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Evolution and Cognitive Development

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The purpose of brain and mind is to allow the individual to attend to, process, and guide behavioral responses to the types of information and conditions that have covaried with survival or reproductive prospects during the species' evolutionary history (Cosmides & Tooby, 1994; Gallistel, 2000; Geary, 2004). These conditions include information patterns generated by the body shape and movement of conspecifics (Blake, 1993; Downing, Jiang, Shuman, & Kanwisher, 2001) and by species of predator and prey (Barton & Dean, 1993), as well as by environmental features (e.g., star patterns) used in navigation (Gallistel, 1990), among many other conditions. As emphasized by many evolutionary psychologists, when such information patterns are consistent from one generation to the next, then modular brain and cognitive systems that identify and process these restricted forms of information should evolve, as illustrated by the invariant end of the continuum in Figure 4.1. The systems may also include implicit (below the level of conscious awareness) decision-making heuristics (e.g., Gigerenzer & Selten, 2001). These are cognitive "rules of thumb" that represent evolved behavioral responses to evolutionarily significant conditions. In some species of bird, as an example, parental feeding of chicks can be described as a simple heuristic, "Feed the smallest, if there is plenty of food; otherwise, feed the largest." Davis and Todd (1999) demonstrated how these implicit and simple

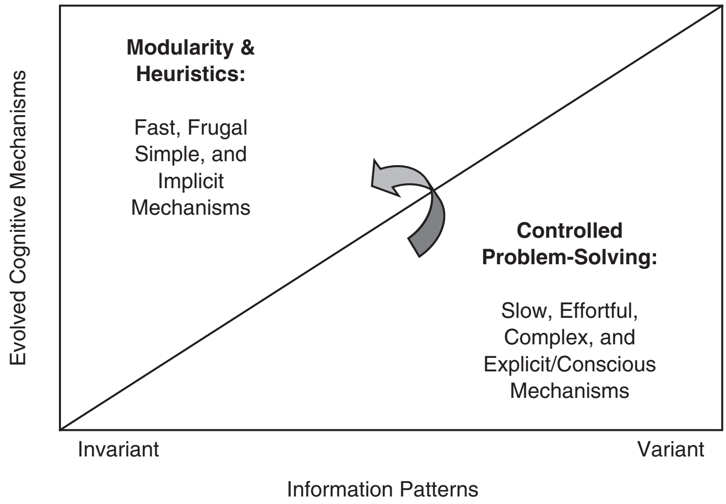

Figure 4.1 The types of cognitive mechanisms that operate on ecological or social information are predicted to vary with the extent to which that information tended to be invariant (resulting in evolved heuristics) or variant (resulting in evolved problem-solving mechanisms) during the species' evolutionary history and during a typical life span.

heuristics can explain the seemingly complex decision making involved in raising the largest number of healthy fledglings.

There can also be conditions that influence survival and reproductive prospects but that produce less predictable, or variant, information patterns across generations and within life spans. This variation might involve fluctuating climatic conditions (e.g., Potts, 1998) but is most likely to emerge from the behavioral interactions between biological organisms that have competing interests (Maynard Smith & Price, 1973). Predator-prey relationships and social competition provide examples of this type of relationship: Variability in the context of these relationships provides an advantage because it renders implicit, heuristic-based behavioral responses less effective. In any case, when the conditions that covary with survival or reproductive prospects are variable across generations or within lifetimes, then the potential for the evolution of less modularized, domain-general mechanisms emerges (Chiappe & MacDonald, 2004; Geary, 2004). As shown at variant end of the continuum in Figure 4.1, these domain-general systems enable the explicit representation of variant information patterns in working memory and support the controlled problem solving needed to cope with these variable conditions.

My goals for this chapter are to outline both modularized and domain-general systems that vary along the continuum shown in Figure 4.1 and to discuss the interaction between these systems as related to children's cognitive development. In the first section, I describe evolved and modularized domains of the human mind and developmental mechanisms for adapting these systems to the nuances of local social and ecological conditions. In the second section, I describe domain-general brain and cognitive systems, the conditions that may have facilitated their evolution, and their relation to psychometric studies of general intelligence. In the final section, I describe how evolutionarily novel cognitive competencies, such as the ability to read, can emerge through the interaction between modularized and domain-general systems; for a more thorough treatment see Geary (2004).

Evolved Domains of Mind

The purpose of behavior is to allow the individual to gain access to and control of the types of resource that have tended to enhance survival or reproductive options during the species' evolutionary history. These resources fall into three domains: social, biological, and physical. The social domain includes the behavior of and resources controlled by conspecifics, and an example of accompanying evolutionary pressures is competing for mates. The biological domain includes other species that can be used as food and, in the case of humans, medicine. The physical domain includes the territory (e.g., nesting site) that contains biological or reproductive resources. These domains will result in information patterns (e.g., basic shape of a human face) that are important from one generation to the next and thereby create conditions that favor the evolution of the type of brain and cognitive module and behavioral heuristic represented by the invariant end of the continuum in Figure 4.1. Although this issue is vigorously debated (see Finlay, Darlington, & Nicastro, 2001; Gallistel, 2000; Pinker, 1994; Tooby & Cosmides, 1995), I am assuming that the result of these invariant information patterns is the evolution of modules and heuristics that coalesce around the domains of folk psychology, folk biology, and folk physics.

Even within these modular domains, there can be evolutionarily significant variation in information patterns. The basic shape of the human face is invariant, but, at the same time, there are differences in the shape of one face versus another. If it is important to distinguish one individual from another, then some degree of plasticity should evolve within the constraints of the modular system that processes faces (Geary & Huffman, 2002). In these situations, plasticity means there are brain and cognitive systems that are modifiable during the individual's lifetime, but within modular constraints and primarily during the developmental period. The result, in this example, is that the individual can identify other individuals by means of distinctive facial features. Thus, for many of the modular systems I describe in the following sections, the associated cognitive competencies likely emerge through an interaction between inherent constraint and patterns of developmental experience (Bjorklund & Pellegrini, 2002; Geary & Bjorklund, 2000). As I describe in the final section, plasticity within modular constraints enables these brain and cognitive systems to be adapted to create nonevolved academic abilities, such as the ability to read. These nonevolved abilities are called "biologically secondary" because their use in modern society is secondary to their primary evolved function; as an example, reading is a secondary ability that is constructed from the primary, or evolved, language system (Geary, 1995; Rozin, 1976). Figure 4.2 presents a taxonomy of evolved, biologically primary modules in folk domains.

Folk Knowledge

Folk Psychology

Folk psychology is composed of the affective, cognitive, and behavioral systems that enable people to negotiate social interactions and relationships. The function of the corresponding cognitive components is to process and manipulate (e.g., create categories) the forms of social information that have covaried with survival and reproduction during human evolution. The associated domains involve the self, relationships, and interactions with other people, and group level relationships and interactions. These dynamics are supported by the respective modular systems corresponding to self, individual, and group shown in the bottom, left-hand sections of Figure 4.2.

