Prepared by Jill Jeffery, September, 2007
For The Teagle Foundation

Cognition and Brain Development in Students of Traditional College-Going Age

Annotated Bibliography

Project Parameters: This bibliography was compiled during a summer internship at the Teagle Foundation. I am a doctoral student interested in how our current understanding of brain development and cognition might be applied to writing instruction. Because of time constraints, this bibliography does not represent a comprehensive review of scholarly literature. I instead targeted literature reviews and other integrative articles on neuroscience and cognition that I found most relevant to teaching and learning on the college level. The individual neuroscience research reports included here should be considered a sample taken from a rapidly expanding field.

Research question: What can recent research on the human brain and its development tell us about how traditional college-age students learn?

Literature search emphasis: Sources include both literature reviews and research reports. Also included are a small number of sources that directly address practical applications (e.g. Donovan & Bransford, 2005) or provide brief, non-technical overviews for lay readers (e.g. Sabbagh, 2006).

Neuroscience: To obtain research of the human brain and its development that university faculty might wish to know about, two categories of neuroscience research were examined: 1) research on structural and functional brain development and 2) research on structural correlates for functions associated with learning (e.g. memory, metacognition, quantitative processing).

College cognition: A search for reviews of research on college cognition and academic discourse was also conducted so that comparisons between brain research and cognitive research findings could be drawn.

Summary of findings:

Research on structural and functional brain development: Much of the developmental research obtained for this review examined adolescence. Little research has been conducted to address developmental characteristics unique to traditionally college-going age people, although several ongoing longitudinal studies should soon provide a clearer picture of the college brain (e.g. Giedd, 2004). Findings suggest that higher-order cognitive capacities that begin to develop in adolescence do not fully develop until surprisingly late (Luna, Thulborn, Munoz, Merriam, Garver, Minshew et al., 2001), perhaps even into the 30s (Lenroot & Giedd, 2006). One facet of this late maturation is increasing functional integration of brain regions (Davies, Segalowitz, & Gavin, 2004; Luna & Sweeney, 2004). A rapidly expanding body of research suggests that the brain's ability to synthesize activity between different regions underlies development of higher-order cognitive capacities such as abstract thinking, metacognition, self-regulation, and goal-setting.

Research points to adolescence as a critical period in the brain's development (Monastersky, 2007). The adolescent brain is especially vulnerable to stress and operates under a heavier cognitive load for complex problem-solving relative to the adult brain (Sabbagh, 2006). Though adolescents possess mature logical and verbal processing abilities, capacities for self-regulation, goal-setting, planning, and emotional and cognitive control continue to develop throughout adolescence (Sowell, Thompson, Holmes, Jernigan & Toga, 1999) and into early adulthood (Giedd, 2004; Yurgelun-Todd, 2007). Adolescence is a controversial and poorly defined developmental period. Some cross-cultural research suggests that the proposed "critical developmental period" of adolescence is really a cultural product. Skeptics argue that the concept of adolescence does not exist in cultures where young people are socially integrated with adults and where they are not subject to intensely competing demands on their attention (see Sabbagh, 2006 for a discussion of this debate). More cross-cultural brain research is needed to investigate the relative importance of culture, individual experience and predictable neurobiological patterns in accounting for adolescent brain characteristics. Currently, adolescent brain research can describe structural and functional developmental differences, but researchers can only

hypothesize as to the reasons for these differences.

Research on structural correlates to functions associated with learning: Facilitated by innovations in brain imaging technologies, researchers have drawn increasingly fine distinctions between brain functions associated with different structures. At the same time, this research points to a model of complex integration of brain activity, making it difficult to straightforwardly interpret research findings (Watanabe, 2007). Though this rapidly expanding body of knowledge is expected to have strong legal, mental health, and educational implications, far more cross-disciplinary research is needed to understand how the brain and experience interact to influence cognitive growth (Keating, 2004).

Research on cognition: Much research in cognition centers on a debate over the roles of domain-specific and general cognition in learning. In cognitive research, "domain" refers to a particular field of knowledge, such as basketball or biology. In the domain-specific framework, cognition is thought to be "situated" in a particular domain; therefore, teaching general skills such as logic, text comprehension, and critical thinking, is not beneficial because these skills won't transfer across domains. Conversely, the general cognition framework assumes that cognition is readily transferable and that general strategy instruction is therefore effective. A third framework proposes that domain-specific and general cognition interact in complex ways (Alexander, 1992). This last view suggests teachers should center instruction on core disciplinary principles and draw explicit analogies between disciplines to facilitate transfer. More interdisciplinary research exploring the connections between domain-specific and general brain functions as they relate to cognition across domains is needed to address this ongoing debate.

The interactive framework is consistent with academic literacy research examining college reading (Nist & Holschuh, 2000) and writing (Flower, 1990) processes. These researchers advise instructors to cultivate a metacognitive awareness of the epistemological foundations for a particular field of study. Metacognitive awareness of core discipline principles helps students put content in a broader context and make connections across domains, thus capitalizing on the interactions between specific and general cognition.

Summary of implications for college instruction: Research on brain development and research on cognition both emphasize cognitive control and integration. Cognitive control—variously described as metacognitive awareness, and strategic knowledge—involves the capacity to set goals, plan, and self-monitor. Developmental brain research shows that the latest regions to mature in the prefrontal cortex are associated with cognitive control, and these regions continue to undergo dramatic restructuring well into the 20s. Likewise, research on college cognition emphasizes the importance of cognitive control for success with college level work. Research on academic literacy suggests that the capacity to set goals, use strategies flexibly in meeting these goals, and reflect on progress toward meeting goals largely accounts for academic success.

