Chapter 9
Evolution and Children's Cognitive and Academic Development

David C. Geary and Daniel B. Berch

Natural selection is the unifying theory for all of the life sciences and one of humanity's most important scientific accomplishments (Darwin, 1859). As living organisms, human behavior, cognitive biases, and other traits are necessarily a reflection of the survival and reproductive pressures experienced by our ancestors, and as such, the study of the here-and-now development and expression of these traits can be situated in an evolutionary context. This is not to say that social context does not influence human behavior; it does. Rather, a deep understanding of how evolution works will provide insights into human behavior and development that are not fully achievable from other theoretical perspectives. Unfortunately, the power of evolutionary theory has not been fully appreciated by many psychologists or social scientists more generally, with of course the exceptions represented in this volume and a few others. In this chapter, we examine cognitive and academic development from an evolutionary perspective to provide a cohesive framework for understanding children's ability and motivation to learn evolutionarily novel competencies in modern schools, such as reading, writing, and arithmetic.

Cognitive Development

A complete understanding of any trait requires evolutionary analysis on four levels, as outlined by Tinbergen (1963): The ultimate selection pressures that resulted in the evolution of the trait; the function of the trait in terms of increasing survival

D.C. Geary (✉)
University of Missouri, Columbia, MO, USA
e-mail: GearyD@Missouri.edu

D.B. Berch
University of Virginia, Charlottesville, VA, USA
e-mail: dberch@virginia.edu

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prospects; the proximate, reductive mechanisms that support the here-and-now operation of the trait; and the development of the trait. As Tinbergen noted, "All concerned agree that a complete understanding of behavior requires an understanding of its ontogeny, just as morphologists agree that it is not sufficient to understand the adult form, but also the way in which this develops during ontogeny" (Tinbergen, 1963, p. 423). Our focus is on development, specifically aspects of children's cognitive development that are likely to be universal and the experiences and mechanisms that support this development. One cannot actually study development without first determining or at least speculating as to what it is that develops. We do this in the next two sections and then move to a discussion of how cognition develops in children and finally the evolution and function of the domain general abilities of working memory and fluid intelligence.

Function of Mind and Brain

Evolution shapes brains and minds such that they are biased to attend to and process the classes of information that were correlated with survival and reproductive outcomes during the species' evolutionary history. Brains and minds also organize behavior toward the achievement of these outcomes, which Geary (2005) described as a "motivation to control." This is not an explicit motivation, but rather a heuristic that allows us to more easily understand the function of behavior. Consider as an example the well-documented differences in beak size and shape across the many species of finch that reside on the Galapagos islands (Darwin, 1845; Grant, 1999), as shown in Fig. 9.1. These reflect differences in species' specialization in different types of food, such as smaller or larger seeds. When combined with a bias to attend to the appropriate seeds and engage in associated foraging behaviors (e.g., cracking open seed shells), these physical traits allow the birds to gain control of these foods. Having birdbrains, they of course have no explicit awareness of what they are doing or an explicit motivation to control. This heuristic nevertheless allows one to readily see how these perceptual, behavioral, and physical traits coevolved because they enable successful seed foraging or more abstractly successful resource control.

The developmental period is an evolved trait in and of itself, and any lengthening of this period necessarily results in delayed reproduction. The costs of delayed reproduction generally include fewer offspring during the reproductive lifespan and elevated risk of dying before having the opportunity to reproduce at all. An extended period of immaturity must therefore result in cognitive, behavioral, or social changes that enhance resource control in adulthood. Bjorklund and Beers (this volume) refer to these as deferred adaptations—skills that emerge over the course of development that function to improve outcomes in adulthood—and this is our focus here; ontogenetic adaptations, those that enable developing organisms to negotiate specific developmental tasks, are important as well but are not considered here (see Bjorklund & Ellis, 2014). We begin by outlining broad classes of information, or folk domains, that were likely important for survival and reproductive prospects during our

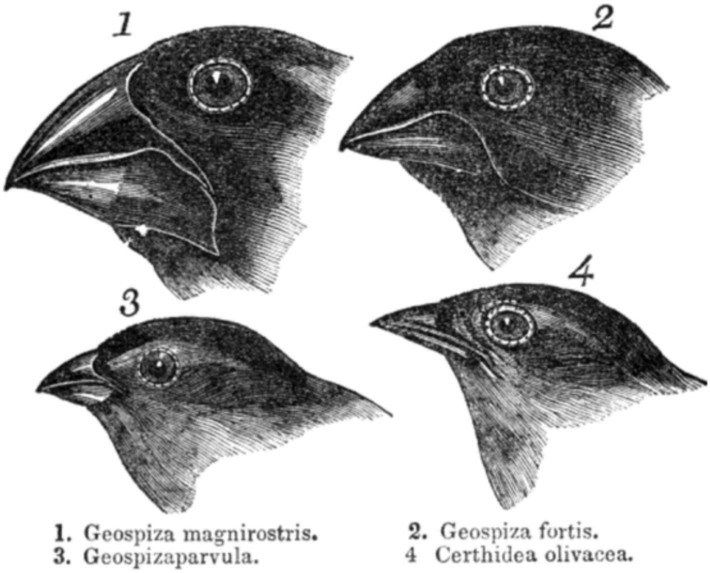

Fig. 9.1 Four species of finch from the Galápagos islands; (1) Large ground finch (*Geospiza magnirostris*); (2) Medium ground finch (*G. fortis*); (3) Small tree finch (*Camarhynchus parvulus*); (4) Warble finch (*Certhidea olivacea*) from *Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. Beagle round the world, under the Command of Capt. Fitz Roy, R.N. (2nd edition), by C. Darwin, 1845, London:* John Murray, p. 379

evolutionary history, followed by a discussion of children's behavioral and cognitive biases and developmental changes in these competencies that likely enhanced these prospects.

Folk Domains

All living organisms have to cope with the competing interests of members of their own species, need to exploit (prey) and avoid being exploited by other species (predators), as well as cope with the realities of the physical world. These classes of information have also emerged in studies of children's unschooled cognition and in studies of unschooled adults in traditional populations and are often termed folk psychology, folk biology, and folk physics, respectively (Atran, 1998; Geary, 2005; Gelman, 2003; Leslie, Friedman, & German, 2004; Medin & Atran, 1999; Mithen, 1996; Wellman & Gelman, 1992). *Folk domains* represent universal forms of knowledge and competencies that emerge from a combination of inherent cognitive biases and evolutionarily expectant experiences. The latter results from self-initiated activities that give rise to experiences that in turn elaborate on inherent biases and flesh out folk knowledge such that it is adapted to local conditions (Gelman, 1990; Greenough, Black, & Wallace, 1987), as elaborated in *Mechanisms*. In Fig. 9.2, we

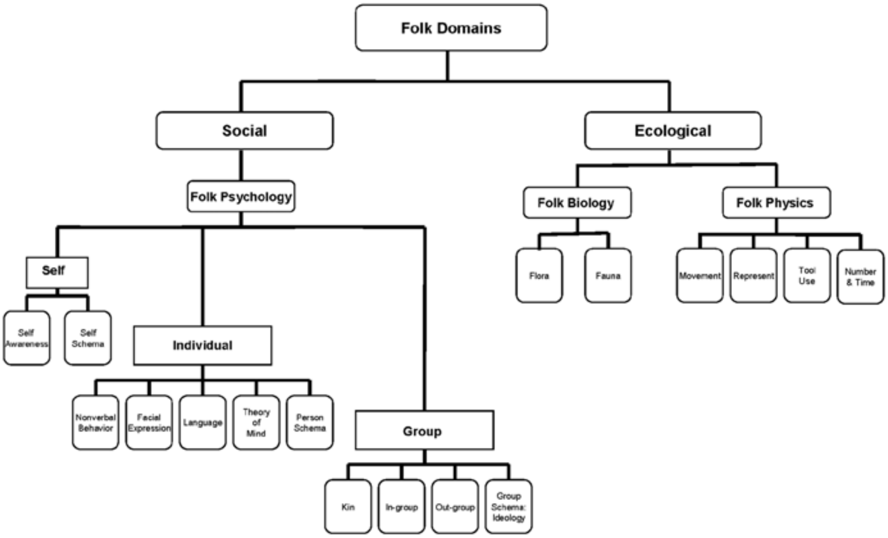

Fig. 9.2 Evolutionarily salient information-processing domains and associated cognitive modules that compose the domains of folk psychology, folk biology, and folk physics. Adapted from "*The origin of mind: Evolution of brain, cognition, and general intelligence*," by D. G. Geary, 2005, p. 129. Copyright 2005 by American Psychological Association

present a taxonomy of folk competencies and knowledge (Geary, 2005; Geary & Huffman, 2002). Functionally, these abilities evolved because they allowed our ancestors to focus their behavior on attempts to achieve access to and control of the social (e.g., finding a mate), biological (e.g., food), and physical (e.g., control of rich territory) resources that tended to enhance survival or reproductive prospects during human evolution.

Folk Psychology

The evolution of this complex system of cognitive, emotional, and behavioral traits was almost certainly driven by intense social competition and the cooperation that often facilitates competitive ability (e.g., Alexander, 1989; Bailey & Geary, 2009; Dunbar, 1998; Flinn, Geary, & Ward, 2005; Geary, 2005; Humphrey, 1976). This constellation of traits allows people to negotiate social interactions and relationships, and the corresponding social cognitions are largely organized around the self, relationships, and interactions with other people, and group-level relationships (see also Shaw, this volume; Hawley, this volume).