Self. Self-related cognitions include awareness of the self as a social being and of one's behavior in social contexts (Tulving, 2002), as well as a self schema (Markus, 1977). The self schema is a long-term memory network of information that links together knowledge and beliefs about the self, including positive (accentuated) and negative (discounted) traits (e.g.,

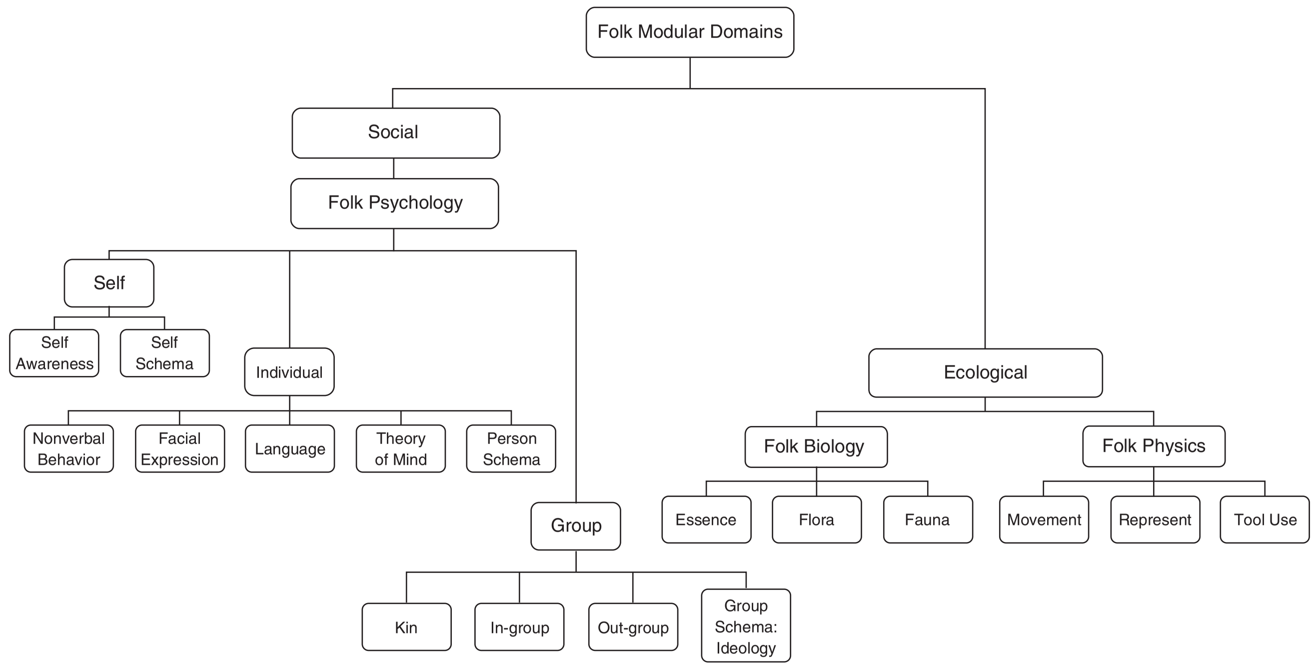

Figure 4.2 Evolved Cognitive Modules That Compose the Domains of Folk Psychology, Folk Biology, and Folk Physics

friendliness), personal memories, self-efficacy in various domains, and so forth. Whether implicitly or explicitly represented, self schemas appear to regulate goal-related behaviors, specifically, where one focuses behavioral effort and whether or not one will be persistent in the face of failure (Sheeran & Orbell, 2000). Self-related regulation results from a combination of implicit and explicit processes that influence social comparisons, self-esteem, valuation of different forms of ability and interests, and the formation of social relationships (Drigotas, 2002).

Individual. The person-related modular competencies function to enable the monitoring and control of dyadic interactions and the development and maintenance of one-on-one relationships. Caporael (1997) and Bugental (2000) have described universal forms of these interactions and relationships, including parent-child attachments and friendships, among others. There are, of course, differences across these dyads, but all of them are supported by the individual level modules shown in Figure 4.2. These modules include those that enable the reading of nonverbal behavior and facial expressions, language, and theory of mind (e.g., Baron-Cohen, 1995; Brothers & Ring, 1992; Pinker, 1994; Rosenthal, Hall, DiMatteo, Rogers, & Archer, 1979). Theory of mind refers to the ability to make inferences about the motives underlying the behavior of other people, their future intentions, and so forth.

The person schema is a long-term memory network that includes representations of another person's physical attributes (age, race, sex), memories for specific behavioral episodes, and more abstract trait information, such as the person's sociability (e.g., warm to emotionally distant) and competence (Schneider, 1973). It seems likely that the person schema will also include information related to the other person's modular systems, such as theory of mind, as well as the person's network of social relationships and kin (Geary & Flinn, 2001). The former would include memories and trait information about how the person typically makes inferences and responds to social cues, his or her social and other goals, and so forth.

Group. A universal aspect of human behavior and cognition is the parsing of the social world into groups. The most consistent of these groupings are shown in Figure 4.2 and reflect the categorical significance of kin, the formation of in-groups and out-groups, and a group schema. The latter is an ideologically based social identification, as exemplified by nationality, religious affiliation, and so forth. The categorical significance of kin is most strongly reflected in the motivational disposition of humans to organize themselves into families of one form or another in all cultures (Brown, 1991).

In traditional societies, nuclear families are typically embedded in the context of a wider network of kin (Geary & Flinn, 2001). Individuals within these kinship networks cooperate to facilitate competition with other kin groups over resource control and manipulation of reproductive relationships. As cogently argued by Alexander (1979), coalitional competition also occurs beyond the kin group, is related to social ideology, and is endemic throughout the world (Horowitz, 2001). As with kin groups, competition among ideology-based groups is over resource control. The corresponding selective pressure is the competitive advantage associated with large group size; that is, ideologies enable easy expansion of group size during group level competition (Alexander, 1989).

Folk Biology and Folk Physics

People living in traditional societies use the local ecology to support their survival and reproductive needs. The associated activities are supported by, among other things, the folk biological and folk physical modules shown in the ecological section of Figure 4.2 (Geary, 1998, 2004; Geary & Huffman, 2002). The folk biological modules support the categorizing of flora and fauna in the local ecology, especially species used as food, medicines, or in social rituals (Berlin, Breedlove, & Raven, 1973). Folk biology also includes systems that support an understanding of the essence of these species (Atran, 1998), that is, heuristic-based decisions regarding the likely behavior of these species. In particular, the essence is knowledge about growth patterns and behavior that facilitates hunting and other activities involved in securing and using these species as resources (e.g., food). Physical modules are for guiding movement in three-dimensional physical space, mentally representing this space (e.g., demarcating the in-group's territory), and using physical materials (e.g., stones, metals) to make tools (Pinker, 1997; Shepard, 1994). The associated primary abilities support a host of evolutionarily significant activities, such as hunting, foraging, and the use of tools as weapons.

Heuristics and Attributional Biases

In addition to describing "rule of thumb" patterns of behavior, heuristics also encompass inferential and attributional biases that are integral features of folk knowledge, at least for humans. For instance, social attributional biases that favor members of the in-group and derogate members of out-groups are well-known (Stephan, 1985) and facilitate coalitional competition (Horowitz, 2001). The essence associated with folk biology allows people to make inferences (e.g., during the act of hunting) about the behavior of members of familiar species, as well as about the likely behavior of less familiar but related species (Atran, 1998). Attributions about causality in the physical world have also been studied. Children and adults have, as an example, natural, naive conceptions about motion and other physical phenomena (Clement, 1992).