In addition to the shared emphasis on cognitive control, research findings in both neuroscience and cognition emphasize integration. Emerging theories on brain development emphasize increasing brain region integration as characterizing maturation (Davies et al., 2004; Gusnard, Akbudak, Shulman, & Raichle, 2001; Luna et al., 2001; Luna & Sweeney, 2004). Similarly, emerging cognitive theories emphasize domain-specific and general cognitive integration (Alexander, 1992) as well as cognitive, emotional, and social integration (Keating, 2004).

Strategies for facilitating cognitive control and transfer of knowledge suggested in the sources reviewed here include: making performance expectations clear; making discipline epistemology explicit; examining the relationship between discourse conventions and epistemology; drawing analogies between domains; assessing and making connections to students' prior knowledge and experience; engaging students in challenging and meaningful tasks. While such explicitness may seem better suited to high school than college instruction, research on the late development of higher-order capacities associated with cognitive control suggests that college students may need more direct guidance and instructional scaffolding to help them acquire necessary skills. This additional support could be especially important first year college students, who undergo the largest cognitive transformation (Pascarella, 2004).

References:

Structural and functional brain development:

Arnsten, A. F. T., & Shansky, R. M. (2004). Adolescence: Vulnerable period for stress-induced prefrontal cortical function? Introduction to part IV. *Annals of the New York Academy of Sciences, 1021*(1), 143-147.

Summary: This brief introduction to the *Annals of the New York Academy of Sciences* issue on adolescent brain development provides a succinct overview of research on neurochemical factors correlated with adolescents' vulnerability to stress. Findings indicate that the adolescent prefrontal cortex (PFC) is "extraordinarily sensitive to stress" and that adolescents may be especially vulnerable to even mild stressors, especially those over which they feel they have little control. This heightened vulnerability holds the potential for impaired judgment and may contribute to mental health problems. Gender differences are also discussed.

Practical implications: The authors do not discuss implications for teaching and learning. However, as the authors point out, the perception of limited control is common to adolescence and this perception might contribute to impaired judgment—even in situations that adults do not perceive as being particularly stressful. Research suggests that this heightened vulnerability to stress and corresponding impaired judgment continues well into the 20s.

Bunge, S. A., & Wright, S. B. (2007/4). Neurodevelopmental changes in working memory and cognitive control. *Current Opinion in Neurobiology, 17*(2), 243-250.

Summary: The authors call for more research to help us distinguish between the effects of predictable developmental patterns and the effects of experience on changes in brain structure. For example, researchers have found that children sometimes display adult-like brain activity in one task, but not in another. Such results point to a greater need for understanding of training effects.

Practical implications: The authors are consistent with other neuroscientists in cautioning

that we are only beginning to understand how the brain develops. Descriptive studies alone do not allow us to draw clear conclusions about educational practice. However, this article provides some insight into the debate over the acquisition of expert knowledge. Competing theories variously emphasize the roles of practice, talent, and critical developmental periods (see Gobet & Campitelli, 2007 for an overview of this debate) in expertise. These competing theories carry implications for best educational practice including: how much practice is needed; what kinds of educational experiences are most beneficial; and when such experiences are developmentally appropriate. While current understandings of neurobiological development do little to clear up this debate, the authors suggest that future longitudinal studies may improve our understanding.

Davies, P. L., Segalowitz, S. J., & Gavin, W. J. (2004). Development of error-monitoring event-related potentials in adolescents. *Annals of the New York Academy of Sciences, 1021*(1), 324-328.

Summary: The authors report on event-related potential (ERP) research that addresses adolescents' affect regulation and decision-making. Their results indicate that the integration of cognition, motivation, and emotion is associated with the brain's anterior cingulated cortex (ACC), a region that is maturing into the late teen years. This integration may account for the ACC's role in self-regulatory behavior.

Practical implications: This research adds further credence to the notion that the brain development associated with increased self-regulatory function continues into young adulthood. However, the educational implications for this late development are not clear.

Giedd, J. N. (2004). Structural magnetic resonance imaging of the adolescent brain. *Annals of the New York Academy of Sciences*, 1021(1), 77-85.

Summary: Giedd summarizes results from an ongoing longitudinal fMRI study conducted at the National Institute for Mental Health. This research suggests that areas in the brain associated with higher-order functions such as impulse control develop latest, and that these areas do not fully mature until well into the 20s. In addition, the development of these areas

is linked to more efficient, integrated brain function. Because this study measures brain images at approximately two year intervals, it provides rare insight into brain development in late adolescence.

Practical implications: The surprising finding that brain areas associated with impulse control and planning undergo dramatic structural changes well into the 20s undoubtedly has implications for college education. However, it is unclear exactly what those implications might be because fMRI research on adolescence is relatively new and the relationships between brain structure and function are not yet clear. The research does suggest that brain areas continuing to mature during this period are associated with the higher-order functions necessary for success in college.

Ladouceur, C. D., Dahl, R. E., & Carter, C. S. (2004). ERP correlates of action monitoring in adolescence. *Annals of the New York Academy of Sciences, 1021*(1), 329-336.

Summary: This EEG study's results are consistent with previous research suggesting that prefrontal cortex (PFC) structures involved in cognitive control are still developing in late adolescence. Specifically, the anterior cingulated cortex (ACC), which matures in late adolescence, appears to be related to behavior regulation and monitoring.

Practical implications: This study compared early and late adolescent group performance, so there is no direct relevance to college instructors. However, these results are consistent with other research indicating that structures underlying cognitive control mature relatively late.

Lenroot, R. K., & Giedd, J. N. (2006). Brain development in children and adolescents: Insights from anatomical magnetic resonance imaging. *Neuroscience & Biobehavioral Reviews, 30*(6), 718-729.

Summary: This review provides a snapshot of results from an ongoing longitudinal brain development study. The authors describe the state of current research on brain maturation by filling gaps in their own findings with descriptions of other research. It also provides concise descriptions of what is being measured in MRI studies. Though the authors emphasize that individual variation complicates attempts to identify developmental patterns, they do

identify several emerging patterns, including: 1) although the brain is at 95% of its size by age 6, "significant remodeling of gray and white matter" (p. 720) continues into the 30s; and 2) Brain regions mature differentially, with areas associated with motor and sensory function maturing earliest and those associated with the integration of these functions maturing latest. Regions associated with impulse control and decision-making mature very late.

