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FOLK KNOWLEDGE AND ACADEMIC LEARNING

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The field of evolutionary psychology is growing in prominence and influence despite the reluctance of many social scientists to apply evolutionary principles to understanding human behavior (Segerstrale, 2000). Included among the phenomena that are now studied from this perspective are developmental activities and processes, and with this, the emergence of the subfield of evolutionary--developmental psychology (Bjorklund, 1997; Bjorklund & Pellegrini, 2002; Freedman, 1974; Geary & Bjorklund, 2000). One focus of theory and research in this subfield is on the relation between children's evolved cognitive and motivational biases and the demands of academic learning (Geary, 1995, 2001, 2002a; Rozin, 1976). In this chapter, I present an overview of a framework I am developing to understand the relation between evolved abilities and the non evolved academic competencies that are built through instructional practices. The former are called biologically primary abilities, and the latter, biologically secondary abilities. In the first section, I present a taxonomy of primary cognitive domains (see also Geary, 2005; Geary & Huffman, 2002), and in the second, I discuss some of the ways in which these evolved cognitive and associated motivational and developmental systems may be related to academic learning and the construction of secondary abilities.

TAXONOMY OF PRIMARY COGNITIVE ABILITIES

In the first section, I set up the basic theoretical frame for conceptualizing the function and evolution of primary abilities. In the second and third sections, I present a taxonomy of primary abilities and place these abilities in a developmental context.

Motivation to Control

There is consensus among psychologists that humans have a basic motivation to achieve some level of control over relationships, events, and resources that are significant in their lives (Fiske, 1993; Heckhausen & Schulz, 1995; Thompson, Armstrong, & Thomas, 1998). There is no consensus as to whether this motivation to control has evolved. Nonetheless, it is necessarily true that any motivational disposition will evolve if it contributes to the ability to achieve control of the resources that covary with survival and reproductive outcomes, and if individual differences in the trait are heritable. My thesis here and elsewhere is that the human motivation to control is indeed an evolved disposition and is implicitly---sometimes explicitly---focused on attempts to control social relationships and control the forms of biological (e.g., food) and physical (e.g., territory) resources that tended to covary with survival and reproductive prospects during human evolution, and the variants of these resources that are of importance in the local ecology and social group (Geary, 1998, 2005).

I am not arguing that people always have a conscious and explicit goal to control other individuals and resources in their environment; often they do not. What I am proposing is that selection pressures (e.g., social competition) will operate such that behavioral biases will evolve that focus on securing social and ecological resources, and that these biases covaried with survival or reproductive outcomes during the species' evolutionary history. The biases result from the activity of an array of brain, cognitive, and affective mechanisms that process the corresponding information patterns (e.g., movement patterns of prey species) and guide behavioral activities toward these features of the social and ecological world. In other words, one way of organizing brain, cognitive, affective, and behavioral systems under a single principle is to cast them as reflecting a fundamental motivation to control within-species and between-species (e.g., prey capture, or predator avoidance) behavioral dynamics and to gain control of resources that have tended to covary with evolutionary outcomes. With respect to humans, the Darwin and Wallace (1858, p. 54) conceptualization of natural selection as a “struggle for existence” becomes additionally a struggle with other human beings for control of the resources that support life and allow one to reproduce.

Figure 19.1 shows the affective, psychological, and cognitive mechanisms and underlying modular systems that support control-related behavioral strategies. The details of the affective and psychological systems are described elsewhere (Geary, 2005). Briefly, the functions of the affective systems are to generate social displays, such as facial expressions, and form a conscious awareness of corresponding feelings, such as fear or happiness (Damasio, 2003). These regulate social and other behavioral dynamics, and provide the individual with feedback as to how the current or simulated future situation might affect his or her well-being. The psychological system is defined, in part,

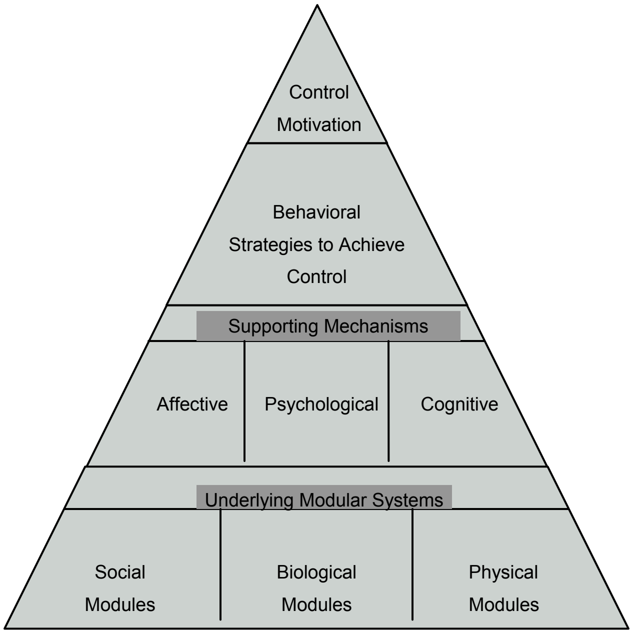

FIGURE 19.1. The apex and following section represent the proposal that human behavior is basically driven by a motivation to control the social, biological, and physical resources that have tended to covary survival and reproductive outcomes during human evolution. The midsection shows the supporting affective, psychological (e.g., attributional biases), and cognitive (e.g., working memory) mechanisms that support the motivation to control and operate on the modular systems shown at the base.

by the ability to form an explicit and conscious representation of the self (Tulving, 2002), and the ability to create a self-centered mental simulation of the "perfect world." A perfect world is one in which the individual is able to organize and control social (e.g., mating dynamics), biological (e.g., access to food), and physical (e.g., shelter) resources in ways that would have enhanced the survival or reproductive options of the individual and kin during human evolution. The evolved function of the simulation is to enable the use of problem solving, reasoning, attributions, and so forth, to devise behavioral strategies that can be used to reduce the difference between one's current situation and this perfect world.

