships. For example, concepts about executive function in cognitive science have led to educational practices that are overly simple and do not engage the variability that teachers encounter every day with students in their classrooms.

SIMILARITIES ACROSS DOMAINS: SIMILAR PATTERNS DO NOT SIGNIFY A UNITARY ABILITY

In a common type of unwarranted leap, researchers uncover similar patterns of behavior or brain functioning and assume that the similarities reflect a single underlying process or structure. The discovery of these similarities, such as parallel patterns of learning or development, provides the basis for many important scientific discoveries, so researchers should seek them, but the interpretation of the parallels requires caution: Even when the similarities point to some common process or function, they typically do not imply a unified or singular capacity, so implications for educational practice are not simple (Fischer & Bidell, 2006). One of the most general characteristics of human functioning (both body and behavior) is that many components operate mostly independently while at the same time having some important links and similarities.

In medicine, when a person experiences a sudden high fever, doctors dare not assume that this symptom indicates a singular cause. A fever can come from bacterial infection, viral infection, overheating of the body, insufficient cooling of the body, malfunction of the immune system, and many other diverse causes. In every case, the body's temperature regulation system is involved, but there is no single cause across cases. A veterinarian can build her practice on the understanding that both poodles and schnauzers are dogs, but she dare not assume that the
various dogs are identical, or she will make critical mistakes in treat-
ment. We will now discuss several examples of similarities in patterns of
biological and cognitive development and then how to interpret the simi-
larities and what the insights from these examples imply for analyzing
executive function.

**Motor System(s)**

The motor system—the functions of the body that allow and control
movement—can in many ways be viewed as a single entity. Like the
digestive system or the respiratory system, students tend to study the
motor system as a unit. Understanding the functioning of muscles, ten-
dons, ligaments, and the rest will provide a solid foundation for under-
standing how people can tap their toes, nod their heads, or throw a
baseball. Given the common functions and the strong connections of
some components, it makes sense to view the motor functions as a sys-

At the same time, the shared functions of the motor system do not
make it unitary or uniform, and assuming such a unity leads to critical
misunderstanding. For example, an impairment or injury in one aspect
of motor activity often has little or no influence on another aspect. The
motor system is highly differentiated into gross and fine motor activities,
voluntary and involuntary muscles, distinct organs (arms, legs, heart,
stomach, motor cortex, cerebellum, etc.) and even further specialized
within each of these categories.

Any basic anatomy and physiology textbook makes clear the com-
plexity of the processes that enable human movement. In any one part of
the motor system, such as muscles, crucial distinctions must be made.
One textbook highlights the need to consider both differences and simi-
larities among types of muscles (Marieb, 2006). There are three types of
muscle tissue, which differ in cell structure, body location, and type of
stimulation to cause contraction, but all types have the same kinds of fil-
aments that participate in contraction. In another piece of the motor sys-
tem, different joints are capable of different types of rotation, each with
different implications for injury and treatment (Mader, 2005). Regard-
ing how components work together, there are distinct categories that
specify characteristic patterns of coordination, such as voluntary and
involuntary movements and gross and fine motor skills.

Viewing the motor system as a unified entity, then, is useful for ana-
lyzing how bodily movement happens, but the system is composed of
many different parts and processes. It cannot be treated as a unitary
structure. The parts function independently in most ways, although they
are partly connected and coordinated. The same is true of behavioral
systems.
Cognitive Development

The traditional view of development assumes that components that show similar growth functions involve the same unitary underlying process or capacity—a single stage of logic for Piaget's (1983) theory or a single buffer of short-term memory for classical information-processing views (Case, 1974; Klahr & Wallace, 1976). This traditional view treats development as a ladder on which people move upward step by step to successively higher general cognitive stages in a linear fashion. An individual functions at a single general stage across domains and no longer uses earlier ones, according to this view. The stages on this metaphorical ladder assume a common state of development across all domains of learning and behavior, from the ability to solve arithmetic problems to the maturity to respond to social challenges. A 5-year-old will show the same (pre-operational) stage of cognitive development in arithmetic and social understanding, and an adult will show the same (formal operational) stage in both domains.