Practical implications: The authors caution that while brain imaging studies have provided rich and detailed data about age-related changes in brain structure, we are limited in our ability to infer relationships between these structural changes and brain functional development. Far more cross-disciplinary research will be required before we can draw such inferences. However, they do note that the "notably late" (p. 723) development of the dorsolateral prefrontal cortex (DPFC), the area associated with control and judgment, will likely have major educational and judicial implications.

Luna, B., & Sweeny, J. A. (2004). The emergence of collaborative brain function: FMRI studies of the development of response inhibition. *Annals of the New York Academy of Sciences, 1021*(1), 296-309.

Summary: The authors review adolescent brain research, highlighting the dearth of work in this age range compared to child and adult groups. Recent research supports a theory of adolescence as a critical period in which cognition becomes increasingly integrated and synchronized. This maturation process is facilitated by neurochemical and structural changes in the brain that begin in and continue throughout adolescence. The authors propose that qualitative differences between adolescent and adult brains may help explain behavioral (e.g. adolescent risk-taking) and cognitive (e.g. problem-solving capacity) differences between these age groups.

Practical implications: Although the authors are not explicit about the age range involved in this maturational process, the characterization of adolescence as a critical maturation phase is relevant for college instructors because development of structures underlying cognitive control continues well into the 20s. The authors conceptualize this period as one in

which the brain is unstable and is therefore vulnerable to "hot" (p. 304) situations involving stress or competing stimuli. The authors emphasize the implications of this emerging theory for understanding psychiatric disorders such as schizophrenia, rather than implications for education.

Luna, B., Thulborn, K. R., Munoz, D. P., Merriam, E. P., Garver, K. E., Minshew, N. J., et al. (2001/5). Maturation of widely distributed brain function subserves cognitive development. *NeuroImage, 13*(5), 786-793.

Summary: The authors describe research to uncover brain activity associated with self-regulation. Consistent with other research (e.g. Giedd, 2004) the authors find a relatively late integration of the prefrontal cortex (PFC) in suppression of inappropriate behaviors. This research helps to establish the theory that brain maturation is characterized by increasing integration of brain regions, rather than by independent development of frontal brain structures alone (see Luna & Sweeney, 2004).

Practical implications: These maturational changes are relevant to college instructors because PFC development continues into adulthood. Though the study includes subjects in the 8-30 age range, the authors do not describe changes specific to late adolescence and young adulthood that might be of interest to college instructors. Rather, the 18-30 age range is grouped as "adult" so that it can be compared to children and adolescent groups.

Monastersky, R. (2007). Who's minding the teenage brain? *Chronicle of Higher Education, 53*(19), A14-A18.

Summary: This succinct review of research on the adolescent brain focuses on the relationship between error detection capabilities and risk-taking behavior in adolescents. The author discusses 1) brain structural correlates for risk-taking behavior; 2) possible evolutionary explanations for adolescents' increased vulnerability to error, risk and short term rewards; 3) social and emotional theories about adolescents' increased vulnerability to group influence; and 4) additional risks, such as lack of sleep, increasingly early puberty and heavy homework loads, that "stack the deck" against adolescents during this developmental

period.

Practical implications: The author quotes experts in the field as suggesting that adolescents need more "scaffolding" and "supervision" from adults as they navigate adolescence.

Sabbagh, L. (2006). The teen brain, hard at work. *Scientific American Mind, 17*(4), 20-25.

Summary: This article provides a succinct overview of recent findings on developmental differences in brain activity during decision-making. Specifically, recent fMRI research indicates that adolescents' brains are working harder than adults' when they try to control their behavior. Researchers cited in the article conclude that it is this extra effort, and not simply irresponsibility, that accounts for adolescents' relatively poor self-control. Adolescents are even more likely to make inappropriate decisions in stressful situations, when their brains are especially taxed. The author also provides a good snapshot of the ongoing debate about whether adolescent brains are indeed unique, or whether brain research findings are the result of environmental rather than biological differences.

Practical implications: Though this article does not explicitly focus on college age, research findings the author describes indicate that brains are undergoing structural and functional changes well into young adulthood. These developmental changes may impact on students' ability to use working memory efficiently, to manage time effectively, and to negotiate complex problem-solving tasks, especially when under stress.

Shaw, P., Greenstein, D., Lerch, J., Clasen, L., Lenroot, R., Gogtay, N., et al. (2006). Intellectual ability and cortical development in children and adolescents. *Nature, 440* (7084), 676.

Summary: This article describes a dynamic relationship between changes in cortical thickness and IQ. Results suggest that correlations between cortical thickness and IQ scores vary depending on the developmental stage: IQ is associated with cortical *thickening* in children and with cortical *thinning* beginning in adolescence. The authors conclude that intelligence appears to be related to brain plasticity in both age groups.

Practical implications: The authors explain that the reasons for these differences in cortical thickness are unknown. However, they suggest it is related to "usage-dependent" factors

such as synaptic pruning. This hypothesis suggests that intelligence and the brain structures that support it are highly flexible.

Snook, L., Paulson, L., Roy, D., Phillips, L., & Beaulieu, C. (2005/7/15). Diffusion tensor imaging of neurodevelopment in children and young adults. *NeuroImage, 26*(4), 1164-1173.

Summary: The authors report on research using what they propose is a more sensitive measure of differences in brain structure across age groups. Results support previous research identifying adolescence as a critical developmental period.

Practical implications: The authors' results are consistent with models showing increasingly diffuse brain activity as the brain matures. However, the implications for these developmental trends are unclear.