Self. Humans are very likely to be unique among species in their awareness of their emotional and mental states and their ability to compare and contrast their unobservable traits (e.g., personality, intelligence) with those of others. *Self-awareness* is a conscious representation (in working memory) of the self as a social being and of one's relationships with other people (e.g., Harter, 2006), and may have been evolutionarily preceded by visual self-recognition (Butler & Suddendorf, 2014). Self-awareness is tightly related to the ability to mentally time travel; specifically to project oneself backward in time to recall and relive episodes that are of personal importance and to project oneself forward in time to create a self-centered mental simulation of potential future states (Suddendorf & Corballis, 1997; Tulving, 2002), as we elaborate in Variation and the Evolution of Domain General Abilities. *Self-schema* is a long-term memory network of information that organizes knowledge and beliefs about the self, including positive (accentuated) and negative (discounted) traits (e.g., warmth), memories of personal experiences (Fiske & Taylor, 1991; Markus, 1977), and self-efficacy—beliefs about one's ability to achieve a goal in various domains (Bandura, 1997). Self-schemas can regulate, at least to some extent, goal-related behaviors; specifically, where one focuses effort and whether or not one will persist in the face of failure.

Individual. Common one-on-one human relationships can be found across societies, including attachment between a parent and a child and friendships (Bugental, 2000; Caporael, 1997). Although there are emotional and motivational differences across these relationships, they are all supported by the same suite of folk competencies shown in Fig. 9.2, including the ability to read nonverbal communication signals (e.g., body posture), facial expressions, language, and theory of mind (Adolphs, 2003; Baron-Cohen, 1995; Brothers & Ring, 1992; Humphrey, 1976; Leslie, 1987; Pinker, 1994; Wellman, 2014: Wellman, Fang, Liu, Zhu, & Liu, 2006; Wellman, Fang, & Peterson, 2011; Wellman & Liu, 2004). Theory of mind represents the ability to make inferences about others' desires, beliefs, and emotional states, and awareness that other people can differ on these. This is a set of competencies that may be especially developed in humans (Leslie et al., 2004) and are important in educational contexts (e.g., in students' making inferences about the intentions of teachers and teachers' understanding of the beliefs of students; Gopnik & Wellman, 2012). In any case, all of these competencies are engaged during the dynamics of one-on-one social interactions and provide the functional competencies needed to understand and modulate the dynamics of the interaction.

The integration of these cognitive systems with motivational and emotional systems provides the basis for the development and maintenance of long-term relationships and the development of *person schema*. People develop these schemas for familiar people and people for whom future social relationships are expected (Fiske & Taylor, 1991). The schema is a long-term memory network that includes representations of the other persons' physical attributes, especially race, sex, and age, as well as memories for specific behavioral episodes, and the same warmth and competence traits associated with the self-schema (Schneider, 1973). This knowledge allows people to better understand and predict the behavior of familiar others (Kahneman & Tversky, 1982).

Group. In all cultures, people parse the world into social groups, largely in terms of kinship, in-groups and out-groups, and group schema. An evolved bias to differentially favor kin over nonkin is found in all species and should not be surprising (Hamilton, 1964). In-groups and out-groups are constellations of people with whom one has shared interests and cooperative relationships and people with competing interests, respectively; out-groups need not be competing groups, but the salience of "our group" and "the other group" is more prominent during times of conflict (Fiske, 2002). In traditional societies, in-groups and out-groups are often determined by kinship, but this is not always the case (e.g., Macfarlan, Walker, Flinn, & Chagnon, 2014). People have more positive attitudes and beliefs about members of their in-group and more negative and often hostile attitudes and beliefs about members of out-groups, especially when the groups are competing (Fiske & Taylor, 1991; Hewstone, Rubin, & Willis, 2002; Horowitz, 2001). *Group schema* is an ideologically based social identification, as exemplified by nationality and religious affiliation (Abrams & Hogg, 1990). These ideologies allow for the formation of larger groups than would be possible based only on personal relationships. These large cooperative groups are particularly advantageous during between-group conflicts, given the competitive advantage that results from being a member of a large group (Alexander, 1990).

Folk Biology

Analogous to species' variation in beak size among Darwin's finches, there are species-specific brain, cognitive and behavioral specializations that enable the location and manipulation (e.g., raccoons, *Procyon lotor*, cleaning of food) of edible plants, fruits, and nuts, as well as the location and capture of prey species (e.g., Barton & Dean, 1993; Huffman, Nelson, Clarey, & Krubitzer, 1999). The folk biological competencies represent the most rudimentary cognitive specializations that support humans' ability to learn about, identify, and secure biological resources in the wide range of ecological niches occupied by our species (Atran, 1998; Caramazza & Shelton, 1998; Malt, 1995; Medin & Atran, 2004). These competencies emerge from a combination of biases and experiences in the ecology and support hunting, gathering, and horticulture in traditional societies.

There is both cross-cultural variation in the extent and organization of folk biological knowledge and a universal core. As a reflection of the latter, people throughout the world are able to categorize the flora and fauna in their local ecologies and show similar categorical and inferential biases when reasoning about these species (Atran, 1998; Berlin, Breedlove, & Raven, 1966). Through the study of this knowledge across traditional societies, "it has become apparent that, while individual societies may differ considerably in their conceptualization of plants and animals, there are a number of strikingly regular structural principles of folk biological classification which are quite general" (Berlin, Breedlove, & Raven, 1973, p. 214). Bailenson, Shum, Atran, Medin, and Coley (2002) asked groups of novices and bird experts from the United States and Itza' Maya Amerindians (Guatemala) to classify about 100 birds from their region and from the region of the other group. There were similarities in the classifications of all three groups, as well as differences. The classification system of US experts and the Itza' Maya was more similar to the scientific taxonomy of these species than that of the US novices. For the Itza' "their consensual sorting agrees more with (western) scientific taxonomy than does the consensual sort of US non-experts. This difference held for both US birds and Tikal birds" (Bailenson et al., 2002, p. 24).

Bailenson et al.'s (2002) findings for novices are not unique; without sufficient experience with the natural world (e.g., children living in modern urban areas), only rudimentary aspects of folk biology develop (Medin & Atran, 2004). With sufficient experience, people develop at least a three-level organization to their knowledge of the biological world. The most general level—corresponding to the kingdom level in the scientific classification—is shown in Fig. 9.2. People further subdivide flora and fauna into classes of related species, including birds, mammals, and trees, and then more specific species, such as bluebirds (*Sialia*) and robins (*Turdus*).

Knowledge of the species' morphology, behavior, growth pattern, and ecological niche (e.g., arboreal versus terrestrial) help to define the *essence* of the species (Atran, 1994; Malt, 1995). The essence is a species schema, analogous to the person schema, and includes knowledge of salient and stable characteristics (e.g., Medin et al., 2006). This knowledge enables use of mental models of flora and fauna for representing and predicting the likely behavior of these organisms (e.g., seasonal growth in plants). The combination of folk biological categories, inferential biases, and knowledge of the species' essence allows people to use these species in evolutionarily significant ways (Figueiredo, Leitão-Filho, & Begossi, 1993, 1997).

Folk Physics

Folk physics, as noted, enables organisms to negotiate the physical world, as in finding food, shelter, or mates and avoiding potential threats (Dyer, 1998). Our inclusion of movement and representation in Fig. 9.2 is based in part on Milner and Goodale's (1995) analysis of the functional and anatomical organization of the visual system. They argue that the systems for movement and representation are functionally and anatomically distinct, but interact. Indeed, there are examples of distinct visuomotor pathways for a variety of movement-related functions, such as predator avoidance and navigating around obstacles. Barton and Dean (1993), for instance, examined the relations among the number and size of neurons in one specific visual pathway and predatory behaviors within four groups of mammals, *Rodentia*, *Primates*, *Carnivora*, and *Marsupials*. Within each of these groups, species were classified as more (i.e., diet heavily based on prey capture) or less (e.g., heavy reliance on fruits) predatory. Predatory species had more and larger neurons in this visual pathway than did their less predatory cousins, but there were no cross-species differences in the volume of adjacent visual pathways not related to prey capture.

The search for prey, shelter, and other resources requires systems for navigating in three-dimensional space (Gallistel, 1990; Shepard, 1994). Studies of a variety of mammalian species reveal that organisms have egocentric and allocentric views of this space (Byrne, Becker, & Burgess, 2007; Maguire et al., 1998). The egocentric representation is what the organism sees, including objects and locations with respect to itself (Byrne et al., 2007). The allocentric system codes for large-scale geometric relations and positioning of objects in space independent of the organism. Both systems work conjointly to enable the organism to remain oriented and goal-focused while moving in space. The allocentric representation may result in an implicit three-dimensional analog map that codes the geometric relations among features of the environment and enables navigation by means of dead reckoning; movement from one place to another on the basis of geometric coordinates (Gallistel, 1990). Human navigation involves both the egocentric and allocentric systems, but for different aspects of navigation (Byrne et al., 2007). A few species, especially humans, can also generate explicit cognitive representations of egocentric and allocentric physical space in working memory (Kuhlmeier & Boysen, 2002).

Tool use is found in one form or another in all human cultures and enables people to more fully control biological resources in the local ecology (Murdock, 1981). The neural, perceptual, and cognitive systems that support tool use have not been as systematically studied as the systems that support movement and representation in space. On the basis of brain imaging studies and cognitive deficits following brain injury, Johnson-Frey (2003) concluded that homologous brain regions are involved in basic object grasping and manipulation in humans and other primates. At the same time, it is clear that humans have a much better conceptual understanding of how objects can be used as tools (Pellegrini, this volume; Povinelli, 2000), and their definition of how these objects can be used is influenced by the inferred intentions of potential tool users (Bloom, 1996). At the core, human tool use involves the ability to mentally represent an object as a potential tool, to manipulate this mental representation to explore the different ways in which the object might be used, and finally to integrate such representations with active tool use (Lockman, 2000; Pellegrini, this volume).