The mental simulation of a perfect world requires the ability to decouple cognitive systems from engagement of the actual world (Cosmides & Tooby, 2000), and then use these systems to either re-create a previous episode, simulate a potential future episode, or create a more abstracted and decontextualized representation of social dynamics or other aspects of the world

(Alexander, 1989). Following Johnson-Laird (1983), and others (Deacon, 1997; Kosslyn & Thompson, 2000), the representations are built from more modular, biologically primary systems and are typically language-based, visuospatial, or some combination of the two. The mental reconstitution of a past episode allows the individual consciously and explicitly to evaluate the dynamics of the episode (e.g., "What did he mean when he said. . . ?"), and to plan and rehearse behavioral strategies for anticipated future episodes that involve the same person or theme. Mental simulations can also involve abstractions of common features or themes across episodes.

The creation of psychological simulations is dependent on working memory resources and is driven by executive control (Baddeley, 1986; Moscovitch, 1994) and associated brain regions in the prefrontal cortex. Working memory and executive functions, in turn, are the cognitive component in the middle section of Figure 19.1. The modular systems at the base of the figure are predicted to process evolutionarily significant forms of information (e.g., facial features) associated with domains of resource control; specifically, social (conspecifics), biological (e.g., other species that serve as food or medicine), and physical (e.g., demarcating the group's territory) resources. The modular systems are components of folk psychology, folk biology, and folk physics, respectively (Atran, 1998; Brothers & Ring, 1992; Carey & Spelke, 1994; Gelman, 1990; Humphrey, 1976; Povinelli & Preuss, 1995; Pinker, 1997). These represent forms of information, such as the shape of a human face or specific facial expression, that have been relatively invariant throughout human evolution. The associated brain and cognitive systems automatically and implicitly process this information and through affective mechanisms bias behavioral responding.

There are other forms of information that also have an evolutionary history but can vary from one situation to the next, as in complex social dynamics. The cognitive (e.g., working memory), psychological (e.g., simulated perfect world), and supporting brain systems at the level above the modules in Figure 19.1 are also evolved but function to cope with such conditions, that is, dynamics that fluctuate across generations and within lifetimes. The explicit representation of a psychological simulation in working memory allows people to anticipate these fluctuations and allows the use of problem solving and reasoning to generate and rehearse potential behavioral strategies to cope with the situation. Although not the evolved function of these explicit cognitive and psychological systems, their operation may be the key to understanding the mechanisms involved in creating secondary competencies from evolved, primary domains. I touch on this issue in the Academic Learning section and provide more complete analyses and discussion elsewhere (Geary, 2005).

Primary Domains

As I just noted, evolutionarily significant patterns of information largely coalesce around the domains of folk psychology, folk biology, and folk physics. Although there appear to be other primary abilities that are of educational relevance (e.g., numerical information; Geary, 1995, 2001), my position is that the domains shown in Figure 19.2 capture the essential primary abilities that are common to all people; of course, individual differences in these abilities (e.g., sensitivity to facial expressions) are expected. The defining features of modules and the extent to which modular competencies are the result of inherent constraint or patterns of postnatal experience are vigorously debated (Finlay, Darlington, & Nicastro, 2001; Gallistel, 2000; Pinker, 1994; Tooby & Cosmides, 1995), the details of which are beyond the scope of this treatment (Geary, 2005; Geary & Huffman, 2002). It is, however, assumed that these competencies emerge through an epigenetic process, specifically, interaction between inherent constraint and patterns of developmental experience (Bjorklund & Pellegrini, 2002; Geary & Bjorklund, 2000).

Most of the time, primary knowledge is implicit; that is, it is represented in the organization of primary brain systems and the corresponding long-term memories; the latter represent the types of information (e.g., shape of a human face) to which the brain and perceptual systems respond. Conscious, explicit representations result when more automatic, primary systems do not result in a desired outcome r do not allow for easy explanation of the current situation (Geary, 2005). These are situations that appear to result in automatic attentional shifts to representations of the self, the goal, and features of the situation that are thwarting achievement of the goal (Botvinick, Braver, Barch, Carter, & Cohen, 2001). As I describe in the section Folk Knowledge and Academic Learning, the attentional shifts result in the representation of the information in working memory, and thus make this information available for use in control simulations.

Folk Psychology

Folk psychology is defined as the affective, cognitive, psychological, and behavioral systems that are common to all people and enable them to negotiate social interactions and relationships. For instance, even infants preferentially orient their attention and much of their behavior toward other people, and behave in ways (e.g., smile or cry) that result in parental engagement in the relationship (Freedman, 1974). The attentional and behavioral biases of infants and parents are guided by the implicit (below conscious awareness) operation of folk psychology systems. From an evolutionary perspective, the cognitive systems should function to process and manipulate (e.g., categorize) 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 and leftmost sections of Figure 19.2.