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999). *In vivo* evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature Neuorscience, 2*(10), 859-861.

Summary: This research examines post-adolescent brain maturation by comparing brain images of subjects age 12-16 with age 23-30. The authors find that although brain areas associated with spatial and language processing are mature in adolescence, areas associated with "response inhibition, emotional regulation, planning and organization" (p. 860) are continuing to mature post-adolescence. Also maturing post-adolescence are striatal structures associated with learning.

Practical implications: These results are consistent with later brain imaging studies on development in late adolescence and early adulthood. However, it is difficult to draw conclusions about the implications of late brain maturation for instruction.

Spear, L. P. (2004). Adolescent brain development and animal models. *Annals of the New York Academy of Sciences, 1021*(1), 23-26.

Summary: This article describes the overlap between human and animal adolescent brain development research findings. The author argues for the usefulness of animal studies in

understanding adolescence as a distinct developmental stage characterized by increased socialization and risk taking. The article presents analogies between human and animal adolescent development to promote use of animal research in this field.

Practical implications: This article reinforces the idea of adolescence as a poorly researched, but distinct, complex and multi-staged developmental period.

Yurgelun-Todd, D. (2007/4). Emotional and cognitive changes during adolescence. *Current Opinion in Neurobiology, 17*(2), 251-257.

Summary: The author provides a succinct overview of brain research on adolescent cognition. As reported elsewhere, research suggests that brain regions associated with higher cognitive functions, such as response inhibition and goal-directed behavior, are continuing to undergo major structural changes into early adulthood. Also provided are concise explanations of technology used for research in cognitive neuroscience (e.g. fMRI, PET, DTI) as well as descriptions of key changes in brain structure such as myelination, white and gray matter differentiation, and sequential regional development.

Practical implications: This article focuses on the relationship between affect and cognition. Increased cognitive control over planning, emotional response, and emotional discrimination (the ability to interpret social and emotional cues from others) continue to develop well into the 20s.

Research on structural correlates to functions associated with learning:

Amso, D., Davidson, M. C., Johnson, S. P., Glover, G., & Casey, B. J. (2005/8/15). Contributions of the hippocampus and the striatum to simple association and frequency-based learning. *NeuroImage, 27*(2), 291-298.

Summary: The authors describe learning as "a continuous reduction in the discrepancy between the predicted and actual outcome of an event" (p. 291) and investigate the brain regions that support this process. Their results are consistent with other research that associates the hippocampus and striatum with different aspects of learning. Specifically, the hippocampus is associated with learning new associations between events, while the striatum is associated with encountering novel events. The data suggest that "simple frequency learning" (habituating to novel details) precedes associational learning (the integration of details).

Practical implications: This descriptive study does not discuss educational implications. However, it does provide a theory of learning that might be of interest to college instructors. This theory, supported by research described in the article, posits that learning has to do with the degree of alignment between our past experiences and future expectations. The greater the alignment, the less our reaction time to novel stimuli, and the more learning can be said to have occurred. This article contributes to an increasingly elaborate portrait of the neural processes that underlie learning. However, it will take a good deal of cross-disciplinary research before we can begin to interpret the connections between neural processes and the classroom processes that best support learning.

Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *Proceedings of the National Academy of Sciences,*

Summary: This fMRI study investigates possible functional differences among areas of the medial prefrontal cortex (MPFC). Though results are consistent with other research indicating the MPFC's role in self-referential activity, the authors do not uncover

statistically significant differences between areas within the MPFC. From these results, the authors infer that the MPFC might be involved with "the integration of emotional and cognitive processes" (p. 4262).

Practical implications: The MPFC has been implicated in complex cognitive processes such as metacognition and introspection. The authors do not discuss practical implications of their results; however, relatively late development in the PFC observed elsewhere may affect college students' performance on the complex tasks typical of postsecondary schooling.

Im, K., Lee, J., Lee, J., Shin, Y., Kim, I. Y., Kwon, J. S., et al. (2006/5/15). Gender difference analysis of cortical thickness in healthy young adults with surface-based methods. *NeuroImage, 31*(1), 31-38.

Summary: The authors report on a gender comparison of brain cortical thickness. Previous research finds significant gender differences in overall brain size as well as in gray matter relative to white matter volume. Results reported here are consistent with previous research indicating women's increased cortical thickness, especially in left hemisphere regions associated with language use.

Practical implications: Because the reasons for these gender differences are unknown, it is difficult to draw practical conclusions on this topic. Previous research suggests women have a performance advantage in language use, which would be consistent with research on structural gender differences reported here and elsewhere. However, we do not know if these differences are the result of environmental influences (e. g. cultural, educational), biological influences, or some combination of the two. Given the language processing demands inherent in college course work (see Nist & Holschuh, 2000), results suggesting gender differences in such processing might be of interest given recent concerns about boys' lagging academic achievement.

Ischebeck, A., Zamarian, L., Siedentopf, C., Koppelstätter, F., Benke, T., Felber, S., et al. (2006/5/1). How specifically do we learn? Imaging the learning of multiplication and subtraction. *NeuroImage, 30*(4), 1365-1375.

Summary: Results suggest that subtraction and multiplication are associated with different but overlapping brain activation patterns. Specifically, multiplication appears to activate brain regions associated with memory, while subtraction activates brain regions associated with quantitative processing. The authors explain that this may either be the result of training effects (multiplication typically learned by memorizing tables) or of features in the operations that make particular cognitive processes (memorization or quantitative processing) inherently more efficient.

Practical implications: This article provides a good overview of research on training effects. As with other fMRI studies, however, the behaviors designed to represent a particular cognitive process (e.g. mathematical problem-solving, language processing) are necessarily reductive and do not seem to resemble the kinds of complex tasks typical of higher education.

Luders, E., Narr, K. L., Thompson, P. M., Woods, R. P., Rex, D. E., Jancke, L., et al. (2005/6). Mapping cortical gray matter in the young adult brain: Effects of gender. *NeuroImage, 26*(2), 493-501.