Finally, we have classified organisms' intuitive sense of time and number—for instance the approximate quantity of food available in two distinct foraging patches—as an aspect of folk physics. These competencies support the representation and discrimination of the exact quantity of small collections of items and the approximate quantity of larger collections or continuous quantities (e.g., area; Feigenson, Dehaene, & Spelke, 2004; Geary, Berch, & Mann Koepke, 2015) and appear to be integrated with systems for representing the passage of time (Meck & Church, 1983).

Folk Heuristics and Attributional Biases

The behavioral features of folk domains can be described as "rules of thumb" (Gigerenzer, Todd, & ABC Research Group, 1999). The information to which the folk systems are sensitive is processed implicitly and the behavioral component is more or less automatically executed (Simon, 1956), although people have the ability to override these if necessary (below). Barton and Dean's (1993) analysis of the visuomotor pathway in mammals as related to prey-capture illustrates the point. Cells in this system are likely to be sensitive to the movement patterns of prey species and enable the coordination of these perceptions with behaviors necessary to capture this prey. The organization of this integrated neural system results in built-in attentional and perceptual biases and an implicit understanding of how to catch prey. Competence at prey capture is likely to improve with experience, including play behavior during development for many species of mammal, but the foundation is built-in (Burghardt, 2005).

The same applies to folk knowledge more generally. For instance, during face processing the pattern generated by the shape of the eyes and nose provides information about the sex of the individual, whereas the pattern generated by the configuration of the mouth provides information about the individual's emotional state (Schyns, Bonnar, & Gosselin, 2002). The receiver automatically and implicitly processes this information, and in turn, expresses corresponding emotional and other social signals (e.g., smile) as appropriate. The receiver may also make implicit decisions regarding the interaction, but these do not need to be explicitly represented in working memory and made available to conscious awareness (see below). These quick, rule-of-thumb decisions can be based on automatically generated feelings and other social information. Angry facial expressions, for example, often generate fear and behavioral avoidance and can do so in a matter of seconds (Damasio, 2003).

Explicit inferential and attributional biases are also features of folk heuristics, as least for humans. People often attribute their failures to achieve desired goals, for instance, to bad luck or biases in other people. The tendency to make attributions of this type has the benefit of maintaining effort and control-related behavioral strategies in the face of inevitable failures (Heckhausen & Schulz, 1995). Social attributional biases that favor members of the in-group and derogate members of out-groups are well-known (Fiske, 2002) and facilitate intergroup competition (Horowitz, 2001). The folk-biological essence allows people to make inferences (e.g., during the act of hunting) about the behavior of members of familiar species and about the likely behavior of less familiar but related species (Atran, 1998). Attributions about causality in the physical world are also common (Clement, 1982).

From an educational perspective, it is important to note that these biases may provide good enough explanations for day-to-day living and self-serving explanations for social and other phenomena. However, an evolved functional utility in terms of everyday living in traditional settings does not mean the explanations are necessarily scientifically accurate, as aptly described by Sinatra and Danielson (this volume; also Shtulman, 2006). In fact, *descriptions* of psychological, physical, and biological phenomena are often correct (Wellman & Gelman, 1992), but many of the explicit *explanations* of the *causes* of these phenomena are objectively and scientifically inaccurate. People can, for instance, describe the trajectory of a thrown object, but they do not understand the forces that produce this motion (Clement, 1982).

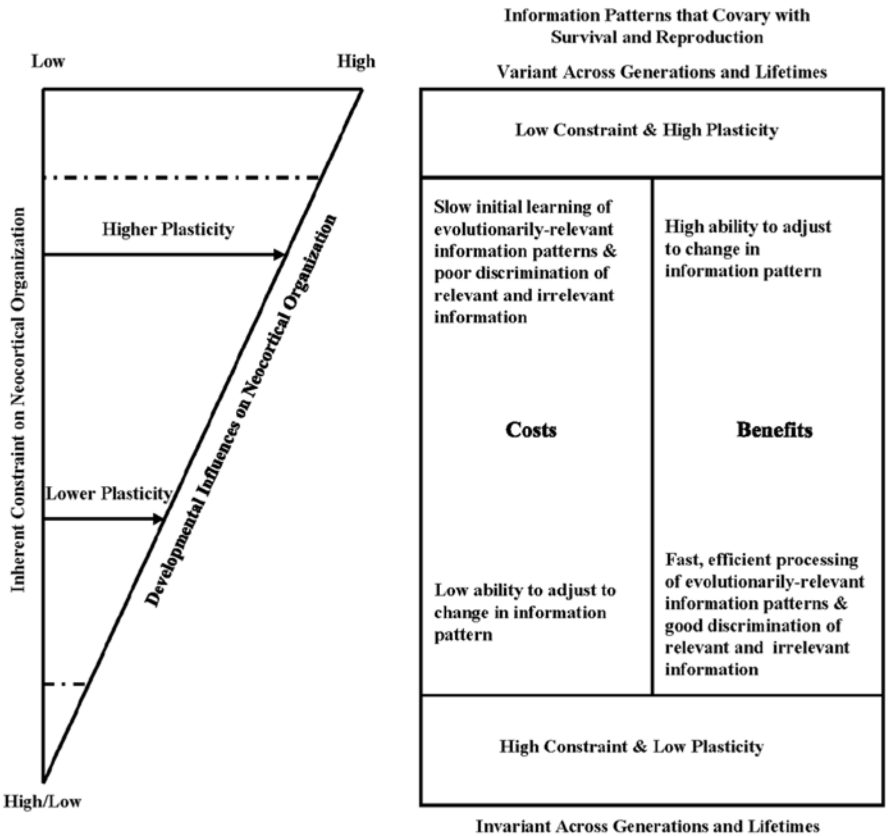

Fig. 9.3 The triangle represents the relation between inherent constraint and the influence of developmental experience on brain organization and cognitive functions. The length of the line segments with arrows represents the corresponding degree of plasticity. The area above (no inherent constraint) and below (no plasticity) the dashed lines represents extreme views that few theorists posit for humans. The rectangle highlights cost-benefit trade-offs that are predicted to influence the evolution of brain and cognitive plasticity. Adapted from “Brain and cognitive evolution: Forms of modularity and functions of mind,” by D. C. Geary and K. J. Huffman, 2002, Psychological Bulletin, 128, p. 668. Copyright 2002 by the American Psychological Association

Mechanisms

Given the wide range of ecological and social niches occupied by humans, it is unlikely that most folk knowledge is “prepackaged” either fully or unfolds in a predetermined manner across development. Rather, the extent of inherent constraint or developmental plasticity might vary with the temporal and spatial variability in the associated ecological or social pressures and attendant information patterns that need to be processed to cope with these (Geary, 2005; Geary & Huffman, 2002). These tradeoffs are represented in Fig. 9.3. Strong neurobiological and cognitive constraints direct attention and behavior toward evolutionarily significant information patterns, and in doing so, reduce the number of false positives (Gelman, 1990). The cost is reduced plasticity of these systems. Weak constraints increase the risk of false positives, but result in enhanced system flexibility. The cost-benefit tradeoffs should be modulated by the variability of associated information patterns.

The three-dimensional structure of the physical world results in stable information patterns that would, in theory, result in the evolution of constrained systems for detecting and acting on this information (Gallistel, 1990; Shepard, 1994). Of course, movement in space creates variation in the information to which the organism is exposed and advantages to systems for remembering location and for navigating, systems that would be anchored by the more constrained folk physics systems (O'Keefe & Nadel, 1978). Human social dynamics, in contrast, are necessarily more dynamic and we would anticipate greater plasticity in folk psychological systems, but constraints are still needed. As noted, variation in facial expression provides dynamic information about the individuals' current emotional state, but would be missed if not anchored by attentional focus to specific facial features (Baron-Cohen, 1995; Schyns et al., 2002).

In the context of the tradeoffs associated with constraint and plasticity, the developmental period provides opportunity to adjust folk systems to the nuances of the local geography, flora and fauna, and social relationships (Geary, 2004; Geary & Bjorklund, 2000). The mechanisms for adapting folk systems to local variation must include behaviors that result in exposure to this variation, as we describe in the first section. In the second, we provide discussion of the nature of the plasticity of folk systems during cognitive development.

Behavioral. In theory, children's self-initiated engagement of the ecological and social contexts in which they are embedded provides the experiences needed to flesh out the plastic components of folk domains (Bjorklund & Pellegrini, 2002; Gopnik & Wellman, 2012; Greenough et al., 1987; Scarr, 1992). These behavioral biases are common juvenile activities, including social play, exploration of the ecology, and experimentation and play with objects (see also Bjorklund & Beers, this volume; Lancy, this volume; Toub et al., this volume; Pellegrini, this volume). A critical aspect of these experience-expectant processes is that they result in automatic and effortless modification of plastic features of folk systems and implicit knowledge.

An example is provided by infants' early attentional and behavioral biases. They attend to human faces, movement patterns, and speech in ways that reflect the inherent organizational and motivational structure of the associated folk psychological systems (Freedman, 1974). These biases evolved because of the evolutionary significance of social relationships and result in the re-creation of the microconditions (e.g., parent–child interactions) associated with the evolution of the corresponding systems (Caporael, 1997). Attention to and processing of this information provides exposure to the within-category variation needed to adapt the architecture of these systems to variation in parental faces, behavior, and so forth (Gelman & Williams, 1998). In this example, these experience-dependent modifications allow infants to discriminate the voice of their parents from the voice of other people with only minimal exposure. 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 mother and discriminate her voice from that of other women (Kisilevsky, 2003).