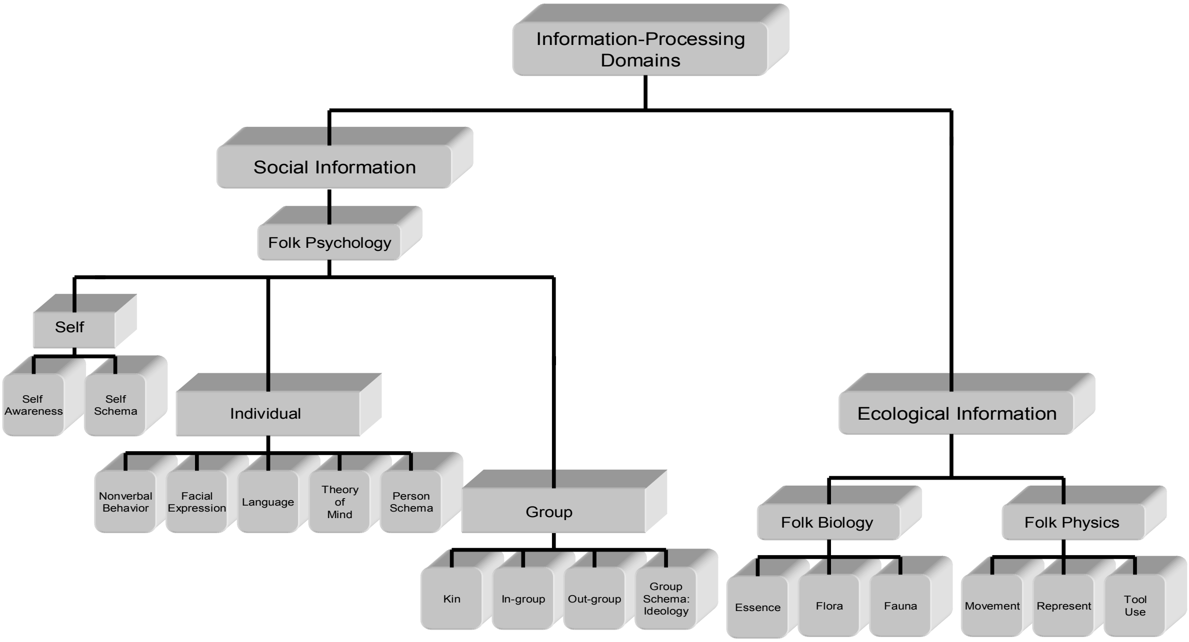

FIGURE 19.2. Evolutionarily salient information-processing domains and associated cognitive modules that compose the domains of folk psychology, folk biology, and fold physics.

Self. Self-related cognitions include awareness of the self as a social being (Tulving, 2002), and 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., friendliness), episodic 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 persist in the face of failure (Sheeran & Orbell, 2000). Social 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). For instance, when evaluating the competencies of others, people focus on attributes that are central features of their self-schema, and prefer relationships with others who provide feedback consistent with the self-schema. Athletes implicitly compare and contrast themselves to others on dimensions that involve physical competencies, whereas academics focus more on intellectual competencies (Fiske & Taylor, 1991). People value competencies on which they excel and discount competencies for which they are at a competitive disadvantage (Taylor, 1982).

Person. The person-related 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) described universal patterns of dyadic interaction and individual relationships, including parent-child attachments and friendships, among others. There are, of course, some differences across these dyads, but all of them are supported by the person-level sociocognitive modules shown in Figure 19.2. These modules include those that support the reading of nonverbal behavior and facial expressions, language, and theory of mind (Baron-Cohen, 1995; Pinker, 1994; Rosenthal, Hall, DiMatteo, Rogers, & Archer, 1979). The latter represents the ability to make inferences about other people's intentions, likely future behavior, and so forth.

The person schema is a long-term memory network that includes representations of the other persons' physical attributes (age, race, sex), memories for specific behavioral episodes, and more abstract trait information, such as individuals' sociability (e.g., warm to emotionally distant) and competence (Schneider, 1973). It seems likely that the person schema will also include information related to other 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 (e.g., tends to attribute hostile intentions to others, the hostile attribution bias), responds to social cues, and their social and other goals.

Group. A universal aspect of human behavior and cognition is the parsing of the social world into groups (Alexander, 1979; Premack & Premack, 1995). The most consistent groupings are shown in Figure 19.2 and reflect the categorical significance of kin, the formation of ingroups and outgroups, and a group schema. The latter is an ideologically based social identification (e.g., nationality, religious affiliation). 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 social 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-supported groups is over resource control.

Basically, individual- and group-level cooperative relationships and conflicts of interest are invariably generated as each individual attempts to gain control of social relationships and the biological and physical resources that covary with survival or reproductive prospects in the local ecology and culture (Alexander, 1979; Chagnon, 1988; Horowitz, 2001; Irons, 1979; Keeley, 1996). People develop cooperative relationships to the extent that social influence, resource control, and other issues that are of significance in their lives require such relationships.

Folk Biology and Folk Physics

Humans living in traditional societies use the local ecology and other species 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 rightmost sections of Figure 19.2 (Geary, 1998, 2005; 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 (e.g., Berlin, Breedlove, & Raven, 1973). Folk biology also includes systems that support an understanding of the *essence* of these species (Atran, 1998). 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 space, mentally representing this space (e.g., demarcating the ingroup's territory), and for using physical materials (e.g., stones, metals) for making tools (Pinker, 1997; Shepard, 1994). The associated primary abilities support a host of evolutionarily significant activities, such as hunting and the use of tools as weapons or to secure biological resources (e.g., stone hammers to break open bones and secure high-fat marrow).