People do not show this kind of consistency. Research strongly documents that the ladder metaphor is wrong when applied across domains (Fischer & Bidell, 2006), and any experienced teacher or observer of children knows that students show different capacities in different domains. Only within a domain do children develop along a relatively unified, consistent pathway.

A dynamic view of development moves from the traditional ladder view to a different metaphor that includes both consistency and variability, consistent pathways within a domain and different pathways among different domains. Development proceeds along the strands of a web as shown in Figure 4.1. Each strand in the web represents a different specific domain of development. Depending on the breadth of the content one chooses, the strands might represent broad domains such as motor skills, arithmetic knowledge, and literacy, or they might represent specific subdomains within a narrower domain such as simple arithmetic problems, with addition on one strand, subtraction on another, and multiplication on a third. The strands in the figure specify domains in the development of executive processes. Development proceeds from the top of the diagram to the bottom, but a person can develop along different strands at different paces. While the ladder metaphor and the theory behind it emphasize the normative commonalities in development across domains, the web and the dynamic view capture variations in development across domains, as well as connections and separations (represented by intersections and branches).

Besides this variability across domains of functioning, the web metaphor also allows for variability within domains for individual learners. A person working on a specific task does not stay fixed at one point on a
strand but varies his or her activity depending on context and state (Fischer & Bidell, 2006; Fischer, Bullock, Rotenberg, & Raya, 1993). A 1-year-old learns to walk on a level carpet inside the home but is unable to make a few steps across the grass in the backyard. Everyone has experienced situations such as being able in practice to remember lines for a play or shoot a free throw and then failing with the same behavior in the performance that matters. What does it mean to “know” material or to have “mastered” a skill? On any particular task, a person acts at a wide variety of levels, ranging from the functional, or typical, level to the optimal level (what can be done with contextual support). The role of a supportive environment in causing variation along a strand in the web has been widely documented for tasks as diverse as telling a story about social interactions or predicting whether objects will sink or float.

The variability in behavior captured by the web helps illuminate the uniformity seen in some developmental changes. Children demonstrate rapid changes in performance in specific age regions for optimal conditions in familiar domains—changes that have some of the properties of stages. Such spurts have been documented in studies of, for example,
reflective judgment in adolescents and adults (Kitchener, Lynch, Fischer, & Wood, 1993) and use of pronouns in the early speech of Dutch children (Ruhland & van Geert, 1998), as shown in Figure 4.2. These spurts and other kinds of discontinuities tend to cluster at particular age regions for optimal performance, such as approximately 2 years for spurts in vocabulary, use of sentences, and pretend play. In Figure 4.1, look carefully at when the strands change direction, branch, or join, and you will see that these discontinuities cluster in specific regions.

People develop in spurts under optimal conditions, but typically not under ordinary conditions, which lack contextual support and/or extensive familiarity and practice (Fischer et al., 1993). Figure 4.3 illustrates a typical pattern for development of optimal and functional (ordinary) levels in a domain such as reflective judgment or representation of social interactions. Skills develop in spurts for optimal level (high support, top line) but more slowly and smoothly for functional level (low support, bottom line). The same person shows both optimal and functional levels, which come and go with variations in contextual support and state. In this way, each person acts at multiple levels from moment to moment, even for a single domain (strand in the web), moving up and down within a range of skill levels as a function of support and state.

When observers note only the spurts and other discontinuities, which cluster at a specific age region in the developmental web, they see what appears to be a single ability emerging at that age. Examined more
FIGURE 4.3. Optimal and functional levels in cognitive development. Skills develop along a common complexity scale marked by a series of skill levels. With high support, they grow in spurts for optimal level. Without support, they grow more continuously for functional level.

broadly (in the whole web), this pattern becomes one regularity within the broader picture of variability. There is clearly no single, unitary ability emerging across all skills and domains at one age. Instead, a person builds skills along each strand, following its domain-specific developmental progression, and at certain points along the strand, spurts ahead. This spurt is a local process in the domain, not a shift in a single, unitary new ability.