Cognitive Development and Modular Plasticity

Cognitive development, as contrasted with academic development (see below), is the experience-driven adaptation of biologically primary modular competencies to the nuances of the local social, biological, and physical ecologies (Geary & Bjorklund, 2000). As noted, modular systems should be plastic or open to experiential modification if sensitivity to variation within these domains is of potential survival or reproductive significance. For many folk domains (e.g., language), plasticity appears to be especially evident during the developmental period, although the benefits of plasticity are balanced by potential risk of dying before having the opportunity to reproduce. Given this potential cost, the benefits associated with a long developmental period and the corresponding increase in plasticity must be substantial.

The mechanisms involved in the experience-drive adaptation of plastic modular systems to local conditions are not well understood. At a macrolevel, and following the lead of Gelman (1990), Geary and Huffman (2002) proposed that prenatal brain organization results in an exoskeleton that comprises neural and perceptual modules that guide attention to and processing of stable forms of information (e.g., the general shape of the human face) in the folk domains shown in Figure 4.2. The result is biases in early postnatal attentional, affective, and information-processing capacities, as well as biases in self-initiated behavioral engagement of the environment (Bjorklund & Pellegrini, 2002; Scarr, 1992; Scarr & McCartney, 1983). The latter generate evolutionarily expectant experiences, that is, experiences that provide the environmental feedback needed to adjust modular architecture to variation in information patterns in these domains (Greenough, Black, & Wallace, 1987; MacDonald, 1992). These behavioral biases are expressed as common juvenile activities, such as social play and exploration of the ecology. These experience-expectant processes result in the modification of plastic features of the exoskeleton such that the individual is able to identify and respond to variation (e.g., discriminate one individual from another) within these domains and to begin to create the forms of category described above, such as in-groups/out-groups or flora/fauna.

Folk Psychology

As an illustration of plasticity in a folk domain, consider that the strong bias of human infants to attend to human faces, movement patterns, and speech reflects, in theory, the initial and inherent organizational and motivational structure of the associated folk-psychological modules (Freedman, 1974). These biases reflect the evolutionary significance of social relationships (Baumeister & Leary, 1995) and, in effect, recreate the microconditions (e.g., parent-child interactions) associated with the evolution of the corresponding modules (Caporael, 1997). Attention to and processing of this information provides exposure to the within-category variation needed to adapt the architecture of these modules to variation in parental faces, behavior, and so forth (Gelman & Williams, 1998). It allows your infant to discriminate your voice from the voice of other potential parents with only minimal exposure to your voice. Indeed, when human fetuses (gestation age of about 38 weeks) are exposed in utero to human voices, their heart rate patterns suggest they are sensitive to and learn the voice patterns of their mothers and discriminate her voice from those of other women (Kisilevsky et al., 2003).

Developmental experiences may also facilitate later category formation. Boys' group level competition (e.g., team sports) provides one example of the early formation of competition-based in-groups and out-groups and the coordination of social activities that may provide the practice for primitive group level warfare in adulthood (Geary, 1998; Geary, Byrd-Craven, Hoard, Vigil, & Numtee, 2003). These natural games may provide the practice needed for the skilled formation and maintenance of social coalitions in adulthood and result in the accumulation of memories for associated activities and social strategies. In other words, and in keeping with the comparative analyses of Pellis and colleagues (e.g., Pellis & Iwaniuk, 2000), these games may be more strongly related to learning the skills of other boys and acquiring the social competencies for coordinated group level activities, as contrasted with learning specific fighting behaviors, such as hitting. My assumption is that these activities and the accompanying effects on brain and cognition are related to the group level social selection pressures noted above and provide experience with the dynamic forming in-groups and out-groups.

Folk Biology and Folk Physics

The complexity of hunting and foraging activities varies with the ecology in which the group lives, a situation that should select for plasticity in the associated brain, cognitive, and behavioral systems. Indeed, experiences during development appear to result in the fleshing out of many of these folk systems. Children's implicit folk-biological knowledge and inherent interest in living things result, in theory, in the motivation to engage in experiences that automatically create taxonomies of local flora and fauna and in the accrual of an extensive knowledge base of these species. In traditional societies, these experiences include assisting with foraging and play hunting (e.g., Blurton Jones, Hawkes, & O'Connell, 1997). Anthropological research indicates that it often takes many years of engaging in these forms of play and early work to learn the skills (e.g., how to shoot a bow and arrow) and knowledge needed for successful hunting and foraging (Hill & Hurtado, 1996), although this is not the case with all hunting and foraging activities (Bliege Bird & Bird, 2002; Blurton Jones & Marlowe, 2002).

An example associated with folk physics is provided by the ability to mentally form maplike representations of the large-scale environment, which occurs more or less automatically as animals explore this environment (Gallistel, 1990). For humans, the initial ability to form these representations emerges by 3 years of age (DeLoache, Kolstad, & Anderson, 1991), improves gradually through adolescence, and often requires extensive exploration and exposure to the local environment to perfect (Matthews, 1992). The research of Matthews clearly shows that children automatically attend to geometric features of the large-scale environment and landmarks within this environment and are able to generate a cognitive representation of landmarks and their geometric relations at a later time. Children's skill at generating these representations increases with repeated explorations of the physical environment (see also Landau, Gleitman, Spelke, 1981; Mandler, 1992). Thus, learning about the physical world is a complex endeavor for humans and requires an extended developmental period, in comparison with the more rapid learning that occurs in species that occupy a more narrow range of physical ecologies (Gallistel, 2000). A recent study by Chen and Siegler (2000) suggests that similar processes occur for tool use. Here, it was demonstrated that 18-month-olds have an implicit understanding of how to use simple tools (e.g., a hooked stick to retrieve a desired toy) and with experience learn to use these tools in increasingly effective ways.

Summary

A long developmental period is an evolved feature of human life history and appears to function to enable the fleshing out of folk modules and knowledge. The necessity of a long developmental period results from the complexity and variability of social relationships and social competition (Alexander, 1989; Geary, 2002b; Geary & Flinn, 2001) and the wide range of biological and physical-ecological (e.g., mountainous versus desert) niches occupied by humans (Kaplan, Hill, Lancaster, & Hurtado, 2000). In each domain, there is evidence for both inherent constraints that guide attention to and the early processing of invariant information patterns, such as human biological motion or human voice patterns (Freedman, 1974; Kuhl, 1994), as well as experience-based modifications of the associated systems to accommodate variation, such as recognition of individual voices, within broader constraints (Pascalis, de Haan, & Nelson, 2002). From this perspective, cognitive development is an integral component of human life history; is centered on cognitive abilities, such as language, that define the modules shown in Figure 4.2; and functions to adapt these inherent modular systems to nuances of the local ecologies.