Summary: FMRI research on gender differences in brain tissue type relative to total brain volume is reported. Results indicate women have greater concentrations of gray matter overall and in areas associated with verbal abilities. The authors speculate that these structural differences may help explain women's improved language skills. These findings are consistent with research using other methods to examine gender differences (see Im et al., 2006).

Practical implications: See Im and colleagues (2006) for commentary on gender research.

Schmitz, T. W., Kawahara-Baccus, T. N., & Johnson, S. C. (2004/6). Metacognitive evaluation, self-relevance, and the right prefrontal cortex. *NeuroImage, 22*(2), 941-947.

Summary: The results reported in this article are consistent with previous findings that metacognitive evaluation is associated with the medial prefrontal cortex (MPFC). In the "theory of mind" (ToM) framework, metacognitive evaluation is described in terms of one's ability to maintain conscious awareness of one's own as well as others' mind content "such as beliefs, attitudes, desires, and experiences" (p. 941). Results indicate that evaluations of self are more associated with the right region of the MPFC than are evaluations of others.

Practical implications: The authors do not discuss the practical implications for education. However, this article provides a good overview of the theory of mind framework and research associating metacognition with the MPFC. The development of theory of mind is, not surprisingly, believed to be of great benefit in both interpersonal and academic success.

Watanabe, T., & Tanaka, K. (2007/4). Cognitive neuroscience. *Current Opinion in Neurobiology, 17*(2), 129-131.

Summary: The authors provide an overview of articles in the journal issue as well as progress in cognitive neuroscience. They suggest that future development of the field will extend the current trajectory of increasingly broad and interdisciplinary understandings of brain activity.

Practical implications: The authors also conclude that while research in cognitive neuroscience will become increasingly integrative, this means that it will also become increasingly complex and "difficult to interpret in any simple way" (p. 131). This suggests that it may be some time before we can apply cognitive neuroscience to educational practice.

Wheeler, M. E., & Buckner, R. L. (2004/4). Functional-anatomic correlates of remembering and knowing. *NeuroImage, 21*(4), 1337-1349.

Summary: The authors investigate brain areas associated with memory retrieval. Previous research suggests a relationship between the content being remembered and domain-specific

brain regions. For example, areas associated with visual processing are activated when one retrieves a visual memory. In addition to these domain-specific correlates, memory is also generally associated with the left parietal cortex. To better understand the contributions of different brain areas to memory retrieval, the authors ask: When we remember, are we re-experiencing information in some way (domain-specific retrieval), or are we simply recognizing it as something familiar (general retrieval)? Results from this study suggest that both domain-specific and general brain areas are involved in remembering.

Practical implications: The authors do not discuss implications for teaching and learning. However, this study adds to a growing body of research that points to integrated brain function. In addition, it may support an interactive theory of cognition, as discussed by Alexander (1988, 1992).

Wraga, M., Helt, M., Jacobs, E., & Sullivan, K. (2007). Neural basis of stereotype-induced shifts in women's mental rotation performance. *Social Cognitive and Affective Neuroscience, 2*(1), 12-19.

Summary: The authors review studies establishing a positive correlation between exposure to positive stereotypes and task performance. The study reported here tests the theory that exposure to stereotypes affects performance by affecting cognitive processing. The authors find that a positive stereotype group had 14% fewer errors on a self-rotation spatial task than a negative stereotype group. FMRI scans indicate that performance differences are due to qualitative differences in cognitive processing. The negative stereotype group demonstrated more activity in areas associated with emotional and social processing, while the positive group showed more activation in areas associated with spatial reasoning and working memory. Because brain areas that were more active in the positive stereotype group are more likely to enhance performance on the task, the authors conclude that these results are consistent with the efficiency of processing theory described above. They further suggest that stereotype exposure has an unconscious effect on their female college student subjects, 90% of whom reported that exposure to stereotypes about women's performance on spatial rotation tasks did not affect their responses.

Practical implications: The authors describe the "remarkable power of context in determining cognitive processing" (p. 18) and its implications for academic performance. They suggest that avoiding negative messages and emphasizing positive messages can improve the performance of stigmatized groups. This potential benefit, the authors argue, exists regardless of intrinsic differences between groups. It's difficult to know what constitutes a negative stereotype as discussed by the authors, however. Because groups are known to perform differently on measures of academic achievement, it is unclear if neutral descriptions of these differences (such as those discussed in the social sciences) constitute stereotyping in the authors' view.

Research on cognition and academic literacy:

Alexander, P. A. (1992). Domain knowledge: Evolving themes and emerging concerns. *Educational Psychologist, 27*(1), 33-51.

Summary: The author argues for a new research focus based on the assumption that general and specific knowledge interact. She describes how an interactive framework might help draw finer distinctions between terms like "expert" and "novice", "domain" and "discipline" when researching cognition.

Practical implications: College instructors might find this critical examination of key terms useful for understanding learning processes. For example, the author points out that "misconceptions" are not inherently bad—they are natural part of cognitive development. This article also provides specific advice for instructors about how to capitalize on the interaction between domain-specific and general knowledge. They can do this by focusing students' attention on how knowledge in a particular discipline is organized around fundamental concepts. This instructional strategy helps students transfer knowledge within and across domains. The author's advice is consistent with Donovan & Bransford's (2005) second core principle that teachers should help students organize knowledge around core concepts.

Alexander, P. A., & Judy, J. E. (1988). The interaction of domain-specific and strategic knowledge in academic performance. *Review of Educational Research, 58*(4), 375-404.