In some ways, the experience-dependent fleshing out of folk systems is similar to the constructivist view of learning, but with a very important difference (Geary, 1995). A strict constructivist view does not discriminate learning in school from elaboration of folk knowledge resulting from engagement in evolutionarily expectant activities (see Gray, this volume). In our view, it does not follow that there are inherent anchors and behavioral biases to guide the learning of algebra or most other evolutionarily novel academic material in the same way there are anchors and social biases that allow children to learn about their social world, for instance (see Geary, 2007; Sweller, 2012, 2015, this volume). As we elaborate below, there may well be a gray area in which evolutionarily expectant activities, such as play, can be used to facilitate some aspects of biologically secondary (i.e., evolutionarily novel) learning, as touched upon in Bjorklund and Beer's (this volume) and Toub et al.'s (this volume) chapters. It does not follow, however, that all aspects of secondary learning can be acquired in this way, and *determining the strengths as well as limitations of evolved behavioral biases in the promotion of secondary learning has profound implications for how to improve educational outcomes*.

Cognitive. Debate regarding the origins of human knowledge have spanned several millennia and continue to this day (Carey, 2009; Gelman, 1990; Gelman, 2003; Gopnik & Wellman, 2012; Newcombe, 2011; Spelke & Kinzler, 2007, 2009; Spencer et al., 2009). There is some debate regarding whether or not human cognition and cognitive development is influenced by inherent constraints at all (Spencer et al., 2009), but the focus of debate largely centers on the extent and nature of any such constraints, in keeping with the tradeoffs between constraint and plasticity noted above (Fig. 9.3).

There is agreement that inherent constraints are found for some domains but not others; they are based on at least implicit concepts (e.g., of quantity or living vs. nonliving things) applied to categories of natural things (vs. man-made) and they support inferences about causality related to these things. As an example, young children and even infants discriminate between objects that produce self-generated movement, as do living organisms, and those that only move when acted upon by some other object (e.g., movement after being struck by another object) or a person. Moreover, they implicitly infer that living things have causal intentions—infants and young children behave as if they expect movement of living things to be directed toward a goal—and that living things have "innards" that represent their "essence" (e.g., all elephants have the same essence) and that enable goal-directed behavior (e.g., Gelman, 1990; Gelman, 2003; Setoh, Wu, Baillargeon, & Gelman, 2013). Nonliving things do not have an essence per se, but they do have physical properties, such as solidity (two objects cannot occupy the same space at the same time), that infants appear to implicitly expect (Spelke, Breinlinger, Macomber, & Jacobson, 1992).

There is also agreement that infants' and young children's early conceptual constraints either become elaborated during development and with experience, or they are superseded by more powerful concepts, that is, concepts that provide a more functional and accurate understanding of the organism or object (Carey, 2009; Gelman, 1990; Gelman, 2003; Gopnik & Wellman, 2012; Spelke & Kinzler, 2007); this does not necessarily mean that the original naïve concept disappears, as it may exist alongside the new conceptual understanding. How to best represent initial constraints and associated conceptual change is debated, but regardless of the details the key idea is that inherent constraints and concepts form the scaffolding for children's emerging understanding of natural things, that is, the physical world, other species, and our own species. There is not yet a consensus on the extent of core domains and their organization, but we believe the folk domains shown in Fig. 9.2 are a reasonable approximation.

In any case, an experience-dependent elaboration of nascent folk domains melds easily with humans' long developmental period (Bogin, 1999), and children's self-initiated behaviors described in the section above. In this view, behavioral and cognitive development coevolved and is co-expressed during childhood. Early constraints result in attentional and behavioral biases that in turn result in the experiences needed to adapt these systems to the nuances of local conditions. In keeping with Lancy's (this volume) description of the ethnographic record, children's self-initiated activities do indeed result in their acquisition of human universals (e.g., language) and culture-specific competencies needed to be successful in adulthood in traditional societies without much adult intervention. A fundamental and critical issue is whether the activities that result in the acquisition of culture-specific competencies in traditional societies are sufficient for the acquisition of culture-specific competencies in modern societies.

Variation and the Evolution of Domain General Abilities

Humans can inhabit multiple social and ecological niches, in part because folk systems can be adapted to variation in local conditions during development. These folk systems and associated heuristics enable people to effortlessly cope with a variety of ecological and social demands, as represented by the left section of Fig. 9.4. The associated folk heuristics are toward the invariant end of the continuum because developmental adaptation of these systems is in the context of inherent constraints, that is, the systems (e.g., language) are plastic but only to some extent. If this were not the case, the folk abilities shown in Fig. 9.2 would not be universal, but they appear to be. To be sure, elaboration of one folk domain (e.g., folk biology) or another or the extent to which some attributional biases are favored over others—for instance, the belief that people from other groups are hostile rather than cooperative—varies from one context to the next, but all of this variation is anchored by the same skeletal folk structure. These systems, however, are not sufficient for coping with unexpected (or inexperienced) conditions, that is, novelty. Novelty is defined as conditions that cannot be coped with using only evolved or learned heuristics. For instance, most social dynamics are routine and do not require explicit evaluation of

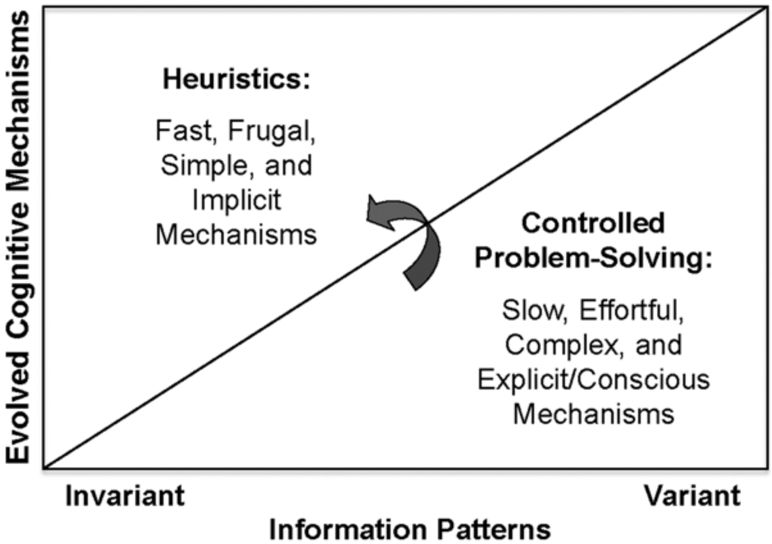

Fig. 9.4 The types of cognitive mechanisms that operate on ecological or social information. These are predicted to vary with the extent to which that information tended to be invariant (resulting in evolved heuristics) or variant (resulting in evolved problem-solving mechanisms) during the species' evolutionary history and during a typical lifetime. Adapted from "*The origin of mind: Evolution of brain, cognition, and general intelligence*," by D. C. Geary, p. 168. Copyright 2005 by the American Psychological Association

the behavior and intentions of other people. During times of conflict, however, behavioral predictability can result in a disadvantage and use of novel arguments or behavioral strategies (e.g., tactics during large-scale conflicts) can result in an advantage because competitors will not have readily accessible counter strategies available to them.

The variant end of the continuum shown in Fig. 9.4 represents conditions that are not readily accommodated by evolved heuristics. Coping with these conditions requires explicit problem-solving abilities. Theories regarding the pressures that drove the evolution of these abilities are debated and beyond the scope of this chapter, but include climatic change (e.g., winter), hunting demands, and social competition (Alexander, 1989; Ash & Gallup, 2007; Bailey & Geary, 2009; Geary, 2005; Kaplan, Hill, Lancaster, & Hurtado, 2000; Potts, 1998). The key idea across all of these models is that there are advantages to being able to anticipate and plan behavioral strategies to cope with novelty and change. Geary (2005) proposed that the core mechanism for coping with novelty and change is the *autonoetic mental model*. These are explicit attention-driven mental representations—supported by working memory—of situations that are centered on the self and one's relationship with other people or one's access to biological and physical resources and support the generation and rehearsal of behavioral strategies for gaining access to these resources. As mentioned earlier, the representations often involve a form of mental time travel; specifically, simulations of past, present, or potential future states that can be cast as images, in language, or as memories of personal experiences (Paivio, 2007; Suddendorf & Corballis, 1997; Tulving, 2002).

A key component is the ability to create a mental representation of a desired or fantasized state and to compare this to a mental representation of one's current situation. The fantasized world is one in which the individual is able to control social (e.g., social dynamics), biological (e.g., access to food), and physical (e.g., shelter) resources in ways that would have enhanced survival or reproductive prospects during human evolution. The mental simulation creates a problem space, including an initial state (one's current circumstances) and a goal state (the fantasized outcome). The proposal is that people's ability to explicitly problem-solve in ways that reduced the difference between the initial and goal states evolved as a core feature of autonoetic mental models. The details are described in Geary (2005), but the gist is the evolution of weak problem-solving methods such as means-ends analyses (Newell & Simon, 1972) was driven by the competitive advantage that results from the ability to inhibit evolved or learned heuristics and to then generate and mentally rehearse more novel social-competitive strategies and to mentally generate the strategies that support greater control of nonsocial resources, as with constructing tools and shelters and planning hunts.

Despite the extraordinary ability to mentally simulate future conditions and problem-solve to devise behavioral goal-directed strategies, people's reasoning about such conditions is influenced by many documented biases that often result in incorrect inferences or less-than-optimal solutions (e.g., Evans, 2002; Johnson-Laird, 1983; Oaksford & Chater, 1998; Tversky & Kahneman, 1974). Some of these biases result from presenting experimental tasks in evolutionarily novel contexts (Cosmides, 1989), and others simply reflect beliefs that are good enough for day-to-day living, albeit they are often inaccurate from a scientific perspective (Clement, 1982; Sinatra & Danielson, this volume). In any event, there are individual differences in the ability to inhibit evolved or learned heuristics and prior knowledge and to generate abstract, decontextualized representations of the problem at hand. There may be even more individual variation in the ability to use formal logic (e.g., deduction based on a set of premises) to operate on these abstract representations (Stanovich, 1999). People who are able to do so can eliminate many reasoning biases and thereby produce more optimal solutions (Stanovich & West, 2000).