Attributional and Inferential Biases

Inferential and attributional biases are also integral features of folk knowledge, and are part of the psychological component of the motivation to control (Geary, 2005). Social attributional biases that favor members of the ingroup and derogate members of outgroups 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; see also Barrett, Chapter 17, this volume). Attributions about causality in the physical world have also been studied. For instance, children and adults have natural, naïve conceptions about motion and other physical phenomena (Clement, 1982; Kaiser, McCloskey, & Proffitt, 1986; Kaiser, Proffitt, & McCloskey, 1985; Spelke, Breinlinger, Macomber, & Jacobson, 1992).

It is often the case that naïve notions and attributional and inferential biases associated with folk knowledge are inaccurate from a scientific perspective, as elaborated in the Academic Learning and illustrated in the Folk Physics sections below. Although such inaccuracies are important from an educational perspective, they are irrelevant from an evolutionary perspective. Selection will operate on attributional and inferential biases that facilitate resource control, whether or not the biases are accurate from a scientific perspective. Indeed, many attributional and inferential biases result in judgments that are generally accurate enough for coping with many everyday situations (Stanovich, 1999), although they often do not result in the most logical conclusions (Tversky & Kahneman, 1974).

Development

A long developmental period is associated with the risk of dying before the age of reproduction; thus, an extended childhood would only evolve if there were benefits that outweighed this risk (Stearns, 1992). Mayr (1974) suggested that one function, and the presumed adaptive benefit, of delayed maturation is the accompanying ability to refine the competencies that covaried with survival and reproductive outcomes during the species' evolutionary history (see Flinn & Ward, Chapter 2, this volume). The corresponding assumption here is that one function of human childhood is to flesh out the cognitive, affective, and psychological systems that comprise folk knowledge, such that these systems are adapted to social conditions (e.g., level of warfare) and the biological (e.g., types of species) and physical (e.g., terrain) nuances of the local ecology (Bjorklund & Pellegrini, 2002; Geary, 2002b, 2005; MacDonald, 1992).

Play, social interactions, and exploration of the environment and objects appear to be the mechanisms through which these emerging competencies are practiced, refined, and adapted to local conditions. In theory, these child-initiated activities are intimately linked to cognitive and brain development, in that these activities result in the environmental experiences that are an integral part of the epigenetic processes that result in adult competencies (Greenough, 1991; Scare & McCarthy, 1983). In other words, children are inherently motivated to attend to and seek out experiences and engage in activities that will lead to the adaptation of inherent but often skeletal folk knowledge, such that the associated cognitive, affective, psychological, and behavioral systems are adapted to the nuances of the local ecology (Gelman, 1990). These child-initiated activities and associated inherent biases in motivational, cognitive, and brain systems will be focused on recreating the experiences that lead to the refinement of the competencies that covaried with survival and reproduction during human evolution.

For instance, 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 re-create the microconditions (e.g., parent-child interactions) associated with the evolution of the corresponding modules (Caporael, 1997), and provide the experiences 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 that they are sensitive to and learn the voice patterns of their mother, and discriminate her voice from that of other women (Kisilevsky et al., 2003).

Boys' group-level competition (e.g., team sports) provides another example with the early formation of competition-based ingroups and outgroups, and the coordination of social activities that may provide 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 & Pellis, 1998), 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 earlier, and provide experience with the dynamics of forming ingroups and outgroups.

As another example, sociodramatic play appears to be an important vehicle for elaborating children's social competencies, such as learning the implicit scripts that choreograph many social interactions. Beginning around age 3, children practice social scripts in the context of their play (Rubin, Fein, &

Vandenberg, 1983). Initially, this type of play involves using dolls or other toys to act out everyday social experiences (e.g., dinner). The use of toys allows the child to practice coordinating social interactions at an age when he or she does not yet have the competencies do to so effectively with other children. Later, particularly between the ages of 4 and 6 years, children rehearse and then expand on these scripts with groups of other children (Rubin et al., 1983). Thus, from ages 3 to 6, children's play activities involve increasingly complex patterns of social interaction. The fantasy element of sociodramatic play might also be involved in the development of the psychological component of the motivation to control. More precisely, the fantasy component of this form of play might provide practice at using mental simulations to rehearse social strategies (Geary, 1998).

ACADEMIC LEARNING

From an evolutionary perspective, the folk knowledge and inferential and attributional biases that define primary abilities are not sufficient for academic learning in modern society, but, at the same time, are the foundation from which biologically secondary academic competencies are likely to be built. The implications for academic learning are multifold and thus, I can only touch on a few of these (Geary, 1995, 2001, 2002a, 2005). In the first section, I provide several examples of the relation between folk knowledge and academic competencies, and in the second section, I discuss the relation between the motivation to control and the motivation to learn in school. The mechanisms through which primary systems are modified to create academic competencies are not known, but in the third section, I suggest that these mechanisms might be related to the cognitive and psychological systems that support the ability to cope with fluctuating conditions. In the final section, I outline a few instructional implications.

Secondary Competencies

When approached from an evolutionary perspective, schools are predicted to emerge in societies in which scientific, technological, and intellectual advances result in a gap between folk knowledge and the academic (e.g., need to read) demands of the society (Geary, 2002a). One of the corresponding goals of schooling should be to narrow this gap; specifically, to ensure that children learn the biologically secondary competencies needed to function successfully (e.g., obtain gainful employment) in the society. In the following sections, I provide examples of how folk knowledge may be related to the learning of secondary abilities. In the first section, I illustrate the construction of novel academic competencies (reading and writing) from primary domains, and in the second and third sections, I illustrate the relation between folk knowledge and scientific knowledge in biology and physics.