Evolution of General Intelligence

The above section provided an outline of how early experiences interact with inherent modular constraints to guide children's cognitive development in the domains of folk psychology, folk biology, and folk physics. However, these mechanisms do not provide a sufficient explanation for the development of nonevolved, or biologically secondary, cognitive competencies, such as reading and writing. The acquisition of these and other nonevolved cognitive competencies must involve at least one other set of mechanisms that operate on modular systems. I recently proposed that these mechanisms are captured by psychometric and cognitive research on general intelligence (Geary, 2004). The details are beyond the scope of this chapter, but an important component is shown in the right-hand section of Figure 4.1, specifically, the ability to explicitly represent information in working memory (defined below) and to systematically manipulate this information so as to engage in controlled problem solving. The brain and cognitive mechanisms that enable the explicit representation of information in working memory appear to underlie the ability to acquire biologically secondary competencies, as I elaborate in the "Academic Learning" section.

Figure 4.1 also shows that the mechanisms that enable controlled problem solving are related to conditions that covaried with survival or reproductive prospects during the species' evolutionary history but have components that are variable across generations and within lifetimes. These conditions are produced by social dynamics and some dynamics associated with ecological demands, such as hunting. In other words, aspects of the social and ecological selection pressures that resulted in the evolution of the modular systems represented in Figure 4.2 also resulted in conditions that favored the evolution of less modularized, domain-general brain and cognitive systems. I explain the nuances of this model and supporting evidence elsewhere (Geary, 2004). The gist is that the evolutionary function of general intelligence, the component cognitive abilities (e.g., working memory), and supporting brain regions is to cope with the unpredictability that results from fluctuating social and ecological conditions.

More precisely, these systems enable the individual to generate a self-centered mental model of the perfect world, a world in which other people behave in ways consistent with one's best interest, and biological (e.g., food) and physical (e.g., land) resources are under one's control. General intelligence, working memory, and mechanisms that represent the essential part of the ability to engage in explicit problem solving are then used to devise and simulate behavioral strategies that can be used to reduce the difference between one's current circumstances and the simulated perfect world. General intelligence is related to academic learning and learning in other evolutionarily novel contexts (e.g., work).

As noted, research on general intelligence has led to the discovery of several components of an evolved brain and cognitive system that enables the simulation of behavioral strategies to cope with social and ecological novelty (Geary, 2004). Because biologically secondary abilities are, by definition, novel from an evolutionary perspective, the cognitive systems that compose general intelligence should be engaged when these abilities are constructed from inherent modular domains. In the following sections, I provide a review of empirical research on general intelligence and then outline the evolution of the supporting cognitive and brain systems.

Psychometric Research

Research in this tradition examines individual differences in performance on various forms of paper-and-pencil abilities measures and began in earnest with Spearman's (1904) classic study. Here, groups of elementary and high school students as well as adults were administered a series of sensory and perceptual tasks (e.g., the ability to discriminate one musical pitch from another) and were rated by teachers and peers on their in-school intelligence and out-of-school common sense. Scores on standard exams in classics, French, English, and mathematics were also available for the high school students. Correlational analyses revealed that above-average performance on one task was associated with above-average performance on all other tasks, on exam scores, and for ratings of intelligence and common sense. On the basis of these findings, Spearman (1904) concluded "that all branches of intellectual activity have in common one fundamental function (or group of functions)" (p. 285). Spearman termed the fundamental function or group of functions "general intelligence," or "*g*."

In a series of important empirical and theoretical works, Cattell and Horn (Cattell, 1963; Horn, 1968; Horn & Cattell, 1966) later argued that the single general ability proposed by Spearman should be subdivided into two equally important but distinct abilities. The first ability is called *crystallized intelligence* (*g*C) and is manifested as the result of experience, schooling, and acculturation and is referenced by overlearned skills and knowledge, such as vocabulary. The second ability is called *fluid intelligence* (*g*F), which represents a biologically based ability to acquire skills and knowledge.

Cognitive Research

Speed of Processing. With the development of computer technologies and accompanying conceptual advances, experimental psychologists can study and identify the elementary processes that underlie performance on paper-and-pencil tests, including measures of *g*. As an example of an elementary cognitive process, consider a simple task developed by Posner and his colleagues (Posner, Boies, Eichelman, & Taylor, 1969). Here, upper- and lowercase combinations of various letters, such as "AA," "Ab," "Aa," and "CE," are presented one at a time on a computer monitor. The participants indicate (by depressing a response key) whether the letters are the same or different, with the time between the presentation of the letter pair and participants' response recorded by the computer. With the use of a bit of statistics and arithmetic, the difference in speed of responding to pairs that are physically identical compared with pairs that are identical in name (e.g., "AA" versus "Aa") provides an index of the speed of accessing the name code from long-term memory. College students can access these names codes in about 80-thousandths of a second (i.e., 80 ms).

The initial foci of these studies was on identifying the elementary processes common to all people, but attention soon turned to the study of individual differences in these processes as they related to *g* (Hunt, 1978). Although many details remain to be resolved, several important patterns have emerged from this literature. First, faster speed of cognitive processing is related to higher scores on measures of *g* (e.g., Jensen, 1982; Jensen & Munro, 1979), but the strength of the relation is moderate (*r*s of about –0.3 to –0.4). Second, variability in speed of processing is also related to scores on measures of *g* (*r*s of about –0.4; Jensen, 1992). The variability measure provides an assessment of the consistency in speed of executing the same process multiple times, such as speed of retrieving the name code for "A" across multiple trials. Individuals who are consistently fast in executing these processes have the highest scores on measures of *g* (Deary, 2000; Jensen, 1998; Neubauer, 1997). Third, the speed with which individuals can identify very briefly (e.g., 50 ms) presented information (e.g., whether ">" is pointed left or right) is moderately correlated with *g* (Deary & Stough, 1996).

These studies suggest that intelligence is related to the speed and accuracy with which social or ecological information is identified and then processed by the associated brain and cognitive systems. The processing of this information is often implicit and results in fast and automatic responses to the forms of information (e.g., a facial expression) described in the folk sections above. When this happens, the information is active in short-term memory, but the individual may not be consciously aware of it. When the information is not readily processed by modular systems, the result is an automatic shift in attention to this information (Botvinick, Braver, Barch, Carter, & Cohen, 2001). When attention is focused on this information, the result is in an explicit representation of the information in working memory.

Working Memory. Working memory is important for coping with conditions that cannot be handled by means of the automatic cognitive systems and heuristics that compose folk modules or by means of knowledge acquired during the life span, that is, crystallized intelligence, or *g*C. Basically, working memory is the information that is currently available to conscious awareness and thus available for explicit, controlled problem solving. The attentional system that controls the manipulation of information during problem solving is called the *central executive,* and the modalities in which the information is represented are typically auditory (e.g., language), visual, or spatial (Baddeley, 1986). The latter are often called *slave systems.* The mechanisms that result in an individual becoming consciously aware of information represented in a slave system appear to involve an attention-driven amplification of these short-term memory representations and synchronization of activity in the underlying brain regions with activity in the brain regions that compose the central executive (Damasio, 1989; Miller & Cohen, 2001; Posner, 1994). The latter brain regions include the dorsolateral prefrontal cortex and the anterior cingulate (Kane & Engle, 2002). At a cognitive level, individual differences in working-memory capacity are related to individual differences in the ability to focus attention and prevent irrelevant information from diverting attention from the task at hand (Engle, 2002; Kane & Engle, 2002) and individual differences in speed of processing (Fry & Hale, 1996).