Development is a complex phenomenon that encompasses both (1) elements of uniformity, such as regions of common change across strands or domains, and (2) elements of individuality and variation. As with motor functioning, assuming unity neglects the variation that is present in cognitive development and, thus, oversimplifies and distorts the nature of development, making it seem like a ladder. An accurate view of development must account for both uniformity and variability.

The uniform aspects of cognitive development provide a valuable heuristic based on large-scale patterns of developmental change. Indeed,
they have led to the identification of a general developmental scale underlying both cognitive development and learning (Dawson-Tunik, Commons, Wilson, & Fischer, 2005; Fischer & Bidell, 2006; Fischer & Immordino-Yang, 2002). At the same time, focus on only the uniformity leads to distortions, especially in education. The unitary view produces an emphasis on norms and a neglect of the variation that is inevitably present in educational settings. Children within a classroom will not all reach the same reading level at the same time, despite ladder-like views of reading that mark a text as at one specific grade level. This perspective makes individual variation appear abnormal and problematic rather than a phenomenon to be explored and explained. If a student is able to complete a page of algebra problems one day but seems to have forgotten everything the next day, the behavior appears abnormal and inexplicable (although sensitive teachers know to expect such variation). With the dynamic view of development, such variation is understandable and potentially predictable from context and emotional state (e.g., Did he skip breakfast so he cannot concentrate today? Is a test next period causing anxiety? Did he have a supportive algebra lesson right before he did the problems yesterday?).

A dynamic view of development recognizes the similarities in development across different domains and simultaneously interprets them in terms of the patterns of variation. This dynamic view is more useful and accurate than a traditional view that assumes a unitary process because it deals directly with the complexities of human learning and action. Educators and developmental scientists working together can (1) illuminate the understanding of development by connecting it to variations in students’ behaviors in schools and families and (2) simultaneously create research that feeds back to practitioners to help them use cognitive and developmental analysis to facilitate learning and teaching in schools.

**Brain Development**

The science of brain development is much less mature than that of cognitive development. Yet early evidence suggests that the model for cognitive development applies straightforwardly to important aspects of brain development as well. Brain growth and cognitive growth seem to show the same kind of web pattern and the same type of recurring growth cycle, with multiple developing strands and spurts and other discontinuities in growth along each strand. For instance, the part of the prefrontal cortex that supports working memory (holding information on-line for a time) develops separately from the part of the occipital cortex that analyzes visual information, although both develop with similar discontinuities (Fischer & Rose, 1996). (Scholars frequently nominate the prefrontal cortex as the key brain region for executive function.)
The strongest empirical evidence of these brain growth patterns comes from research on the development of electrical activity in the cortex, measured through the electroencephalogram (EEG). The most studied property of the EEG is its energy (called “power”), which develops through fits and starts at specific ages that correspond to the ages of emergence of optimal levels in cognitive capacity from infancy through early adulthood (Fischer & Bidell, 2006; Somsen, van 't Klooster, van der Molen, van Leeuwen, & Licht, 1997; Thatcher, 1994). Figure 4.4 shows the results of one normative study (Matousek & Petersén, 1973) for the relative energy in the alpha band of EEG in the back of the cortex, with spurts and plateaus clearly evident at approximately 4, 8, 12, 15, and 20 years of age, apparently marking the cognitive levels that are most relevant for the school years. Note the similarity to the growth curve for optimal level in Figure 4.3.

The similarity of growth curves for EEG energy and cognitive performance suggest a connection between development of brain and behavior, but few studies have looked at brain and behavior concurrently to test the correspondence directly. For the current argument, assume that the correspondence is real—that growth spurts in the EEG
indeed reflect brain reorganizations that relate to the new capacities that emerge at specific ages. Even if this scientific hypothesis proves true, there are major issues about the implications for educational practice. Caution is required in drawing conclusions about the nature of learning and development.