But even so, people who are capable of formal logical reasoning often commit common reasoning errors (Stanovich & West, 2008). This is because use of formal logic and explicit problem-solving requires the effortful suppression of heuristics and prior knowledge and, as a result, people use these systems only when necessary. This makes sense because folk and learned knowledge and heuristics are typically good enough for achieving most day-to-day goals, and suppression of these to construct new strategies is only necessary when currently available ones are not effective (i.e., the conditions are toward the variant end in Fig. 9.4). Individual differences in the ability to suppress heuristics and prior knowledge and beliefs and engage in formal logical thinking are independently related to measures of general fluid intelligence (below), syllogistic reasoning, and cognitive flexibility, that is, openness to new ideas and alternative explanations of the same phenomenon (Stanovich & West, 2000; West, Toplak, & Stanovich, 2008).

The important point for us is that the ability to logically and critically evaluate evidence and to engage in other forms of formal problem solving, as is necessary for many aspects of learning in school, does not come easily to most people and requires the suppression of folk biases (see Sinatra & Danielson, this volume; Sweller, this volume). In theory, the more evolutionarily novel the academic content—such as systems of equations in algebra versus understanding the cardinal value of count words—the more effortful is the learning (Geary, 2007). This is because the larger the gap between the conceptual base of the academic domain, such as the principles of natural selection, and the conceptual base and biases that are components of folk systems, such as folk biology (see Shtulman, 2006; Sinatra & Danielson, this volume), the more likely folk beliefs will interfere with learning academic content; the scientifically accurate view of how species change across generations in this case. For the latter to occur, folk biases must be inhibited and the mechanisms that enable explicit goal-directed problem solving need to be engaged.

Working Memory, Intelligence, and Evolutionarily Novel Learning

Geary (2005) suggested the working memory and problem-solving competencies that support the use of autonoetic mental models define the core of general fluid intelligence. In other words, more than a century of research on general intelligence has identified the evolved mechanisms that enable humans to cope with and learn from evolutionarily novel situations, those toward the variant end of the continuum in Fig. 9.4, not unlike Cattell's (1963, p. 3) original description, "Fluid general ability … shows more in tests requiring adaptation to new situations, where crystallized skills are of no particular advantage." The details can be found in Geary (2005): The point here is that the result is represented by the arrow at the center of Fig. 9.4, that is, the transfer of information, procedures, and heuristics learned from effortful, controlled problem solving to long-term memory, including semantic and procedural memory. In keeping with Sweller's cognitive load theory (2015, this volume), the eventual result is the learning of new knowledge or problem-solving heuristics that can thereafter be effortlessly applied to solving the once novel problems.

Our main point is that the ability to learn evolutionarily novel information—including reading, writing, and arithmetic—is the result of two types of brain and cognitive plasticity, both of which evolved to enable humans to cope with variation in ecological and social conditions. The first is the plasticity in folk systems that enable them to be adapted to local conditions during development. The second results from the ability to mentally represent and manipulate information in working memory, which in turn creates mental experiences (e.g., rehearsal of information) that enable the top-down modification of folk systems (Damasio, 2003; Geary, 2005). Moreover, the simultaneous activation of multiple folk systems and the representation of corresponding information in working memory appear to result in the ability to link these systems in novel ways (Garlick, 2002; Sporns, Tononi, & Edelman, 2000) and through this create evolutionarily novel, academic competencies (Geary, 2007).

Academic Development

In contrast to universal folk knowledge, most of the knowledge taught in modern schools is culturally specific; that is, it does not emerge in the absence of formal instruction. Geary (1995) termed these competencies biologically secondary because they are built from the biologically primary folk domains discussed earlier. We illustrate the relation between folk domains and secondary abilities in the first section and outline the corresponding premises and principles of evolutionary educational psychology in the second.

Learning to Read

We assume that the building of secondary abilities and knowledge from folk systems is possible because of the two forms of plasticity noted above; plasticity in folk systems themselves and the ability to modify these through top-down processes that support people's generation of autonoetic mental models. In this view and in keeping with Sweller's (2015, this volume) cognitive load theory, the learning of secondary knowledge is supported by the ability to explicitly represent information in working memory and then to use controlled problem solving for learning academic material. Reading provides an example of how this might work.

We assume that reading and writing systems initially emerged, culturally, from the motivation to socially communicate with and attempt to influence the behavior of other people, and if so, they should be built from folk psychological systems (Geary, 2008a; Mann, 1984; Rozin, 1976). Indeed, the core predictors of children's ease of learning to read indicate a strong dependence on language systems (e.g., Bradley & Bryant, 1983; Hindson et al., 2005; Mann, 1984; Stevens, Slavin, & Farnish, 1991; Wagner & Torgesen, 1987). Initially, the critical skills include phonemic awareness—explicit awareness of distinct language sounds—and the ability to decode unfamiliar written words into these basic sounds (e.g., *ba*, *da*). Decoding requires the explicit representation of the sound in phonemic short-term memory and the association of this sound and blends of sounds with letters (e.g., *b*, *d*) and letter combinations, respectively (Bradley & Bryant, 1983).

Individual differences in kindergartners' phonetic processing system (e.g., skill at discriminating similar sounding phonemes) predict the ease with which they learn basic word-decoding skills in first grade (Wagner, Torgesen, & Rashotte, 1994). Children who show a strong explicit awareness of basic language sounds are more skilled than are other children at associating these sounds with the symbol system of their written language. Unlike acquiring a natural language, the majority of children acquire these basic reading competencies most effectively with systematic, organized, and teacher-directed explicit instruction on phoneme identification, blending, and word decoding (e.g., Hindson et al., 2005; Stevens et al., 1991). Skilled reading also requires fluency and text comprehension. Fluency is the fast and automatic retrieval of word meanings as they are read, which is related in part to the frequency with which the word has been encountered or practiced in the past (Sereno & Rayner, 2003). Text comprehension requires an understanding of the meaning of the composition and is dependent, in part, on the ability to identify main themes in the text and distinguish highly relevant from less relevant passages. As with more basic reading skills, many children require explicit instruction in the use of these strategies to aid in text comprehension (Connor, Morrison, & Petrella, 2004; Stevens et al., 1991).

If social communication was the motivation for the development of written systems, then reading comprehension should also be dependent on theory of mind and other folk psychological domains, at least for genres that involve human relationships (Geary, 2010). Most of these stories involve the re-creation of social relationships, complex patterns of social dynamics, and even elaborate person schema knowledge for main characters, as is the focus of literary Darwinism (Carroll, 2011). The theme of many of the most popular genres involves the dynamics of mating relationships (e.g., romance novels) and competition for mates, and often involves use of autonoetic mental models to build social scenarios. One implication is that once people learn to read, they engage in this secondary activity because it allows for the representation of evolutionarily salient themes, particularly the mental representation and rehearsal of social dynamics. Folk biology and folk physics should also result in some people being interested in biological phenomena (e.g., the magazine *Natural History*) and mechanical things (e.g., the magazine *Popular Mechanics*).

The Creation of Culture

All of the academic activities that occur in modern research universities (politics aside) involve the creation of evolutionarily novel information, especially in engineering and the sciences. In fact, scholars of one kind or another have been building an unprecedented store of information and knowledge over the past few thousand years (Murray, 2003; Simonton, 2009). Murray's analysis revealed historical bursts of creative activity (e.g., the Renaissance) that tended to emerge in wealthier cultures with mores that supported individual freedom and that socially and financially rewarded creative expression. The exceptional accomplishments that have produced the modern world have been made by individuals situated in these cultures and who have a unique combination of traits; specifically, high fluid intelligence, creativity (e.g., ability to make remote associations), an extended period of preparation in which the basics of the domain are mastered, long work hours, advantages in certain folk domains, ambition, and sustained output of domain-related products, such as scientific publications (Ericsson, Krampe, & Tesch-Römer, 1993; Lubinski, 2004; Sternberg, 1999).

These components of accomplishment illustrate the interplay between folk knowledge, fluid intelligence, motivation, and the generation of secondary knowledge and illustrate why children's intuitive folk knowledge and learning biases are not sufficient for secondary learning. Modern physics is one of humanity's most significant accomplishments and yet is understood by only a very small fraction of humanity. One reason is that people's naïve understanding of physical phenomena is influenced by the biases that are aspects of folk physics, but differ from the scientific understanding of the same phenomena (McCloskey, 1983). When asked about the motion of a thrown ball, most people believe there is a force propelling it forward, something akin to an invisible engine, and another force propelling it downward. The downward force is gravity, but there is in fact no force propelling it forward, once the ball leaves the thrower's hand (Clement, 1982). The concept of a forward-force, called "impetus," is similar to pre-Newtonian beliefs about motion prominent in the fourteenth to sixteenth centuries. The idea is that the act of starting an object in motion creates an internal force (impetus) that keeps it in motion until this impetus gradually dissipates. Although adults and even preschool children often describe the correct trajectory for a thrown or moving object (e.g., Kaiser, McCloskey, & Proffitt, 1986), reflecting their implicit folk competencies, their explicit explanations reflect this naïve understanding of the forces acting upon the object.