Summary: The authors outline hypotheses about the relationship between domain-specific and strategic knowledge. Domain-specific knowledge is here defined as "the declarative, procedural, or conditional knowledge one possesses relative to a particular field of study" (p. 376). Strategic knowledge, which spans a continuum between domain-specific and general knowledge, consists of goal-oriented strategies one evokes before, during, or after performing a task. Some research reviewed here suggests that the relative importance of strategic knowledge in successfully completing tasks depends both on the domain and how well-defined the task is. The authors conclude that rather than studying each in isolation,

cognitive scientists should examine domain-specific and strategic knowledge in relation to one another.

Practical implications: As this critical literature review demonstrates, the relative importance of domain-specific and more general types of knowledge is a contentious topic of inquiry in educational psychology. Arguments for educational programs often implicitly embrace one or the other of these perspectives on knowledge. Writing across the curriculum programs, for example, emphasize the acquisition of general writing skills that educators assume will transfer across domains. On the other hand, writing in the disciplines programs emphasize discipline-specific writing skills. This review offers both a comprehensive critique of relevant research on this topic as well as an interactive theoretical framework.

Bransford, J. D., Brown, A. L., & Cocking, R., R. (Eds.). (1999) *How people learn: Brain, Mind, Experience, and School*. Washington: The National Academies Press.

Summary: A searchable 2000 expanded version of this book is available online at http://www.nap.edu/openbook.php?isbn=0309070368. The authors condense an array of research from neuroscience, cognitive psychology, and education into core learning principles. This book and its companion, *How students learn*, (Donovan & Bransford, 2005), are designed to help educators translate "learning science" into teaching practice. The book covers such key topics as expert learning, learning for transfer, and teacher education.

Practical implications: This user-friendly book, developed by the National Research Council, is explicitly designed with teaching practice in mind. It provides guidelines for research-based teaching practice.

Donovan, S. M., & Bransford, J. D. (Eds.). (2005). *How students learn: History, mathematics, and science in the classroom*. Washington: The National Academies Press.

Summary: This book illustrates how three core principles derived from the National Research Council's *How People Learn* (Bransford, Brown, & Cocking, 1999) can be applied in the classroom. These core principles are 1) Engaging resilient preconceptions; 2)

Organizing knowledge around core concepts, and 3) Supporting metacognition.

Practical implications: Because the book addresses K-12 education, college instructors may find the advice less helpful. Nevertheless, it provides an important bridge between cognitive research and teaching practice by presenting concrete, discipline-specific illustrations of the three core principles. English language arts studies are not included, perhaps because much research in cognition has focused on well-defined tasks in well-defined domains. See Alexander and Judy (1988) for a discussion of the difficulties inherent in cognitive research on less well-defined tasks.

Ellis, L. K., Rothbart, M. K., & Posner, M. I. (2004). Individual differences in executive attention predict self-regulation and adolescent psychosocial behaviors. *Annals of the New York Academy of Sciences, 1021*(1), 337-340.

Summary: This study is aimed at understanding the role of individual differences and environmental variables on at-risk behavior. The authors define executive attention as a "system that allows an individual to choose between competing response tendencies and, when necessary, to suppress an inappropriate response" (p. 337). The study included a sample of ethnically diverse 16-17 year-olds and multiple measures of individual and environmental contributors, including subjects' parents' reports of effortful control. The authors argue that such measures of individual and environmental contributors are necessary for better understanding adolescent deviance.

Practical implications: This study provides an example of research aimed at understanding how multiple factors—cognitive, social, emotional—influence behavior. Its emphasis on cognitive control as means of understanding problem behaviors is consistent with other research findings that emphasize cognitive control as contributing to academic literacy. Recent brain research suggests that areas of the brain associated with cognitive control are still maturing into the college years.

Flower, L. (1990). Negotiating academic discourse. *Reading-to-write: Exploring a cognitive and social process.* (pp. 221-261). New York, NY, US: Oxford University Press.

Summary: Flower examines students' cognitive processes as they make the difficult transition from high school to college writing. She proposes that students need to adapt familiar high school writing strategies of reporting knowledge to the new college-level goal of transforming knowledge if they are to meet the often implicit demands of academic discourse. In this view, students fail at academic writing tasks not because they lack the necessary cognitive abilities but because they lack the strategic knowledge—or metacognitive awareness—necessary for "intensely goal-directed" (p. 225) processes.
Practical implications: As Flower herself points out, this research "cannot assert a cause and effect relation or show us what to teach" (p. 242). However, it does imply that students benefit from having expectations for academic writing made explicit. The author suggests that students may not understand why their high school writing strategies are no longer adequate or how college expectations differ. A second implication is that students need a metacognitive awareness of the goals involved in a particular task and the strategies that might be useful for meeting these goals if they are to successfully write academic discourse. What students seem to lack are not essential cognitive and intellectual skills, but the strategic and metacognitive skills for successful writing. Flowers' conclusions are consistent with other sources reviewed here (e.g. Donovan & Bransford, 2005; Keating, 2004; Nist & Holschuh, 2004) that emphasize cognitive control.

Galambos, N. L., & Leadbeater, B. J. (2002). Transitions in adolescent research. *Growing points in developmental science: An introduction.* (pp. 287-306). New York, NY, US: Psychology Press.

Summary: This chapter provides a broad overview of research on adolescence. The authors discuss prominent theories on the transition from adolescence to adulthood and conclude that far more work needs to be done, especially in the promising area of fMRI research.
Practical implications: This chapter provides a good overview of the socioeconomic and emotional factors known to influence adolescent performance in school. In addition, the discussion of transition to adulthood is helpful in understanding the contentious theoretical debates over adolescence. The authors suggest that there is little consensus on whether

phenomena associated with this period (e.g. risk-taking) are more attributable to social or biological factors.

Gobet, F., & Campitelli, G. (2007). The role of domain-specific practice, handedness, and starting age in chess. *Developmental Psychology*, 43(1), 159-172.

Summary: This article provides a good overview of the debate surrounding the relative importance of practice, talent, and critical developmental periods in expert performance. (Cited in Bunge & Wright, 2007 annotation).