Folk Psychology

Following Rozin's (1976) lead, my hypothesis is that the invention of written symbols emerged from the motivational disposition to communicate with and influence the behavior of other people (e.g., morals in the Bible); thus, writing-reading is predicted to be dependent on folk psychological communication systems. More precisely, learning to read and write involves co-opting primary folk psychological systems: "Co-optation" is defined as the adaptation (typically through instruction) of evolved cognitive systems for culturally specific uses (Geary, 1995, 2002a; Rozin, 1976; Rozin & Schull, 1988). The first issue that must be addressed concerns whether or not reading--writing can in fact be linked to folk psychological systems. I emphasize reading, because more is known about learning to read than to write.

Although the research is not definitive, it is consistent with the hypothesis that the acquisition of reading-related abilities (e.g., word decoding) involves the co-optation of primary language and language-related modular systems, among others (e.g., visual scanning), as originally proposed by Rozin (1976). Wagner, Torgesen, and Rashotte (1994) found that individual differences in the fidelity of kindergarten children's phonological processing systems, which are basic components 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 an explicit awareness of basic language sounds are more skilled than other children at associating these sounds with the symbol system of the written language. In further support of the co-optation hypothesis, Pugh and his colleagues (1997) found that the brain and cognitive systems that are engaged during the processing of phonemes are also engaged during the act of reading.

It is also likely that reading comprehension engages related modular systems, including theory of mind and the person schema, at least for literary stories, poems, dramas, and other genres 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, engages theory of mind. Characters within stories typically have personalities, behavioral styles, and so forth---information that could be used to create a person schema for these individuals (e.g., Sherlock Holmes). It is also of interest that some of the more popular forms of literature are focused on interpersonal relationships and dynamics, and reproductive relationships in the case of the romance novel (e.g., Whissell, 1996). The self-schema would be engaged to the extent the individual identifies with the protagonist or antagonist of the story.

Folk Biology

As stated earlier, folk biology represents the evolved ability to develop classifycation systems of flora and fauna, and mental models of the essence of these species (Atran, 1998). Although folk biological knowledge almost certainly provided the foundation for the emergence of the scientific classification system of Western biology, this folk knowledge is rudimentary in comparison to the vast knowledge of modern-day biological science. As an example, people, even young children, infer that living things have innards that differ from the innards of nonliving things, and that offspring will have the same appearance and essence as their parents (Carey & Spelke, 1994; Coley, 2000; Gelman, 1990). The scientific study of "innards" is, of course, anatomy and physiology, and the study of "essence" is behavioral ecology. The latter involves the scientific study of animal behavior in natural environments, and "essence" represents knowledge of, for instance, the behavior of hunted animals and where in the ecology they are most likely to be found (Atran, 1998).

Not only is the gap between folk biology and the knowledge base of the biological sciences widening at a rapid pace but also the inferential biases of this folk system may sometimes interfere with the comprehension of scientific models of biological phenomena. The most fundamental of these are the principles of natural selection independently discovered by Darwin and Wallace (1858). Two of the crucial features of natural selection are that (1) it acts on *individual differences* in those traits (e.g., size at birth) that are related to survival prospects and (2) results in changes in those traits *across* generations. Yet inferential biases in folk biology may conspire to make these basic mechanisms difficult to comprehend. First, one inferential bias results in a focus on similarities across members of the same, and related, species (see Atran, 1998). This bias facilitates the functional goal of being able to predict the behavior (e.g., growth patterns) of these plants and animals, as related to procuring food and medicine. At the same time, the focus on within-species similarities runs counter to the insight that within-species individual differences, or variability, provide the grist for evolutionary selection. Second, folk biological knowledge is also implicitly focused on the behavior of flora and fauna at different points in a single lifespan (e.g., maturity of a plant, relative to when it is best to harvest) and not the cross-generational time scale over which natural selection occurs.

In summary, people are biased to think about and understand the biological world in ways that are at odds with the principles of natural selection. Darwin, in fact, did not recognize the extent of within-species variability in natural environments, and thus the ease with which natural selection can operate in these environments, until his extensive work in the 1850s on barnacles (Desmond & Moore, 1994), 15 or so years after his initial insights on natural selection (Ospovat, 1981). One educational implication is that children need exposure to variation within species, and instruction on how these individual differences are related to survival prospects and mate choice, if they are to fully understand the mechanisms of natural selection.

Folk Physics

As noted earlier, people have a naive understanding of certain physical phenomena (Piaget, 1927/1930, 1946/1970), and the initial emergence of physics as a domain of explicit intellectual activity was likely to have been based on this folk knowledge. As an example, when asked about the forces acting on a thrown baseball, many people infer a force propelling it forward, something akin to an invisible engine, and a force propelling it downward. The downward force is, of course, gravity, but there is in fact no force propelling it forward, once the ball leaves the player's hand (Clement, 1982). The concept of a forward force, called "impetus," is similar to pre-Newtonian beliefs about motion prominent in the 14th-16th centuries. The idea is that the act of starting an object in motion, such as throwing a ball, imparts to the object an internal force-"impetus"-that keeps it in motion until the impetus gradually dissipates. Even though adults often describe the correct trajectory for a thrown object, their explanations reflect this naïve understanding of the forces acting upon the object.