Research on the relation between performance on working-memory tasks and performance on measures of *g* have focused on fluid intelligence, or *g*F (Cattell, 1963; Horn, 1968). As Cattell (1963) stated: "Fluid general ability . . . shows more in tests requiring adaptation to new situations, where crystallized skills are of no particular advantage" (p. 3). In theory then, performance on measures of *g*F should be strongly associated with individual differences in working memory, and this is indeed the case, whether the measure of *g*F is an IQ test (Carpenter, Just, & Shell 1990; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999) or scores on psychometric tests of complex reasoning that are highly correlated with IQ scores (Kyllonen & Christal, 1990; Mackintosh & Bennett, 2003). The strength of the relation between performance on working- memory tasks and scores on measures of reasoning and *g*F range from moderate (*r*s about 0.5; Mackintosh & Bennett, 2003) to very high (*r*s > 0.8; Conway et al., 2002; Kyllonen & Christal, 1990). On the basis of these patterns, Horn (1968) and other scientists (Carpenter et al., 1990; Stanovich, 1999) have argued that measures of strategic problem solving and abstract reasoning define *g*F, and the primary cognitive system underlying problem solving, reasoning, and thus *g*F is working memory.

Summary. Cognitive research has revealed that (a) intelligent individuals identify and apprehend bits of social and ecological information more easily and quickly than do other people and (b) their perceptual systems process this information such that it is activated in short-term memory more quickly and with greater accuracy than it is for other people. Once active in short-term memory, the information is made available for conscious, explicit representation and manipulation in working memory, but this happens only for that subset of information that becomes the focus of attention. Once attention is focused, highly intelligent people are able to represent more information in working memory than are other people and have an enhanced ability to consciously manipulate this information. The manipulation, in turn, is guided and constrained by reasoning and inference-making mechanisms (see Stanovich, 1999). The mechanisms that enable faster and more accurate processing and an attention-driven ability to represent and manipulate information in working memory also contribute to the ease of learning biologically secondary knowledge and procedures, as I discuss in the "Academic Learning" section.

Neuroscience Research

Brain Size. Research on the relation between brain volume, as measured by neuroimaging techniques, and performance on measures of *g* has revealed a consistent but modest relation (*r* of about 0.4); the bigger the better

(Deary, 2000; Flashman, Andreasen, Flaum, & Swayze, 1998; Rushton & Ankney, 1996; Vernon, Wickett, Bazana, & Stelmack, 2000). In one of the most comprehensive of these studies, Wickett, Vernon, and Lee (2000) examined the relations between total brain volume and performance on measures of *g*F, *g*C, short-term memory, and various speed of processing measures. Larger brain volumes were associated with higher *g*F ($r = 0.49$), larger short-term memory capacity ($r = 0.45$), and faster speed of processing (*r*s about –0.4) but were unrelated to *g*C ($r = 0.06$). Raz et al. (1993) examined the relation between performance on measures of *g*F and *g*C and total brain volume, and volume of the dorsolateral prefrontal cortex, the somatosensory cortex, portions of the parietal cortex, and the hippocampus. Higher *g*F scores were associated with larger total brain volume ($r = .43$), a larger dorsolateral prefrontal cortex ($r = .51$), and more white matter (i.e., neuronal axons) in the prefrontal cortex ($r = .41$) but were unrelated to size of the other brain regions. Performance on the *g*C measure, in contrast, was not related to size of any of these brain regions or to total brain volume.

Regional Activation. A number of studies have examined the brain regions that become activated or deactivated while individuals solve items on measures of *g*F (Duncan et al., 2000; Gray, Chabris, & Braver, 2003; Prabhakaran, Smith, Desmond, Glover, & Gabrieli, 1997). These are early and pioneering studies, and thus the most appropriate interpretation of their findings is not entirely certain (Deary, 2000). Nonetheless, most of the studies reveal a pattern of activation and deactivation in a variety of brain regions, much of which is likely due to task-specific content of the reasoning measures (e.g., verbal vs. visual information). Recent studies using the imaging methods most sensitive to regional change in activation/deactivation suggest fluid intelligence may be supported in part by the same system of brain regions that supports working memory and attentional control. As noted, these regions include the dorsolateral prefrontal cortex and the anterior cingulate (Duncan et al., 2000).

Integration

Brain-imaging studies and especially those that employ the most sensitive measures of regional brain activity support the hypothesis that the same brain systems that underlie working memory and explicit controlled problem solving are engaged when people solve items on measures of *g*F (Duncan et al., 2000; Gray et al., 2003; Kane & Engle, 2002). High scores on measures of *g*F are associated with activation of the dorsolateral prefrontal cortex and several brain regions associated with attentional control, including the anterior cingulate and regions of the parietal cortex. These same regions also appear to support the ability to inhibit irrelevant information from intruding into working memory and conscious awareness (Esposito, Kirkby, van Horn, Ellmore, & Berman, 1999).

An attention-driven synchronization of the activity of dorsolateral prefrontal cortex and the brain regions that support the working-memory representations of external information or internal mental simulations would be facilitated by faster speed of processing and rich interconnections among these brain regions. The latter is associated with larger brain size and especially a greater volume of white matter (i.e., axons). Speed of processing may be important for the synchronization process: Synchronization appears to occur through neural connections that communicate back and forth between different brain regions, creating feedback cycles. Faster speed of processing would enable more accurate adjustments in synchronization per feedback cycle. With repeated synchronized activity, the result appears to be the formation of a neural network that automatically links the processing of these information patterns (Sporns, Tononi, & Edelman, 2000).

Mental Models and Fluid Intelligence

My proposal is that research on general fluid intelligence has identified many of the core features that support the use of mental simulations. These function to anticipate and generate behavioral responses to social and ecological conditions that are toward the variant end of the continuum in Figure 4.1. The core of a mental model is the generation of a "perfect world." In the perfect world, the individual is in control of the social, biological, and physical resources that have tended to covary with survival and reproductive prospects during human evolutionary history: The behavior of other people and the flow of resources align with the individual's best interests. The real world operates differently, however. The goal is to generate strategies that will reduce the difference between conditions in the real world and those simulated in the perfect world, that is, to generate ways to gain better control of important relationships and resources.

The problem-solving processes, inference making, and reasoning employed to devise the corresponding social and behavioral strategies are dependent on working memory, attentional control, and the supporting brain systems, along with a sense of self. In this view, the mechanisms that support an explicit, conscious awareness of information represented in working memory evolved as a result of the same social and ecological pressures that drove the evolution of the ability to generate and use these mental models, and *g*F. Self-awareness is important to the extent that one must cope with the maneuvering of other people; that is, the perfect world of most people will involve manipulating others to behave in ways that is counter to their best interests. When many people with competing interests are able to anticipate and mentally simulate these moves and countermoves, the complexity of social dynamics explodes and the predictability of the dynamics decreases accordingly (Alexander, 1989; Humphrey, 1976).