Careful observation, use of the scientific method (secondary knowledge itself; Geary, 2012), and use of inductive and deductive reasoning are necessary to move from an intuitive folk understanding to scientific theory and knowledge. In his masterwork, the *Principia* (Newton, 1995, p. 13), Newton said as much: "I do not define time, space, place and motion, as being well known to all. Only I must observe, that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects." The "vulgar" only understand physical phenomena in terms of folk knowledge and Newton went well beyond this. Newton corrected the pre-Newtonian beliefs about forces acting on objects, but still appears to have relied on other aspects of folk physical systems to complete this work. His conceptualization of objects in motion and the gravitational and rectilinear forces underlying the pattern of this motion were based on his ability to explicitly use visuospatial systems to construct geometric representations of motion and then to apply Euclidean geometry and formal logic to mathematically prove the scientific accuracy of these representations. The explicit and exacting use of formal logic is associated with high general fluid intelligence (Stanovich, 1999), as noted. Despite popular stories and an assumption of an "Aha" insight, Newton devoted an extended period of sustained effort and attention to this work and appears to have been obsessed with understanding physical phenomena (e.g., Berlinski, 2000; White, 1999).

The point is that Newton's efforts transformed the physical sciences and at the same time created a substantial gap between the scientific understanding of gravity and motion and folk beliefs about these same phenomena. The folk intuitions of the fourteenth century natural philosophers were no longer sufficient after Newton.

Fortunately, it is not necessary for students to reconstruct Newton's efforts; in fact, few could do so. But, it is necessary that they come to understand the basics of Newtonian physics. Cognitive and brain imaging studies indicate that giving up folk-physical intuitions and grasping Newton's insights about motion do not come easily, even for college students (Dunbar, Fugelsang, & Stein, 2007; Zimmerman, 2005). The same is true for the theory of evolution, the scientific method, and many other evolutionarily novel innovations and knowledge (Klahr & Li, 2005; Klahr & Nigam, 2004; Shtulman, 2006; Sinatra & Danielson, this volume).

Evolutionary Educational Psychology

The innovative contributions of Newton and others have altered the society and culture in which we live, including substantive increases in the need for formal education. To live successfully in the modern world, children must now acquire a wide range of evolutionarily novel knowledge. To make matters worse, the requisite knowledge is a moving target, because scientific and technological changes are accruing at an accelerated pace, as is the store of literature, poetry, plays, drama, and so forth. How then do we best prepare children to be successful in the modern world? Of course, the modern field of education is focused on this question, but has not been informed by an evolutionary understanding of cognitive development, nor considered the question of how folk abilities can be modified to create secondary competencies. Evolutionary educational psychology is an attempt to bridge evolutionary insights and educational science (Geary, 2007, 2008a). In the sections below, we outline the basic premises and principles of this approach.

Premises. Evolutionary educational psychology is the study of how educational interventions interact with children's folk abilities, biases, and motivations to create secondary abilities and knowledge. The first premise follows from our discussion of folk domains (Fig. 9.2); children have inherent but not fully developed attentional, perceptual, and cognitive systems that support their understanding of universal social, biological, and physical phenomena. The associated concepts and abilities support good enough functioning in traditional contexts, but is not the same as a scientific understanding of the same phenomena.

The second premise is based on the co-evolution of children's behavioral and cognitive development as related to the adaptation of folk domains to local conditions; specifically, children's self-initiated behavioral biases create the same types of experiences that led to the evolution of folk systems and provide the evolutionarily expectant experiences needed for the normal development of these competencies (Caporael, 1997; Greenough et al., 1987; Scarr, 1992). A critical point is that children's primary behavioral activities are directed toward those features of the social, biological, and physical worlds that were recurrent, though variable (e.g., in the facial features of different people), during human evolution, not information relevant to secondary learning. As Lancy (this volume) describes, children also attend to and imitate adults and more competent older children and in this way learn culture-specific knowledge and skills, such as cooking and hunting (e.g., Blurton Jones, Hawkes, & O'Connell, 1997). We have no doubt that children have an evolved motivation to acquire the skills needed to be successful in their culture, but note the gap between the skills needed to be successful in traditional cultures and those needed to integrate into a modern, developed economy. Observation of parental reading may pique children's interest in books, but playing with books does not result in the ability to phonetically decode written words in the same way that playing with a bow and arrow contributes to learning how to use this weapon (Gurven, Kaplan, & Gutierrez, 2006; Toub et al., this volume).

The third premise follows from the first two and the traits of innovators. It is almost certainly the case that these innovators engaged the cognitive systems that support autonoetic mental models—attentional control, working memory, fluid intelligence, explicit problem solving—during the generation of their insights and secondary knowledge. We do not see how it is possible for students to learn this same knowledge without explicitly engaging the same systems (Sweller, this volume).

Principles. Innovators generate new knowledge and technical advances by using fluid intelligence and other less well-understood processes (e.g., creativity) to modify and link together folk systems in novel ways. The useful advances are retained across generations through artifacts (e.g., books) and traditions (e.g., apprenticeships) and accumulate from one generation to the next. The first principle of evolutionary educational psychology is that the cross-generational accumulation of these advances has resulted in a more scientifically accurate understanding of the phenomena that are the foci of folk psychology, folk biology, and folk physics. Darwin's principles of natural selection and Newton's theory of gravity and motion resulted in a gap between people's folk biological and folk physical knowledge and these core principles of modern biology and physics (Clement, 1982; Sinatra & Danielson, this volume). In other words, there is now a substantial and growing gap between the folk knowledge and heuristics that were sufficient for day-to-day living during much of human evolution and the knowledge and competencies needed to function in the modern world.

The second principle is that schools themselves are cultural innovations. They are not found in traditional societies (Lancy, this volume), and only emerged in societies in which scientific and cultural advances created gaps between folk knowledge and the competencies needed to be successful in these societies. In this view, the function of schools is to organize the activities of children, so they can acquire the secondary competencies needed to close the gap between folk abilities and the knowledge needed to be successful in the modern world. The third principle is that secondary competencies are built from primary folk systems, but, unlike the fast implicit learning that adapts folk systems to local conditions, most secondary learning will require the effortful engagement of working memory, explicit problem solving, and fluid intelligence to modify primary systems. As we describe in the next section and as noted by Bjorklund and Beers (this volume) and Toub et al. (this volume), this does not mean that children cannot learn some secondary skills through engagement in primary activities, but we suspect there are limitations to this approach (Gray, this volume, provides a counter argument). Fourth, children's inherent motivational bias to engage in activities that will adapt folk knowledge to local conditions will often conflict with the need to engage in activities that will result in secondary learning. We would then expect the average adolescent to be more interested in peer relationships than high school algebra.

Implications for Research on Instructional Interventions

For the most part, the premises and principles of evolutionary educational psychology are concerned with characterizing the evolved cognitive and motivational biases that may interfere with the acquisition of secondary knowledge and the implications of these dispositions for designing effective instructional methods to enhance secondary learning (see also Sinatra & Danielson, this volume; Sweller, this volume). As Geary (2008a) has previously pointed out, evolutionary educational psychology is not ready for translation into school curricula, although as Sweller notes (2015, this volume) the framework does help to explain many previously documented instructional effects. More generally, "it provides a theoretical foundation for (a) conceptualizing children's learning in school and their motivation to engage in this learning, (b) generating empirically testable hypotheses about learning and motivation, and (c) *discussing implications for understanding and ultimately improving educational outcomes*" (Authors' emphasis; Geary, 2008a, p. 179). In this section, we move beyond a discussion of educational implications by proposing an evolutionarily informed pedagogical framework for generating explicit hypotheses concerning the types of instruction that would most likely improve the acquisition of secondary knowledge, taking into account: (a) the degree to which the secondary information is evolutionarily novel; (b) the species-typicality of the contexts and settings (physical and social) in which these skills are to be learned; and (c) individual differences in various cognitive competencies, motivational dispositions, personality traits, and demographic characteristics that could potentially moderate the effectiveness of any given instructional approach.

Which Is Better: Explicit Formal Instruction or Discovery Learning?

The relative effectiveness of different instructional strategies has been hotly debated in both the academic educational literature and the popular press and touched upon by many of the chapters in this volume (Bjorklund & Beers, this volume; Gray, this volume; Lancy, this volume; Sweller, this volume; Toub et al., this volume). Not infrequently, two opposing types of methods are pitted against one another, as exemplified by the paradigmatic case of whether direct or explicit instruction leads to better learning than unstructured discovery learning (cf. Kirschner, Sweller, & Clark, 2006). Berch (2007) has discussed the limitations of taking such a binary approach to these matters, as originally outlined by Newell (1973), who argued that this is a poor model for doing science. Berch concluded that a more productive approach would be to examine the conditions under which specific types of instructional methods are most effective in facilitating the learning of various types of secondary knowledge for children of differing ages and abilities.

Additionally, Berch (2007) discussed some interesting comments made by David Klahr subsequent to his earlier and highly controversial report demonstrating the unequivocal superiority of explicit instruction over discovery learning with respect to children's understanding of control variables in carrying out experimental manipulations (CVS) (Klahr & Nigam, 2004). Namely, Klahr acknowledged that based on a series of such studies he and his colleagues had conducted, the best they could say was that their "*particular specification* of learning via explicit instruction worked better than an *extreme form* of learning via discovery for learning CVS" (Authors' emphasis, p. 234). They concluded that "[we] certainly do not know if our CVS instruction is the 'best way' to teach CVS, or if Direct Instruction is the best way to teach *all* process skills" (Klahr & Li, 2005, p. 234). Similarly, Geary (2008b) has previously concluded that "It is unlikely that teacher-directed, peer-assisted, or self-discovery alone will be the most effective way to learn secondary academic material" (p. 224), and that "only empirical studies will allow us to determine the best mix of methods for different academic domains and for different children" (p. 224). Although this assertion is most certainly true, a more comprehensive evolutionary educational psychology should be able to offer a theoretical framework from which explicit, testable hypotheses can be generated to guide the design of such empirical studies.