Although "impetus" is in fact a fictional force, it is a reasonable explanation of most everyday situations. Nevertheless, this and other naïve conceptions about the workings of the physical world interfere with learning the scientific principles associated with mechanics, as well as many other principles, such as those representing centrifugal force and velocity (Clement, 1982; McCloskey, 1983). Moreover, as with biology, the knowledge base of the physical sciences is exponentially larger than the knowledge base of folk physics, and in some cases (e.g., quantum mechanics) the accompanying conceptual models bear little resemblance to the naïve concepts of folk physics. Educational implications are discussed below.

Folk Knowledge and Academic Learning

Rozin (1976) and Karmiloff-Smith (1992) proposed that one of keys to understanding the relation between primary abilities, such as language, and secondary abilities, such as reading, is the mechanism or mechanisms involved in making the implicit primary systems explicit---the individual is consciously aware of the information (e.g., a language sound)---and then rewriting them, so to speak, as a secondary competency. My goal is to integrate research on the relation between general intelligence and learning and with the cognitive mechanisms (e.g., working memory) that support control-related behavioral strategies (Geary, 2005). One reason is because the best predictor of the ease of learning secondary competencies is general intelligence, or g (Jensen, 1998): Walberg (1984) reviewed 3,000 studies of the relation between performance on academic achievement tests, which largely assess secondary abilities, 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 g, specifically IQ ($r = .7$). Moreover, the cognitive mechanisms that underlie g are likely to be engaged when primary abilities are rewritten as secondary abilities (Geary, 2005) These mechanisms include the central executive component of working memory and attentional control (e.g., Baddeley, 1986; Conway & Engle, 1994), as well as the supporting areas of the prefrontal cortex and anterior cingulate cortex (Duncan et al., 2000; Kane & Engle, 2002). These mechanisms also support control-related mental simulations.

The details of how these domain-general systems may be involved in academic learning and the co-opting of primary abilities for the construction of secondary competencies are described elsewhere (Geary, 2005). As an illustration of the basics, consider that the dorsolateral prefrontal regions are particularly important for explicitly representing goals and information to be manipulated in working memory (Duncan, 2001; Kane & Engle, 2002; Miller & Cohen, 2001; Shallice, 2002). These ends appear to be achieved by biasing, perhaps through attentional amplification (Dehaene & Naccache, 2001; Posner, 1994), the activation of posterior and subcortical pathways that represent the information needed for goal achievement. These posterior regions include those that support many of the primary modules, such as the processing of language sounds that I described in the Primary Domains section. The result appears to be a simultaneous and synchronized activation of the dorsolateral prefrontal areas and the posterior brain regions engaged for the specific task.

To illustrate how the process may work: One of the basic academic competencies that supports learning how to read, phonemic decoding (Bradley & Bryant, 1983) requires an explicit awareness and representation in working memory of a basic language sound and the association of this sound, as well as blends of sounds, with corresponding visual patterns, specifically, letters 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 posterior brain regions that process this information and the simultaneous representation of both forms of information in working memory. The process should result in the synchronization of this posterior brain activity with activity in the dorsolateral prefrontal cortex and the formation of a learned association between the sound and letter. With practice, the association becomes represented in long-term memory and thus becomes implicit knowledge, presumably due to the formation or strengthening of neural links among these posterior regions (Garlick, 2002). 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.

Academic learning also involves more complex activities, including problem solving, reasoning, and the understanding of complex intellectual and scientific principles. Elsewhere, I described how these processes may also engage the dorsolateral prefrontal areas and accompanying central executive and working memory systems (Geary, 2001). The psychological component of the motivation to control is also important for the formation of mental simulations of many phenomena and is likely engaged in the creation of many forms of secondary knowledge. For instance, Darwin and Wallace (1858) likely used mental simulations, as well as reasoning, problem solving, and so forth, in their construction of the principles of natural selection (see Geary, 2005). The point is that learning simple associations involved in phonemic decoding, and the more complex processes involved in scientific discovery and the creation of secondary knowledge, may involve many of the same cognitive and brain systems, specifically, the psychological and cognitive components of my motivation to control model.

Motivation to Learn

Another implication of the evolutionary approach is that children are innately curious about and motivated to engage actively in and explore social relationships and the biological and physical world. These are biases directed toward information and activities associated with fleshing out folk knowledge and adapting these brain and cognitive systems to local conditions, as I noted earlier (Gelman, 1990; Gelman & Williams, 1998; Geary, 1995). However, if the activities that promote the fleshing out of folk knowledge differ from the activities that promote academic learning, then a motivational mismatch will arise between children's preferred activities and effective instructional activities. In other words, the motivation to engage in activities related to folk knowledge will often conflict with the need to engage in activities that will lead to the mastery of academic competencies (see Geary, 1995, 2001, 2002a).

For instance, if social competition over resource control generated selection pressures that contributed to human cognitive and social evolution, then children should have a strong and inherent motivational bias to engage in activities that will re-create the forms of social cooperation and competition that were important during human evolution (Caporael, 1997). The finding that a universal aspect of children’s (and adults’) self-directed activities are social and typically involve a mix of cooperative and competitive endeavors is consistent with this prediction (Baumeister & Leary, 1995). Competition over friends, called relational aggression, is one example (Feshbach, 1969). A corollary prediction is that a burning desire to master algebra or Newtonian physics will not be universal, or even common.