The ability to use these simulations is dependent on working memory, attentional control, and the underlying brain systems that I noted above. These brain and cognitive systems function to deal with novelty in social and ecological conditions, and thus they will not be constrained to process a particular form of information as are the modular systems shown in Figure 4.2. These domain-general systems should therefore be engaged when individuals must cope with conditions and information that cannot be automatically and implicitly processed by modular systems. In other words, 100 years of empirical research on *g*, and especially *g*F, has isolated those features of self-centered mental models that are not strongly influenced by content and that enable explicit representations of information in working memory and an attentional-dependent ability to manipulate this information in the service of strategic problem solving.

Cattell's (1963) and Horn's (1968) definition of fluid intelligence and subsequent research on the underlying cognitive and brain systems are consistent with this view: There is considerable overlap in the systems that support self-centered mental models and those that support fluid abilities (e.g., Duncan et al., 2000). One important discrepancy involves self-awareness, which is a core feature of my proposal but not an aspect of fluid intelligence (Geary, 2004). The reason for the discrepancy lies in the initial development and goal of intelligence tests, specifically to predict academic performance (Binet & Simon, 1916). Because the initial goal was to predict learning in a evolutionarily novel context (i.e., school), the content of the items that compose intelligence tests was largely asocial.

Modularity and Crystallized Intelligence

In the most comprehensive review of the psychometric literature ever conducted, Carroll (1993) concluded that most of the psychometric tests that index *g*C "involve language either directly or indirectly" (p. 599). Included among these are tests of vocabulary, listening comprehension, word fluency, reading, and spelling. The two latter skills are taught in school, as are some of the other competencies that index *g*C, such as complex arithmetic, other school-taught quantitative skills, and mechanical abilities. General cultural knowledge is also an indicator of *g*C, as are some measures of spatial and visual abilities. In total, these tests appear to tap many of the modular domains shown in Figure 4.2, in particular, language and spatial representation.

They do not appear to tap all of these domains, but this is potentially because not all of the modular competencies have been assessed. When other modular competencies are measured and correlated with intelligence, there is a relation. Legree (1995) found that scores on tests of knowledge of social conventions and social judgments are positively correlated with scores on measures of *g*. In other words, I am suggesting that the inherent knowledge represented in the modular systems defines one class of crystallized intelligence. The other class is represented by the knowledge (e.g., facts, concepts, procedures) learned during the individual's lifetime through formal or informal instruction, or just incidentally, as proposed by Cattell (1963). In the next section, I discuss how this evolutionarily novel knowledge might be constructed through the interaction of *g*F, plasticity in modular systems, and experience.

Academic Learning

If the evolution of fluid intelligence was driven by behavioral and social variability and unpredictability, then the mechanisms that compose fluid intelligence are designed to identify, anticipate, represent, and reason about evolutionarily novel information patterns. Novelty is a matter of degree, of course, because the variability involves social dynamics and perhaps dynamics associated with ecological conditions (e.g., hunting). Still, the mechanisms are not constrained to process highly specific forms of information (e.g., contour of a human face), as are modular systems. The implication is that the evolution of fluid intelligence, though likely driven by social competition, opened the door to the ability to develop evolutionarily novel, biologically secondary abilities during the life span (Geary, 1995; Rozin, 1976). As I describe in the first and second sections, following, empirical research on the relation between *g* and learning in evolutionarily novel contexts, such as school and work, supports this hypothesis. In the third section, I focus on brain-imaging studies of the learning process as these relate to the brain systems that support fluid intelligence and the mechanisms that appear to support the construction of secondary competencies.

School and Work

In modern society, school and work represent important but evolutionarily novel contexts. Success in these contexts is important because it influences one's ability to gain access to and control of the forms of resource (e.g., money) that are important for success in modern society. If the evolved function of general intelligence, and especially *g*F, is to enable the individual to cope with evolutionarily novel conditions, then performance on measures of *g,* such as IQ tests, should be predictive of outcomes in school and at work.

School. Walberg (1984) reviewed 3,000 studies of the relation between performance on academic achievement tests and a variety of student attributes (e.g., intelligence), home environment (e.g., television viewing), and classroom variables. By far, the best individual predictor of achievement was IQ ($r = 0.7$). Jensen (1998), Lubinski (2000), and Matarazzo (1972) also reviewed research on the relation between IQ scores and performance on academic achievement tests and reached the same conclusion. They estimated the correlation between general intelligence and academic achievement ranges between 0.6 and 0.8, indicating that between 36% and 64% of the individual differences in performance on academic achievement tests can be explained by individual differences in general intelligence. Moreover, Jensen estimated that individual differences in general intelligence explain about 36% of the individual differences in years of education completed.

Work. It is clear that individuals with higher IQ scores populate higher-status occupations in the modern work force (Gottfredson, 1997; Jensen, 1998; Nyborg & Jensen, 2001; Reynolds, Chastain, Kaufman, & McLean, 1987; Scullin, Peters, Williams, & Ceci, 2000). In an analysis of the nationally (U.S.) representative standardization sample for the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981), Reynolds et al. found that for 20- to 54-year-olds, the average IQ score of professional and technical workers was at about the 75th percentile, whereas that of unskilled workers was below the 25th percentile. Evidence for a casual relation between *g* and occupational status comes from several longitudinal studies. Scullin et al. (2000) found that performance on a measure of *g* administered in high school was positively correlated (*r*s about 0.5) with occupational prestige 15 years later.

Fluid intelligence is the best single predictor of occupational performance (e.g., sales, scientific publications) across the broad swath of jobs available in modern economies (Gottfredson, 1997; Hunter & Hunter, 1984; Schmidt & Hunter, 1998). Predictive validity represents the economic value of using the test as a selection criterion, that is, increases in job-related productivity and reductions in training and retraining costs that accrue as a result of using the test to make employment decisions. For some jobs (e.g., mechanic, electrician), work samples have slightly higher predictive validities than IQ tests, but IQ is the best predictor of performance for most jobs and is the best predictor of the ability to learn on the job, including jobs in which work samples are a valid selection criterion. Across jobs, the validity coefficient for IQ tests is .51, and .56 for success in job training programs. Hunter and Hunter (1984) estimated that the widespread use of IQ tests in employment decisions would result in nearly $16 billion per year in economic benefits in the United States.

Learning and Cognition

Theory and Research. The relation between *g*, academic achievement, and job-related outcomes suggests that individuals who are high in fluid intelligence learn evolutionarily novel information more easily than do other individuals. These correlations, however, do not inform us as to how fluid intelligence actually affects the learning process. Ackerman has been at the forefront of efforts to understand this relation (Ackerman, 1988) and has proposed that the process of learning can be divided into three stages: cognitive, perceptual speed, and psychomotor (see also Anderson, 1982). The gist is that different abilities are related to individual differences in academic and job-related performance at different points in the learning process.