Hatano, G., & Inagaki, K. (2002). Domain-specific constraints of conceptual development. In W. W. Hartup, & R. K. Silberseisen (Eds.), *Growing points in developmental science: An introduction.* (pp. 123-142). New York, NY, US: Psychology Press.

Summary: The authors outline what they stress is a tentative and evolving theory about domain-specificity in human cognition. This "neo-Piagetian" framework posits that domain-specific cognitive constraints—rather than the general logico-mathematical structures proposed by Piaget—drive knowledge acquisition. Concrete illustrations of domain specificity from both animal and human studies are offered to support this theory.

Practical implications: The authors are careful to point out that the theory is not yet fully developed, which makes it difficult to draw practical implications from this chapter. However, a theoretical framework that emphasizes domain-specific cognitive development suggests that knowledge does not spontaneously transfer across domains.

Keating, D. P. (2004). Cognitive and brain development. In R. M. Lerner, & L. Steinberg (Eds.), *Handbook of adolescent psychology (2nd ed.).* (pp. 45-84). Hoboken, NJ: John Wiley & Sons Inc.

Summary: Keating broadly reviews research in adolescent cognition and proposes an emerging consensus on adolescent cognitive development. Beginning with Siegler's question, "What develops?" the author tentatively answers: increased integration and

conscious control. Keating argues that conclusions drawn from research on cognition as reasoning, decision making, information processing and achieving expertise are consistent with biological research on puberty and brain development in that all paths lead to an integrated developmental model. That is, it is not so much the development of one "device" (e.g. formal logic, biological maturity) that drives cognitive development as it is the integration of brain function that supports increased cognitive control.

Practical implications: This chapter brings a vast array of adolescent cognition research together under a coherent theoretical framework. In particular, Keating's juxtaposition of biological with more socially and behaviorally oriented research, such as research on cultural differences and expert performance, is helpful for understanding the potential implications of brain research for teaching. The author describes adolescence as a critical developmental period in which "the biological embedding of experience"(p.73) shapes cognition. Though the author is careful to point out that far more interdisciplinary research is needed to draw conclusions about what kinds of experiences teachers should provide to support students' cognitive maturation, he does generally describe "opportunities . . . for purposeful engagement that will lead to self-aware, flexible, conscious control" (p. 77) as being consistent with this integrated developmental model.

Ledoux, K., Camblin, C. C., Swaab, T. Y., & Gordon, P. C. (2006). Reading words in discourse: The modulation of lexical priming effects by message-level context. *Behavioral and Cognitive Neuroscience Reviews, 5*(3), 107-127.

Summary: This review of research on language processing supports an "interactive" theoretical model. In the interactive model, multiple levels of language processing--lexical, contextual, and extralingual--occur simultaneously. The competing "modular" processing model in which levels of processing occur in distinct stages, the authors argue, is not supported by current research. Though context clearly influences the way we process language, research is needed on brain activity underlying these interactive processes. Methodological challenges involved in studying the neural bases for language processing are discussed.

Practical implications: This article provides a good overview of research examining language processing. The authors do not explicitly address practical implications for the interactive model. However, this review appears to support pedagogical approaches that emphasize making connections between context and course content.

Masten, A. S. (2004). Regulatory processes, risk, and resilience in adolescent development. *Annals of the New York Academy of Sciences, 1021*(1), 310-319.

Summary: The author describes a complex matrix of cultural, environmental, behavioral, and neurobiological adolescent influences that contribute to adult outcomes. She calls for more cross-disciplinary research on risk and resilience, which involves looking at adolescents who prevail despite being subject to known detrimental factors (e.g. living in high poverty neighborhoods). Masten characterizes transitional periods, including the transition from adolescence to adulthood, as critical developmental periods in which "changes in vulnerabilities and opportunities may arise and redirect the course of development" (p. 311).

Practical implications: This article focuses on distinctions between normative and deviant behavior rather than on teaching and learning. However, adolescents' experiences influence brain development and vice versa. The author presents a "short list" of regulatory processes beneficial for helping young people overcome challenges. Among these are “attachments to adults who monitor and support youth effectively”and the provision of "opportunities for regulatory capacity-building" (p. 315).

Nist, S. L., & Holschuh, J. L. (2000). Comprehension strategies at the college level. In R. F. Flippo, & D. C. Caverly (Eds.), *Handbook of college reading and study strategy research*. (pp. 75-104).

Summary: The authors begin by noting that the overwhelming majority of college students' information is derived from independent reading; that college students may lack the metacognitive skills necessary to read well; and that college instructors may have "little sympathy" for such difficulties. Drawing on recent theoretical models that emphasize

metacognitive evaluation, domain specificity, and prior knowledge, the authors discuss the benefits and drawbacks of providing college students with direct instruction in reading strategies. Included reading strategies are aimed at improving metacognitive interaction and affective engagement, with the understanding that cognition and affect are intertwined. Metacognition is here defined as students' knowledge of available reading strategies and their ability to self-regulate their use of those strategies.

Practical implications: The authors stress that metacognitive strategies are domain specific; therefore instructors should introduce students to strategies that reflect the epistemology of the discipline under study. For example, in history, timelines would help students understand the relationship between events in relevant historical texts. In addition, the authors provide specific strategies for motivating students and for encouraging metacognitive reflection. These include: collaborative learning; emphasizing reading processes rather than products; cultivating students' sense of choice and control over their learning; engaging students in challenging tasks; emphasizing a mastery approach to learning; activating students' prior knowledge; encouraging and modeling sophisticated epistemological beliefs; emphasizing the process of knowing over static content knowledge when assessing learning; and providing direct instruction in reading strategies. Reading strategies supported by research include concept mapping, annotating, and self-assessing. General learning strategies, the authors assert, do not necessarily transfer across domains. It follows that instructors in each discipline are responsible for teaching students how to read effectively in that discipline. That is, reading instruction is a means of teaching the processes—the ways of knowing, understanding and thinking—that characterize a discipline.