There are, of course, many individuals who pursue learning in secondary domains and engage in secondary activities on their own initiative, but this follows from the assumption that most activities, primary and secondary, can be categorized as related to social, biological, or physical interests (Geary, 2002a). From this perspective, scholars in the humanities and social sciences are predicted, and appear, to be fundamentally motivated to understand human social relationships, and biologists and physicists, to be motivated to understand the biological and physical worlds, respectively (Roe, 1956). The difference between scholars in these domains and other people is predicted to be related to several dimensions of human individual differences, including the cognitive systems underlying g (i.e., working memory and attentional control; Jensen, 1998), certain dimensions of personality (e.g., open mindedness;

Stanovich, 1999), a touch of psychopathology (Simonton, 2003), and the willingness to engage in the long and often tedious training required to master the academic discipline (Ericsson, Krampe, & Tesch-Romer, 1993). It is individuals at the extreme end of all of these distributions---which makes them very rare---who generate a disproportionate number of scholarly, scientific, and technological advances (Simonton, 1999).

There may also be individual differences in the degree of inherent elaboration of folk psychological, biological, and physical systems, and these in turn may contribute to the foci on one domain or another and the degree to which secondary knowledge dependent on these domains can be developed. Baron-Cohen and his colleagues found that at least some highly successful mathematicians and physical scientists appear to have an enhanced understanding of folk physics but a poor understanding of aspects of folk psychology (Baron-Cohen, Wheelwright, Stone, & Rutherford, 1999). When an enhanced intuitive understanding of folk physics and an enhanced motivation to engage in associated activities is combined with high g, the result can be advances in the associated scientific or scholarly domain. Newton's social isolation and near obsessive focus on physical phenomena (e.g., optics; White, 1998) and Linnaeus's obsession with creating an explicit taxonomy of flora (e.g., Lindroth, 1983) are but two examples: Linnaeus created the binomial rules (e.g., based on similarities in the shape of flower petals) for the scientific classification of species and was the first to use this taxonomic system. The result of the work of Newton and Linnaeus was scientific revolutions in physics and biology, respectively, and a significant widening of the gap between folk knowledge and these emerging scientific disciplines.

For most people, however, the motivational disposition will be expended on rather more mundane activities. These activities are predicted to be largely social in nature, based on a social-competition model of human evolution (Alexander, 1987; Geary, 2005), but can involve more secondary activities. The motivation to engage in secondary activities is predicted to be related to evolutionary themes embedded in the content of the activity and not directed toward secondary learning per se. To illustrate, reading is a biologically secondary activity, but many people choose to read. The motivation to read is probably driven by the content of the activity rather than by the process itself. As I noted earlier, the content of many stories and other secondary activities reflects evolutionarily relevant themes (e.g., social relationships), and it is interest in these themes that motivates engagement in the activity.

In any case, the point is that children's inherent motivational dispositions and activity preferences are likely to be at odds with the need to engage in the activities, such as the drill and practice needed to learn mathematical procedures, that promote academic learning. This does not preclude self-initiated engagement in secondary activities, but it does lead to the prediction that children's natural curiosity and preferred mode of learning (e.g., play and exploration) will not always be sufficient for acquiring secondary competencies.

Instructional Implications

Considerable debate has been expended on attempts to understand the acquisition of academic competencies (Hirsch, 1996; Loveless, 2001). Almost none of the associated research programs have been informed by evolutionary considerations and, as a result, fail to explain even basic observations, such as why children learn language more readily than they learn how to read and write. The difference in the ease of acquiring language as contrasted with reading and writing is readily understandable from the evolutionary perspective: The inherent cognitive systems and child-initiated activities that foster the adaptation of primary abilities, such as language, to local conditions will not be sufficient for the acquisition of secondary abilities, such as reading and writing. In the two sections below, I discuss related instructional implications.

Folk Knowledge and Instruction

If folk knowledge and inferential biases sometimes run counter to related scientific concepts, then this folk knowledge will impede the learning and adoption of these scientific concepts or procedures. To illustrate, most people make judgments about the relative risk of various activities based on how easily they can remember examples of mishaps associated with those activities. This memory-based heuristic probably works rather well in environments in which the inferential bias evolved (Gigerenzer & Selten, 2001), that is, environments in which memories for risk-related accidents can only be accrued through personal experience or folk tales based on experiences in similar environments. However, this risk heuristic often leads to poor probability and risk judgments in modern societies. This is because mass media create memories for events individuals have not actually experienced, but these memories sometimes affect people as if they had actually experienced the event. Most people can remember many disturbing plane crashes but have not personally experienced these crashes. They were exposed to them through television (Lichtenstein, Slovic, Fischhoff, Layman, & Combs, 1978). The result is that many people overestimate the very small risk associated with flying. Statistical and mathematical methods provide a much more accurate and reliable method of risk assessment, but reliance on this evolved heuristic appears to interfere with the learning and use of formal statistics to make risk assessments (Brase, Cosmides, & Tooby, 1998).