For school-based and job-related learning, the cognitive stage refers to the relation between fluid intelligence and initial task performance. The prediction is that novel and complex tasks will require an attention-driven, explicit representation of task goals and information patterns in working memory. During this phase, the task goals and the sequence of steps needed to perform the task are learned and memorized. With enough practice, the eventual result is the automatic, implicit processing of task features and automatic behavioral responses to these features. These phases of learning represent the shift from explicit representations and controlled problem solving to automatic, implicit, and sometimes heuristic-based processing of and responding to the task, as illustrated by the darkened arrow in the center of Figure 4.1. In this view, one difference between evolved, biologically primary modular competencies and biologically secondary competencies is the need for Ackerman's cognitive phase of learning. The inherent constraints associated with evolved competencies can be understood as putting them at Ackerman's second or third phase of learning, without the need for the first phase.

Ackerman and his colleagues have extensively tested the hypothesis that individual differences in *g*F and task-relevant crystallized knowledge will predict individual differences in the early phases of learning, whereas individual differences on measures of speed of perceptual and motor processes will predict individual differences after extensive task practice (Ackerman, 1988). A work-related example is provided by tasks that simulate the demands of an air traffic controller, which is clearly an evolutionarily novel demand. One task involves learning the rules that govern decision making, such as whether to keep a plane in a holding pattern or allow it to land, based on air traffic, wind, and so forth. Another task involves the especially complex demands of tracking and making decisions based on information patterns (e.g., multiple plane icons) represented on dynamic radar screens (Ackerman & Cianciolo, 2000, 2002). Performance on these tasks is indexed by the number of flights that are properly routed (e.g., landed or allowed to fly over the airport) and speed of making these decisions. Ease of initial rule learning is moderately correlated with fluid intelligence (*r*s of about 0.4 to 0.5) and remains so even after 6 hours of practice (*r* about 0.3). Performance on the radar task is moderately to highly correlated with fluid intelligence (*r*s from 0.4 to 0.8) and remains so throughout training. A causal relation between performance and *g*F was experimentally demonstrated by manipulating the number of planes the individual needed to simultaneously monitor. As the number of planes increased, the importance of fluid intelligence increased.

Mechanisms. As mentioned earlier, individual differences in fluid intelligence are determined by individual differences in attentional control, speed of processing, working-memory resources, and the ability to draw inferences from the information patterns represented in working memory (Embretson, 1995; Fry & Hale, 2000; Kane & Engle, 2002). It then follows that the initial learning of evolutionarily novel academic and job-related competencies, as illustrated by Ackerman's (1988) research, is driven by the ability to control attention, simultaneously represent multiple pieces of information in working memory, and logically piece this information together. In many cases, the drawing of inferences about information represented in working memory will be facilitated if the information is made available to conscious awareness, although pattern learning can occur without conscious awareness (Stadler & Frensch, 1997). A more fundamental issue concerns how these working-memory resources, speed of processing, attentional processes, and activities of the supporting brain systems create competencies that do not have an evolutionary history (Rozin, 1976). We are only beginning to explore these issues, and thus I can only offer speculation at this time.

As I noted earlier, the dorsolateral prefrontal regions, the anterior cingulate, and attentional regions of the parietal cortex are particularly important for explicitly representing goals and information to be manipulated in working memory (Duncan & Owen, 2000; Kane & Engle, 2002; Miller & Cohen, 2001). These ends appear to be achieved through an attention-driven amplification of neural activity in the posterior and subcortical pathways that process the information needed for goal achievement (Dehaene & Naccache, 2001; Posner, 1994). To illustrate how the process might work in an evolutionarily novel context, consider how children initially learn to read. One of the underlying component skills is phonemic decoding (Bradley & Bryant, 1983). Decoding requires an explicit awareness of and representation in working memory of a basic language sound (e.g., "ba," "da," "ka") and the association of this sound, as well as blends of sounds, with corresponding visual patterns, specifically letters (e.g., "b," "d," "k") and letter combinations. Attentional focus on the relation between the sound and the letter should, in theory, result in the amplification of the activity of the brain regions that process both forms of information and the simultaneous representation of both forms of information in working memory. The process should result in the synchronization of this brain activity with activity in the dorsolateral prefrontal cortex and, with sufficient practice, the formation of a learned association between the sound and letter.

With extended practice, the association becomes represented in long-term memory and thus becomes implicit knowledge, representing Ackerman's (1988) final stages of learning. When this is achieved, the association between the sound and letter, or letter combination and word-sound, is automatically triggered when the letter string is processed during the act of reading and thus no longer engages the prefrontal cortex, working memory, or related cognitive and brain systems, and no longer requires *g*F. We now have an evolutionarily novel cognitive competency (i.e., reading), the linking of a language sound with a visual pattern such that the visual pattern automatically triggers the word-sound and associated concept.

The learning of phonetic decoding is a simple task but illustrates how the processes may work for the learning of more complex skills. The primary difference across task complexity would involve the length of the first phase of learning, to use Ackerman's (1988) model. More precisely, complexity will be related to the extent to which the task is evolutionarily novel, the amount of information that must be identified and processed to deal with task demands, and the extent to which this information changes across time. As each of these features increases in complexity, there is an accompanying increase in the need for sustained attention, working memory, and the ability to reason and make inferences, that is, an increased reliance on *g*F.

Learning and Brain Mechanisms

In a review of brain-imaging studies of working memory, problem solving, and learning, Duncan and Owen (2000) concluded that these cognitive functions are dependent on the dorsolateral prefrontal cortex and the anterior cingulate. Other areas are also active when people are engaged in these tasks, and there are, of course, different patterns of brain activity associated with learning one type of skill or another (e.g., McCandliss, Posner, & Givón, 1997). Regardless, the brain regions identified by Duncan and Owen are consistently engaged when people are learning novel information and or coping with complex tasks that require working-memory resources and attentional control (see also Kane & Engle, 2002). Additional research is needed, but the evidence suggests the dorsolateral prefrontal cortex and anterior cingulate are engaged only during Ackerman's (1988) first phase of learning (Raichle et al., 1994), in keeping with the proposed mechanism described in the above section. Thereafter, brain activation is associated with the particular type of stimulus (e.g., visual vs. auditory) and the specifics of task demands.

Only a few studies have combined learning and brain imaging with assessments of general intelligence (e.g., Gevins & Smith, 2000; Haier, Siegel, Tang, Abel, & Buchsbaum, 1992). Haier et al. assessed the brain's use of glucose during the learning of a novel spatial problem-solving task. Individuals with high IQ scores learned the task more quickly than their less intelligent peers and showed more rapid declines in glucose metabolism across learning trials. Using electrophysiological methods, Gevins and Smith found the dorsolateral prefrontal cortex was initially engaged during the learning of a complex task that required working memory and attentional control, but engagement of this region declined as individuals learned the task. The decline was especially pronounced for intelligent individuals, who, in turn, appeared to shift the processing of task requirements to more posterior regions of the brain. The results of these studies are consistent with studies of the relation between *g*F and ease of learning (Ackerman, 1988); specifically, through attentional control and inhibition, intelligent individuals use only those cognitive and brain systems needed to cope with the task at hand.