In the 1970s and 1980s, several American biologists and educators used evidence about age-related spurts in head circumference and EEG energy, which they called "phrenoblysis" (Epstein, 1974, 1978) to draw conclusions about how schoolchildren learn (Fischer & Lazerson, 1984). They treated these conclusions as facts and used them to make extensive recommendations to school boards, teachers, and parents. For example, the scholars went directly from their findings about spurts in head growth and EEG to conclusions that when the head is in a growth plateau (a period of little change, not a spurt), no learning can occur. They told educators that instruction in new concepts should focus on periods of growth because that was when new learning could occur. Yet there was absolutely no research testing how learning related to periods of brain and head growth, and there was substantial evidence that children learn new material at all ages during the school years, with no flat periods where learning does not occur.

One reason for the popularity of these recommendations in education was that few educators knew much about the biology of the brain, so many of them simply accepted the claims of phrenoblysis as scientific fact. With stronger reciprocal connections between neuroscience, cognitive developmental science, and education, the scientists' hypothesis about the relation of spurts and plateaus to learning would have been subject to empirical test before being used to make recommendations for educational policy and practice.

The model of phrenoblysis assumed that the brain and cognition worked together as a unitary system instead of being composed of many parts, most of which are only loosely coupled. Contrary to that assumption, development does not happen in a single process across all regions of the brain, although there are important similarities in some aspects of brain development across many brain regions. An overly simple look at the EEG evidence can lead to the conclusion that the entire brain is developing during a growth spurt. In reality, development takes place along separate strands (in a developmental web), and one of the goals of neuroscientific research is to characterize relations among the growing strands. Early evidence indicates that the growth process occurs in cycles, moving systematically around locations in the brain, not as a single spurt at the same time across all brain regions (Thatcher, 1994). The left and right hemispheres seem to develop in different sequences, which appear to repeat for each cycle of cortical reorganization (Fischer &
Rose, 1996). Again, what at first appears like a unified process is in fact a diverse set of individual processes acting in concert with each other. Scientists and educators can understand how the “system” works only by examining the parts and how they vary, which will eventually lead to an explanation of the neuroscientific principles of brain development and learning.

**Executive Function Is Not Unitary**

Executive function is typically conceived as a broad cognitive capacity and is subject to the same kinds of pitfalls in interpretation as other concepts about cognition and brain. The idea of a single, unified executive function falls into the same trap as concepts of unitary motor abilities, cognitive development, and brain development. The continuing lack of consensus regarding a definition of executive function arises in large part from the problems that result from treating it as a single, unitary cognitive ability. Teuber (1972) was one of the first to address the question directly, in his article entitled “Unity and Diversity of Frontal Lobe Functions,” and a number of researchers have taken up the issue more recently (Duncan, Johnson, Swales, & Freer, 1997; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). As Baddeley (1996) puts it, the question remains whether it will “prove more appropriate to regard the executive as a unified system with multiple functions, or simply as an agglomeration of independent though interacting control processes” (p. 5).

Analyses of executive function have taken positions of both unity and divergence and various stances in between. The Norman and Shallice (1986) model of the control of action posits a relatively unified system during completion of non-routine activities. It posits two modes of control, one responsible for routine activities and one for non-routine ones. Routine tasks are triggered whenever appropriate stimuli are present, and the system proceeds automatically without further monitoring. Tasks that are more complex or novel require higher-order control by an executive system that regulates the execution of the activities. While the early version of this model was strongly unitary, it has moved toward differentiation in revised versions (Miyake et al., 2000).

Toward the other end of the spectrum from unified to independent is Pennington and Ozonoff’s (1996) model, which treats executive function as a useful functional construct but moves away from the broad frontal cortex metaphor, in which all types of executive tasks are seen as reflecting a single brain function. The authors interpret the metaphor as a logical outgrowth of findings about deficits in patients with frontal lobe damage. Many patients have difficulty with planning or prob-
lem solving, but their intelligence is often preserved. Pennington and Ozonoff propose a cluster of weakly coupled functions converging upon “planning or programming future actions, holding those plans or programs on-line until executed, and inhibiting irrelevant actions” (p. 55).