Pascarella, E. T. (2004). Cognitive impacts of the first year of college. In R. S. Feldman (Ed.), *Improving the first year of college: Research and practice* (pp. 111-140).

Summary: This chapter provides an overview of recent, large-scale, quantitative analyses of first-year college students' cognitive development. In this synthesis of research, cognitive development encompasses both the acquisition of content knowledge and the acquisition of

general cognitive skills such as critical thinking, reflective thinking, and problem-solving. Drawing from a vast body of research, Pascarella finds: 1) strong evidence that the first year of college accounts for much, or even most, of the cognitive gains students achieve during college; 2) little or no effect of college characteristics such as selectivity, size, student demographics, or even class size on students' cognitive development; 3) evidence for significant effects of within-college characteristics such as teacher behaviors, innovative pedagogical approaches, and out-of-class experiences (e.g. sports, work, Greek system) on cognitive development; and 4) evidence that the direction and/or strength of effects on cognitive development may depend on student characteristics such as learning style, ethnicity, and gender.

Practical implications: Pascarella identifies three teaching behaviors that have a positive impact on student content knowledge acquisition and general critical thinking. These include 1) clarity, 2) enthusiasm, and 3) organization. Teachers can improve clarity by presenting examples and identifying key points. Teachers convey enthusiasm when they make eye contact and speak emphatically. Teachers improve organization by providing course outlines, identifying course objectives, using class time effectively, and presenting information in a well-organized manner. Readers of this chapter might be struck by the fact that Pascarella identifies positive effects for a wide range of innovative pedagogies when compared to "traditional" pedagogies. Because some of these approaches appear to be based on contradictory assumptions, one wonders if all coherent pedagogies, when approached systematically, result in substantial gains.

Pugh, S. L., Pawan, F., & Antommarchi, C. (2000). Academic literacy and the new college learner. In R. F. Flippo, & D. C. Caverly (Eds.), *Handbook of college reading and study strategy research.* (pp. 25-42). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Summary: The authors describe a theoretical shift in understanding of reading processes. Early models conceptualized reading as an interaction between knowledge available in a text and its reader. More recent models characterize the process as a transaction in which the reader constructs knowledge through the act of reading. In the reading-as-transaction view,

the reader is a more active, critical agent and a literate person is not simply one who reads, but one who views all texts and knowledge as constructed. The effects of the Internet and the availability of rapidly multiplying information sources are also discussed.

Practical implications: This reading-as-transaction view of literacy has numerous practical implications, some of which the authors discuss. Chief among these is the recommendation that instructors equip their students with a variety of reading strategies. In particular, students should understand the text forms specific to the discipline under study and how these forms relate to the construction of knowledge in that discipline. This kind of knowledge of the discipline's wider discourse will help students read more actively and critically. Hence, it will help them achieve the goal of acquiring academic literacy. The authors emphasize that students need a diversity of reading strategies, both general and discipline-specific, for them to effectively manage the increasing diversity of available texts. The argument in this chapter is consistent with Flower's research (1990) on the cognitive processes involved in writing. Both emphasize the importance of equipping students with a range of strategies that they can use with conscious control.

van Merrienboer, Jeroen J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*(2), 147-177.

Summary: Cognitive load theory (CLT) assumes that working memory capacity should be an important factor in designing effective instruction. Though there are no known limits to long-term memory, working memory can hold approximately 7 (+/-2) items at a time. The authors argue that these capacity limits are analogous to limits in the pace of evolutionary change. This evolutionary analogy posits that working memory limitations protect information in long-term memory from being corrupted by "random processes" (p. 155), just as the evolution of species is safeguarded by slow change. The main thrust of the CLT argument is that complex, "authentic" learning tasks need to be carefully scaffolded so that learners' working memories can handle corresponding cognitive loads efficiently. CLT scaffolding strategies are aimed at facilitating transfer of learning from short-term to long-

term memory.

Practical implications: College instruction increasingly emphasizes the use of "real-life" or "authentic" tasks. CLT researchers have developed and tested a number of specific strategies designed to scaffold such tasks. These strategies include the use of goal-free problems, worked examples, and completion problems to reduce cognitive load. Because most research on cognitive load theory involves well-defined tasks in technical domains (e.g. math, science, computer applications), there is little known about how well results can be generalized to other domains. The authors also point out that more research is needed to explore the effects of CLT strategies on students with differing expertise levels and on student motivation.

Conclusions:

When I started this work, I expected to spend most of my time reading about the college-age brain and learning about relatively well-defined developmental characteristics. Instead, I found myself reading about the vulnerabilities of the adolescent brain and being surprised by how relevant this was to the study of college-age development. Who would have thought that neural and cognitive maturation took so long to develop?

I was pleased to find that, despite the lingering controversies over 1) the nature of adolescence, 2) the relative importance of context and biological development in cognition, and 3) the importance of domain-specific vs. general knowledge, the literature converged in its emphasis on cognitive control and increased integration as indicators of both cognitive and neurobiological maturation. It seems to me that, despite the complexity of the research findings and the tentative nature of corresponding theoretical frameworks, and despite our inability to specify exactly what kinds of teaching practices will best support students' cognitive development, we can reasonably draw some general conclusions for teaching and learning on the college level. First, traditional college-going age students may still be developing the very cognitive capacities necessary for success in college: the capacities for strategic cognition and cognitive control. Second, because such students are still developing these capacities, it seems plausible that they benefit from more guidance and transparency from their instructors than we may have assumed. These conclusions have helped me to think about how to effectively plan instruction with students' needs in mind.

For those who are interested in keeping informed about developments in neuroscience, *Current Opinion in Neurobiology* publishes pieces about current and future directions for research (e.g. Watanabe & Tanaka, 2007).