At this point, it appears that one function of the dorsolateral prefrontal cortex, the anterior cingulate, and the posterior attentional system is to ensure the synchronized activity of other brain regions, such that anatomical and functional links are formed among these regions. When couched in terms of *g*F, it appears that the associated ability to focus attentional resources and inhibit the activation of task-irrelevant information (Kane & Engle, 2002) results in the ability to synchronize only those brain regions needed for secondary learning. The result would be lower glucose use and faster learning for individuals high in *g*F, because fewer unneeded brain regions are activated and thus fewer regions are anatomically linked. Functionally, the result would be a sharper representation and better understanding of the new competency, because irrelevant information and concepts would not be linked to this competency. Once formed, an evolutionarily novel, biologically secondary cognitive competency emerges.

Folk Systems

Plasticity. Fluid intelligence is involved during the initial phase of learning biologically secondary abilities, but the fully developed competencies reside in a network of cognitive and brain systems that differ from those that support *g*F (Gevins & Smith, 2000; Raichle et al., 1994). This network of systems represents the class of crystallized intelligence (Cattell, 1963; Horn & Cattell, 1966) or at least that class of knowledge acquired during the individual's lifetime. Such learning is possible to the extent that inherent modular systems evince some degree of plasticity and to the extent that independent modular systems can be interconnected to form unique neural networks and functional competencies (Garlick, 2002; Sporns et al., 2000).

As I explain elsewhere (Geary, 2004; Geary & Huffman, 2002), there is evidence for neural plasticity in most of the brain regions that are likely to support inherent, modular systems. The presumed evolutionary function of plasticity is to enable these systems to be fine-tuned to the nuances of the ecologies in which the individual is situated, although the fine-tuning appears to occur within inherent constraints on the forms of information the brain and cognitive systems can process (e.g., visual contours or prototypical shape of a human face). Modular plasticity also indicates that these systems can be modified to process evolutionarily novel information, if this novel information is similar to the forms of information the system evolved to process (Sperber, 1994). I give an example below. My point for now is that variability in social and ecological dynamics during human evolution not only provides an explanation for the evolution of *g*F but would also result in a selective advantage for plasticity within modular systems. Modular plasticity, in turn, enables the formation of crystallized knowledge during the life span.

Folk Psychology, Reading, and Writing. In the "Learning and Cognition" section, I described how the initial phase of learning how to read might occur. I now consider how reading and writing might be more broadly related to inherent, folk-psychological modules (see also Geary, 2002a). Because the function of written and therefore read material is to communicate with other people, it follows that writing and reading emerged from and currently are based on evolved social communication systems, that is, folk psychology. Writing must have emerged (culturally) from the motivational disposition to communicate with and influence the behavior of other people (e.g., morals in the Bible) and must engage the same folk-psychological systems, especially language and theory of mind. If this is correct, then writing and reading should engage many of the same brain and cognitive systems that support folk psychology. The research base on reading is larger than that on writing, and thus I focus on the former.

The research to date is not definitive, but it is consistent with the hypothesis that the acquisition of reading-related abilities (e.g., word decoding) involves the instruction-driven adaptation of primary language and language-related systems, among others (e.g., visual scanning; Rozin, 1976). Wagner, Torgesen, and Rashotte (1994) reported that individual differences in the fidelity of kindergarten children's phonological processing systems, which are basic features of the language domain, are strongly predictive of the ease with which basic reading abilities (e.g., word decoding) are acquired in first grade (Bradley & Bryant, 1983). Children who show explicit awareness of basic language sounds are more skilled than are other children at associating these sounds with the symbol system of the written language. In further support of the adaptation hypothesis, Pugh and his colleagues (1997) found that the brain and cognitive systems that are engaged during the processing of language sounds are also engaged during the act of reading.

It is also likely that reading comprehension engages theory of mind, at least for literary stories, poems, dramas and other genre that involve human relationships (Geary, 1998). This is because comprehending the gist of these stories involves making inferences about the nuances of social relationships, which, by definition, involves theory of mind. It is also of interest that some of the more popular forms of literature focus on interpersonal relationships and dynamics, typically reproductive relationships, as in the case of romance novels and the male-male competition (with unrestricted sexuality) in the case of spy novels and related genre. In these stories, a sense of self may also come into play, to the extent the individual identifies with the protagonist or antagonist in the story.

Conclusion

The function of brain and cognition is to enable the organism to attend to, process, and behaviorally respond to the forms of information and conditions that covaried with survival or reproductive prospects during the species' evolutionary history (Geary & Huffman, 2002). At a behavioral level, the organism focuses on gaining access to and control of the resources that support survival and allow one to reproduce. These resources fall into three general categories: social (e.g., mates), biological (e.g., prey species), and physical (e.g., nesting sites). The dynamics of the corresponding conditions, as in prey identification and capture, vary along a continuum ranging from information patterns that are static across generations and lifetimes to information patterns that highly dynamic, the specifics of which can fluctuate across generations and within lifetimes. Static or invariant conditions create pressures for the evolution of modularized brain and cognitive systems (Gallistel, 2000; Tooby & Cosmides, 1995), whereas dynamic conditions create pressures for modular plasticity and the evolution of less modularized, domain-general systems (Chiappe & MacDonald, 2004; Geary, 2004). For humans, the modularized systems coalesce around the domains of folk psychology (Baron-Cohen, 1995; Brothers & Ring, 1992), folk biology (Atran, 1998), and folk physics (Pinker, 1997). There is evidence for plasticity within these modularized domains, as well as evidence for domain-general brain and cognitive systems that operate on information patterns generated by modularized brain and cognitive systems (Geary, 2004). These domain-general systems are known as general fluid intelligence (Engle, 2002; Cattell, 1963).

From this perspective, cognitive development is an inherent feature of the human life span and functions to flesh out the plastic features of modularized folk domains such that these brain and cognitive systems become sensitive to nuances in the local social, biological, and physical ecologies (Geary & Bjorklund, 2000). The experiences needed to adjust these plastic features to these ecologies are generated by children's natural social, play, and exploratory activities. The result of these activities, such as parent-infant social play, is the effortless and automatic adaptation of plastic systems such that the individual easily makes discriminations among different people and learns about their personality and behavioral dispositions; forms categories of local plants and animals and learns about their essence; and develops mental maps of the groups' physical territory, among many other cognitive changes. These cognitive competencies are biologically primary; that is, the human mind is inherently biased to acquire knowledge in these domains and to do so with little effort.

Academic development, in contrast, involves the experience-driven acquisition of nonevolved, or biologically secondary, cognitive competencies (Geary, 1995). The acquisition of these competencies is dependent on plasticity in modularized domains and the existence of domain-general mechanisms that can adapt these brain and cognitive systems such that they respond to evolutionarily novel information patterns. An example of the latter is formation of associations among language sounds and visual patterns to create the ability to read and write. Although not typically approached from an evolutionary perspective, research in experimental psychology has identified these domain-general systems; specifically, fluid intelligence (Kane & Engle, 2002). Fluid intelligence is composed of the attentional and working-memory systems that enable people to explicitly represent and manipulate information that has tended to be variable during human evolutionary history or is evolutionarily novel. Although it is not certain, it appears the explicit representation of information in working memory and the reasoned manipulation of this information are at the heart of the human ability to construct nonevolved cognitive competencies (Ackerman, 1988). My proposals here and elsewhere (Geary, 2004) as to how the mechanisms that may govern academic learning can be understood within a wider evolutionary perspective are speculative, but may provide a useful start.

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