Elsewhere, Geary (2008a) has argued that the mechanisms he has previously outlined (Geary, 2005, 2007) "provide a means for generating empirically testable hypotheses about children's academic motivation and their ease of learning in school, *as well as equally important hypotheses about the effectiveness of alternative instructional methods*" (Authors' emphasis, p. 192). In the next section, we elaborate on how these ideas can contribute to the formation of testable instructional hypotheses (see also Sweller, 2015, this volume).

Toward an Evolutionarily Informed Pedagogical Framework

Figure 9.5 illustrates what we refer to as an evolutionarily informed pedagogical framework. As can be observed, there are three axes: (a) The *x*-axis is the Degree of Systematic Instruction (DSI), ranging from Low to High, with the lowest form being unstructured or child-centered and the highest being teach-directed, explicit instruction; (b) the *y*-axis is the Classroom Context (CC) reflecting the physical and social setting along with the goal-related orientation, ranging from species-typical, real-world problem solving (e.g., how to equally share limited acquired resources with playmates) (Shaw, this volume) to species-atypical learning for its own sake (e.g., reading popular novels) (Bjorklund & Bering, 2002); and c) the *z*-axis is the

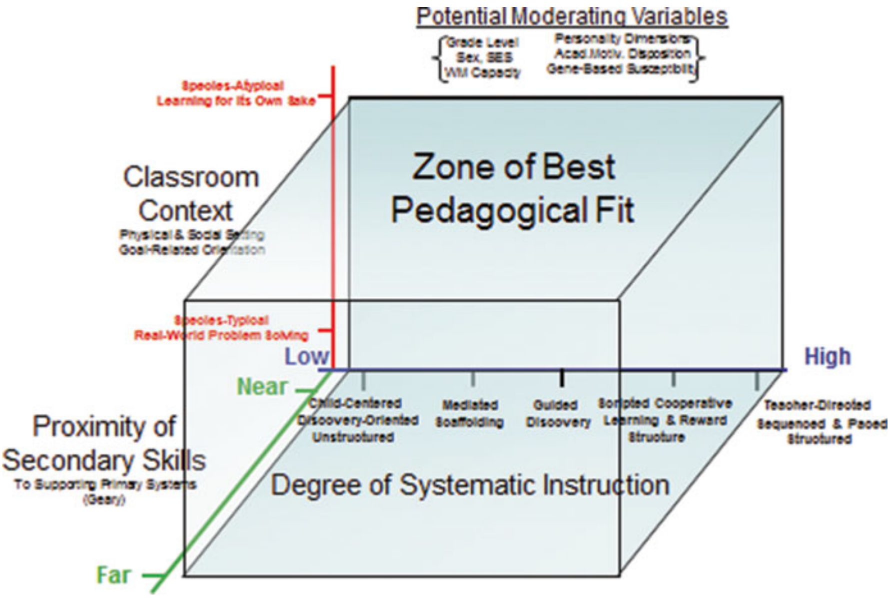

Fig. 9.5 Toward an evolutionarily informed pedagogical framework (after Berch, 2008)

Proximity of Secondary Skills (PSS) to supporting primary systems, ranging from near (e.g., language and reading) to far (e.g., folk biology and natural selection). Finally, a number of variables are proposed as factors that will moderate the effects of the DSI, CC, and PSS, including grade level, sex, and working memory capacity, among others.

Taken together, this framework can be used to generate testable hypotheses concerning what we refer to as the "Zone of Best Pedagogical Fit." In other words, when considering a test of the type of instruction that might be most effective for improving learning, one should simultaneously consider the nature of the CC, the PSS, and the multiple factors that could potentially moderate the value of its impact. For example, following the pedagogical framework outlined above, *we have suggested that structured, explicit, teacher-directed instruction should be most effective when acquiring secondary skills that are remote from supporting primary systems and that take place in a species atypical, classroom context where the goal is oriented toward acquiring knowledge for its own sake*. Note, however, that this framework is not prescriptive; rather, it offers researchers a detailed, systematic, and multidimensional tool that permits both the generation of specific hypotheses for empirical testing and a way of organizing and consolidating the outcomes of such studies to arrive at judgments concerning the Zone of Best Pedagogical Fit.

Among other questions that arise from this framework is the degree to which the various potential moderating variables influence the effectiveness of any given instructional method, either alone or in combination with others. For example, if high working memory capacity is needed for use of a relatively unstructured technique (e.g., guided discovery) to learn abstract information that is remote from its supporting primary systems, its effectiveness is very likely to be different for students with lower than higher working memory capacity. Another example would be Gray's (2013; this volume) assertion that children learn best in mixed-age settings. In a sense, he considers this a more "species-typical setting" than contemporary, age-graded classrooms. Yet the extent to which this hypothesis would hold true is highly likely to depend on: (a) the remoteness of the to-be-acquired secondary content from supporting primary systems; (b) the extent to which the principal instructional methods employed are more or less structured or explicit; and (c) the variability of the students' personality traits, cognitive capacities, motivational dispositions, or other potential moderating factors. To the best of our knowledge, no empirical studies testing these ideas have been published in a refereed journal.

As another example, there has been a major push in mathematics education for students to learn to solve "real-world" mathematics problems concerning everyday objects and settings in order to motivate them to learn abstract concepts and symbols. On the one hand, it could be argued that trying to concretize abstract concepts may reduce the remoteness of the secondary knowledge to be acquired (i.e., abstract symbols), thereby helping engage students' supporting primary systems; but even if true, there is evidence that learning from concrete examples as compared with abstract symbols can limit transferring knowledge to new problems (Kaminski, Sloutsky, & Heckler, 2006, 2008). On the other hand, use of real-world problems may stimulate students' interest in learning abstract mathematics if the problem-solving contexts evoke children's evolved motivational biases to engage in activities such as socializing with peers or intergroup competition. In other words, even a mathematics problem about a real-world context such as sports should be more likely to arouse motivational biases if it concerns using to-be-acquired computational skills for determining the likelihood of a baseball team beating their arch rival than just calculating the square footage of a major league stadium's outfield. To the best of our knowledge, no published studies have been carried out comparing the motivational effectiveness of employing real-world problem-solving contexts that differ not by the degree of authenticity of the real-world contexts themselves, but rather by evolutionarily informed differences in the extent to which these contexts evoke evolved motivational biases.

In sum, the framework we present here permits us to add a number of postulates to the premises and principles of evolutionary educational psychology described earlier. These are shown in Table 9.1 and should be useful in moving the field toward theoretically informed empirical studies (see also Sweller, this volume; Toub et al., this volume).

Conclusion

Humans have the extraordinary ability to create knowledge-based culture supported by shared beliefs (e.g., of the groups' origins) and rules for social behavior that in turn enables the formation of large cooperative groups (Baumeister, 2005;

Table 9.1 Postulates of evolutionary educational psychology

1.	The effectiveness of specific forms of instructional methods will be dependent on: a) the proximity of the secondary skills to their supporting primary systems, b) the classroom context (i.e., the physical and social setting, and the goal orientation), and c) the moderating influences of various developmental (e.g., grade level), demographic (e.g., SES), and individual differences factors (e.g., working memory capacity, academic motivational disposition, personality traits)
2.	The effectiveness of adopting more or less unstructured (i.e., informal, child-centered, discovery-oriented) approaches for improving the learning of secondary knowledge will be a direct function of: (a) the proximity of the to-be-acquired content to its supporting, primary folk domains (other things being equal) (b) the extent to which the physical and social setting of the classroom context is species-typical (c) the degree to which the problem-solving goal is real-world oriented as contrasted with learning for its own sake
3.	The potential advantage of employing real-world contexts for learning secondary, abstract knowledge will be a direct function of the degree to which they evoke evolved motivational biases

Richerson & Boyd, 2005). It is almost certain that children and adults have corresponding learning and motivational mechanisms that support the cross-generational transfer of these beliefs and other culturally useful knowledge. These mechanisms include child-initiated play, observational learning, and adults' use of stories to convey cultural knowledge to children (Lancy, this volume). Over the past several millennia, however, groups have increased substantially in size and economic diversification and some individuals within these groups have discovered better ways of producing food (e.g., agriculture crops), conducting commerce (e.g., monetary systems), and understanding the natural world (i.e., science). These advances have provided many benefits, but many of them have outpaced evolution's ability to adapt cognitive and motivational systems such that children easily learn the associated competencies. In other words, cultural innovations and brain and cognitive evolution are out of sync, creating a gap between what we are motivated to learn and what we easily learn and the competencies needed to live well in the modern world.

Schools are one of these innovations; schools do not exist in traditional societies where day-to-day living does not require reading, writing, or arithmetic (Lancy, this volume). Within the modern world, these are now considered rudimentary competencies, and we expect all children, not just the elite, to acquire them. The goal of universal schooling is very recent (<200 years), with respect to evolutionary time and it is very unlikely that humans have the same cognitive and motivational biases to support learning to read, write, and do arithmetic in the same way they have biases that allow them to form and maintain social relationships (i.e., folk psychology). Yet, learning the three *R*s must be based on the ability to adapt folk systems for acquiring these evolutionarily novel abilities.

Evolutionary educational psychology is the study of how children's evolved cognitive, learning, and motivational biases influence their ability and motivation to learn novel academic abilities and knowledge in school. As illustrated by the diversity of opinion across the chapters of this volume, the best approach for melding evolved biases with educational goals is vigorously debated. At the same time, all of the authors in this volume agree that there is a value-added to framing educational goals (among others) within an evolutionary context, and most importantly, they provide direction for future empirical studies. The ultimate, so to speak, benefit of this approach will be in its ability to generate testable hypotheses about instructional approaches and based on these improve the educational outcomes of all children. In other words, evolutionary educational psychology will flourish or flounder based on its contributions to our ability to meet the goals of a universal education.