A clear indication of the shift even further toward separate processes is to refer to executive functions in the plural (Burmeister et al., 2005; Fischer, Barkley, Smallish, & Fletcher, 2005; Manchester, Priestley, & Jackson, 2004). Recall from the discussions of the motor system, cognitive development, and brain development that this kind of model of separate components that work together is pervasive in cognitive science and biology. A unified executive function may be useful as a construct (Zelazo, Mueller, Frye, & Marcovitch, 2003), but it is misleading as a representation of the true nature of the system. Several pieces of evidence support the stance that executive functioning consists of diverse components that function independently in many ways.

First, people perform differentially on measures of separate aspects of executive function. Just as a theory of unitary stages of cognitive development predicts similar capabilities across domains, a unitary view of executive function predicts similar performance in different components, such as planning and inhibition. Several studies show distinct differences in these components.

For example, Carlson, Moses, and Claxton (2004) found that 3- and 4-year-olds performed differently on tests of planning and inhibitory control, showing largely independent processes. In a landmark study, Miyake and colleagues (2000) focused on differential performance on elements of executive function in college students. Most research uses simple correlations between tasks, which could reflect differences in aspects of the task that do not involve executive functioning, such as language use. Miyake and colleagues used a more powerful statistical analysis, a latent variable approach, to investigate three separate elements of executive function: shifting, updating, and inhibition. With confirmatory factor analysis, they found that the three constructs were clearly distinguishable and that they demonstrated some underlying commonality. They concluded that the results indicated “both unity and diversity of executive functions” (Miyake et al., 2000, p. 87). Just like the strands in the developmental web, they are mostly independent but loosely coupled.

The hypothesized components of executive function neither appear at the same level of mastery within individuals nor do they necessarily develop together. Anderson (2002) suggests that individual elements of executive function show different developmental trajectories, including attentional control, cognitive flexibility, goal setting, and information processing. Each domain involves a distinct developmental strand in the
web for executive function, as shown in Figure 4.1, and evidence suggests that separate processes develop at different rates, reaching skilled levels at different ages. The precise nature of these trajectories needs to be investigated empirically, but clearly the evidence points to diversity in executive functions throughout development.

EDUCATIONAL IMPLICATIONS

Does the debate and confusion about the definition of executive function make any difference for educational practice? Yes. As in the examples of motor functioning, cognitive development, and brain development, assumption of a unity that is not present leads quickly to dangers in practical implications. One of the most potent pitfalls involves decisions about how to support students with deficits in executive function, whose profiles vary dramatically.

Many developmental disabilities, such as attention-deficit/hyperactivity disorder (ADHD) and autism, involve deficits in executive function (Pennington & Ozonoff, 1996). Although these deficits make the disorders appear similar, the executive dysfunction manifests differently in distinct disorders, and diverse interventions are required. For example, the process of inhibition shows less impairment in many individuals with autism than in those with ADHD, even though the impairment in other executive functions, such as planning, is more severe in autism (Hill, 2004; Pennington & Ozonoff, 1996). Following the web model in Figure 4.1, different aspects of executive function develop along separate strands (which sometimes intersect or branch).

Profiles of executive function deficits can even be unique and undetectable by traditional measures. Multiple studies have reported cases of individuals with frontal lobe damage who performed well on executive tasks in a laboratory setting but had clear difficulty with executive tasks in real life (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). Profiles of executive function performance are highly variable and do not warrant a unitary concept.

Recognizing that executive function has multiple aspects and is not unitary thus has practical implications in the classroom. Research and practice that separate distinct aspects of a phenomenon, moving beyond the vague frontal metaphor for executive function, will help educators devise more useful, differentiated diagnoses and interventions. Blanket statements of deficits in executive function are certainly less useful than focused ones highlighting particular component skills like attention, inhibition, and planning. The remarkable success of research and practice that specify the particular functions underlying dyslexia and other
reading difficulties, described early in this chapter, provides an excellent model for this endeavor (Fischer et al., 2006).

An interactive relationship between education and the learning, brain, and developmental sciences will foster this type of nuanced understanding and improve the work of both educators and researchers. Just as doctors facing a particular challenge or novel discovery in patients can inform the work of biological scientists, educators can help foster useful and productive research in complementary disciplines. The benefits are reciprocal because innovative research findings can be appropriately translated into educational practice.

REFERENCES