Similar biases and instructional impediments have been noted for physics (Clement, 1982; Hunt & Minstrell, 1994). One counter to these biases is to set up demonstrations or experiments that create results that are contrary to folk intuitions, as Hunt and Minstrell (1994) have done for teaching basic concepts in high school physics. Prior to performing such an experiment, the teacher piques interest in the principles involved by asking for predictions, with the students discussing their reasons for their predictions. The demonstration is then performed, and the teacher and students discuss the results and their implications. This method appears to facilitate the understanding, retention, and transfer of biologically secondary concepts. When the students make predictions and discuss their reasons for the predictions, they are making their existing knowledge explicit. In making predictions, the students rely on their folk beliefs about physical systems, which are often incorrect or only useful in very limited specific situations. In order for incorrect (or incomplete) beliefs to be changed, the student must be made explicitly aware of them. By comparing predictions based on folk beliefs and those based on scientific knowledge to experimental outcomes, the utility of the latter becomes apparent.

Folk knowledge and inferential biases may, at other times, facilitate the acquisition of secondary abilities. As an example, a relationship between spatial abilities and mathematics, especially geometry, has been posited for thousands of years. Geometry can be defined as the study of space and shape (Devlin, 1998), and the movement and representation modules (i.e., primary spatial abilities) associated with folk physics may provide an intuitive understanding of certain features of geometry (Geary, 1995). Basically, there is order and structure to the physical universe, and many of the spatial abilities of humans, and other species, reflect the evolution of primary systems that are sensitive to this order (Gallistel, 1990; Shepard, 1994). The associated competencies include the ability to navigate in the world and generate a mental map of this world, as well as more basic skills, such as the ability to track moving objects. Nearly all of this knowledge of the physical world is implicit. Some aspects of this intuitive knowledge appear to form the foundation for some aspects of Euclidean geometry. Euclid's first principle---a line can be drawn from any point to any point; that is, a line is a straight line---reflects the intuitive understanding that the fastest way to get from one place to another is to “go as the crow flies,” that is, to go in a straight line. At the same time, there is little reason to believe that other aspects of academic geometry, such as theorems, are as intimately related to spatial knowledge.

It follows that the goals of instructional research will include identifying folk knowledge and inferential biases that relate to academic competencies and then determining instructional approaches that disabuse students of folk knowledge that runs counter to scientific concepts and capitalize on folk knowledge (often implicit) that can be used to teach academic concepts. The latter often involves making implicit knowledge formalized and explicit; Euclid’s first principle is an explicit and formalized representation of an implicit aspect of folk physics. As I described earlier, making the implicit explicit requires attentional focus and the representation of the information in working memory, which implies that direct instruction of some secondary knowledge may be the most efficient method of teaching this information.

Motivation

Surveys of the attitudes and preferences of schoolchildren indicate that most of these children value achievement in sports more than achievement in any academic area (Eccles, Wigfield, Harold, & Blumenfeld, 1993). The result is not surprising. When children are allowed to self-direct their activities, they typically engage in some type of social discourse. Boys, for instance, spontaneously organize their social activities around group-level competition, such as team sports (Lever, 1978). Geary and colleagues (1998; Geary et al., 2003 interpreted this child-initiated activity as a reflection of an evolved motivational disposition that results in the practice of group-level warfare, and a refinement of the supporting group-level social modules, such as the formation of ingroups and outgroups, and coordination of the activities of ingroup members as related to competition with an outgroup. Time spent in these preferred, child-initiated activities is time that cannot be spent engaged in the types of activities that promote the acquisition of secondary competencies.

The first instructional implication is that universal education will be dependent to a large degree on the social and cultural valuation of school-based competencies (Stevenson & Stigler, 1992). In other words, the need to learn many academic competencies comes from the demands of the wider society and not the inherent interests of children. Social and cultural supports, such as spelling bees, social and parental valuation of school achievement, and so forth, are thus likely to be needed to support children's investment in school learning. A second implication is that schooling and instructional activities must to some degree organize the behavior of children such that they engage in activities---effective instructional activities---in which they otherwise would not engage. In essence, instructional materials, lesson plans, and teachers must organize and guide children's academic learning, because it cannot be assumed that children's “natural curiosity” will result in an interest in all academic domains or result in the motivation to engage in the activities that will foster the mastery of these domains.

CONCLUSIONS

An evolutionary approach to cognition and development provides a much needed anchor for conceptualizing academic learning and for guiding instructional research and practice. An evolutionarily informed science of academic development is in fact the only perspective that readily accommodates basic observations that elude explanation by other theoretical perspectives (Geary, 1995). It follows logically from the evolutionary approach that children will easily learn the language of their parents and competencies in the other primary domains shown in Figure 19.1, and do so without formal instruction. However, years later, many of these children will have difficulty learning to read and write, and difficulty in many other academic domains, even with formal instruction. The differences in the ease of learning these primary and secondary competencies follow readily from the evolutionary perspective.

More precisely, much of the learning associated with primary domains occurs automatically and effortlessly, because the brain and mind of children have been designed by selections pressures for learning in these domains; specifically, adapting inherent but skeletal brain and cognitive systems to the nuances of the local social, biological, and physical ecologies (Geary & Huffman, 2002; Gelman, 1990). Learning in secondary domains, in contrast, requires co-opting the brain and cognitive systems that define this folk knowledge, and adapting them for uses for which they were not designed. The process of adapting these systems is academic learning and is effortful because it requires sustained attentional control and working memory resources, as I described earlier (see also Geary, 2005). I am not arguing that the issues outlined here and elsewhere (Geary, 1995) are the final word on the relation between evolved social and cognitive biases and academic development. Rather, they should be viewed as the blueprint for conceptualizing academic development and guiding instructional theory and research. There is much to be learned about the specifics of folk knowledge and associated inferential biases, and still more to be learned of their relation to academic learning.

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