References

Abrams, D., & Hogg, M. A. (Eds.). (1990). *Social identity theory: Constructive and critical advances*. New York, NY: Springer.

Adolphs, R. (2003). Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience, 4*, 165–178.

Alexander, R. D. (1989). Evolution of the human psyche. In P. Mellars & C. Stringer (Eds.), *The human revolution: Behavioural and biological perspectives on the origins of modern humans* (pp. 455–513). Princeton, NJ: Princeton University Press.

Alexander, R. D. (1990). *How did humans evolve? Reflections on the uniquely unique species.* Museum of Zoology (Special Publication No. 1, pp. 1–38). Ann Arbor: The University of Michigan.

Ash, J., & Gallup, G. G., Jr. (2007). Paleoclimatic variation and brain expansion during human evolution. *Human Nature, 18*, 109–124.

Atran, S. (1994). Core domains versus scientific theories: Evidence from systematics and Itza-Maya folkbiology. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 316–340). New York, NY: Cambridge University Press.

Atran, S. (1998). Folk biology and the anthropology of science: Cognitive universals and cultural particulars. *Behavioral and Brain Sciences, 21*, 547–609.

Bailenson, J. N., Shum, M. S., Atran, S., Medin, D. L., & Coley, J. D. (2002). A bird's eye view: Biological categorization and reasoning within and across cultures. *Cognition, 84*, 1–53.

Bailey, D. H., & Geary, D. C. (2009). Hominid brain evolution: Testing climatic, ecological, and social competition models. *Human Nature, 20*, 67–79.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. San Francisco, CA: Freeman.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press/Bradford Books.

Barton, R. A., & Dean, P. (1993). Comparative evidence indicating neural specialization for predatory behaviour in mammals. *Proceedings of the Royal Society of London B, 254*, 63–68.

Baumeister, R. F. (2005). *The cultural animal: Human nature, meaning, and social life*. New York, NY: Oxford University Press.

Berch, D. B. (2007). Instructing evolved minds: Pedagogically primary strategies for promoting biologically secondary learning. In J. S. Carlson & J. R. Levin (Eds.), *Educating the evolved mind* (Psychological perspectives on contemporary educational issues, Vol. 2, pp. 109–118). Greenwich, CT: Information Age.

Berch, D. B. (2008, November). *The emerging field of "evo-edu": Questions, challenges, constraints, and caveats*. Presented at the Evolution Institute Workshop on Early Childhood Education, Miami, FL.

Berlin, B., Breedlove, D. E., & Raven, P. H. (1966). Folk taxonomies and biological classification. *Science, 154*, 273–275.

Berlin, B., Breedlove, D. E., & Raven, P. H. (1973). General principles of classification and nomenclature in folk biology. *American Anthropologist, 75*, 214–242.

Berlinski, D. (2000). *Newton's gift*. New York, NY: Touchstone.

Bjorklund, D. F., & Bering, J. M. (2002). The evolved child: Applying evolutionary developmental psychology to modern schooling. *Learning and Individual Differences, 12*, 347–373.

Bjorklund, D. F., & Ellis, B. J. (2014). Children, childhood, and development in evolutionary perspective. *Developmental Review, 34*, 225–264.

Bjorklund, D. F., & Pellegrini, A. D. (2002). *The origins of human nature: Evolutionary developmental psychology*. Washington, DC: American Psychological Association.

Bloom, P. (1996). Intention, history, and artifact concepts. *Cognition, 60*, 1–29.

Blurton Jones, N. G., Hawkes, K., & O'Connell, J. F. (1997). Why do Hadza children forage? In N. L. Segal, G. E. Weisfeld, & C. C. Weisfeld (Eds.), *Uniting psychology and biology: Integrative perspectives on human development* (pp. 279–313). Washington, DC: American Psychological Association.

Bogin, B. (1999). *Patterns of human growth* (2nd ed.). Cambridge, England: Cambridge University Press.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read—A causal connection. *Nature, 301*, 419–421.

Brothers, L., & Ring, B. (1992). A neuroethological framework for the representation of minds. *Journal of Cognitive Neuroscience, 4*, 107–118.

Bugental, D. B. (2000). Acquisition of the algorithms of social life: A domain-based approach. *Psychological Bulletin, 126*, 187–219.

Burghardt, G. M. (2005). *The genesis of animal play: Testing the limits*. Cambridge, MA: Bradford/MIT Press.

Butler, D., & Suddendorf, T. (2014). Reducing the neural search space for hominid cognition: What distinguishes human and great ape brains from those of small apes? *Psychonomic Bulletin & Review, 21*, 590–619.

Byrne, P., Becker, S., & Burgess, N. (2007). Remembering the past and imagining the future: A neural model of spatial memory and imagery. *Psychological Review, 114*, 340–375.

Caporael, L. R. (1997). The evolution of truly social cognition: The core configurations model. *Personality and Social Psychology Review, 1*, 276–298.

Caramazza, A., & Shelton, J. R. (1998). Domain-specific knowledge systems in the brain: The animate-inanimate distinction. *Journal of Cognitive Neuroscience, 10*, 1–34.

Carey, S. (2009). *The origin of concepts*. New York, NJ: Oxford University Press.

Carroll, J. (2011). *Reading human nature: Literary Darwinism in theory and practice*. Albany, NY: SUNY Press.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*, 1–22.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*, 66–71.

Connor, C. M., Morrison, F. J., & Petrella, J. N. (2004). Effective reading comprehension instruction: Examining child X instruction interactions. *Journal of Educational Psychology, 96*, 682–698.

Cosmides, L. (1989). The logic of social exchange: Has natural selection shaped how humans reason? Studies with the Wason selection task. *Cognition, 31*, 187–276.

Damasio, A. (2003). *Looking for Spinoza: Joy, sorrow, and the feeling brain*. Orlando, FL: Harcourt.

Darwin, C. R. (1845). *Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. Beagle round the world, under the Command of Capt. Fitz Roy, R.N* (2nd ed.). London, England: John Murray.

Darwin, C. (1859). *The origin of species by means of natural selection*. London, England: John Murray.

Dunbar, R. I. M. (1998). The social brain hypothesis. *Evolutionary Anthropology, 6*, 178–190.

Dunbar, K., Fugelsang, J., & Stein, C. (2007). Do naïve theories ever go away? In M. Lovett & P. Shah (Eds.), *Thinking with Data: 33rd Carnegie Symposium on Cognition* (pp. 193–205). Mahwah, NJ: Erlbaum.

Dyer, F. C. (1998). Cognitive ecology of navigation. In R. Dukas (Ed.), *Cognitive ecology: The evolutionary ecology of information processing and decision making* (pp. 201–260). Chicago, IL: University of Chicago Press.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*, 363–406.

Evans, J. S. B. T. (2002). Logic and human reasoning: An assessment of the deduction paradigm. *Psychological Bulletin, 128*, 978–996.

Feigenson, L., Dehaene, S., & Spelke, E. S. (2004). Core systems of number. *Trends in Cognitive Sciences, 8*, 307–314.

Figueiredo, G. M., Leitão-Filho, H. F., & Begossi, A. (1993). Ethnobotany of Atlantic forest coastal communities: Diversity of plant used in Gamboa. *Human Ecology, 21*, 419–430.

Figueiredo, G. M., Leitão-Filho, H. F., & Begossi, A. (1997). Ethnobotany of Atlantic forest coastal communities: II. Diversity of plant uses at Sepetiba Bay (SE Brazil). *Human Ecology, 25*, 353–360.

Fiske, S. T. (2002). What we know now about bias and intergroup conflict, the problem of the century. *Current Directions in Psychological Science, 11*, 123–128.

Fiske, S. T., & Taylor, S. E. (1991). *Social cognition* (2nd ed.). New York, NY: McGraw-Hill.

Flinn, M. V., Geary, D. C., & Ward, C. V. (2005). Ecological dominance, social competition, and coalitionary arms races: Why humans evolved extraordinary intelligence. *Evolution and Human Behavior, 26*, 10–46.

Freedman, D. G. (1974). *Human infancy: An evolutionary perspective*. New York, NY: Wiley.

Gallistel, C. R. (1990). *The organization of learning*. Cambridge, MA: MIT Press/Bradford Books.

Garlick, D. (2002). Understanding the nature of the general factor of intelligence: The role of individual differences in neural plasticity as an explanatory mechanism. *Psychological Review, 109*, 116–136.

Geary, D. C. (1995). Reflections of evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist, 50*, 24–37.

Geary, D. C. (2004). Evolution and cognitive development. In R. Burgess & K. MacDonald (Eds.), *Evolutionary perspectives on human development* (pp. 99–133). Thousand Oaks, CA: Sage.

Geary, D. C. (2005). *The origin of mind: Evolution of brain, cognition, and general intelligence*. Washington, DC: American Psychological Association.

Geary, D. C. (2007). Educating the evolved mind: Conceptual foundations for an evolutionary educational psychology. In J. S. Carlson & J. R. Levin (Eds.), *Educating the evolved mind* (Psychological perspectives on contemporary educational issues, Vol. 2, pp. 1–99). Greenwich, CT: Information Age.

Geary, D. C. (2008a). An evolutionarily informed education science. *Educational Psychologist, 43*, 279–295.

Geary, D. C. (2008b). Whither evolutionarily educational psychology? *Educational Psychologist, 43*, 217–226.

Geary, D. C. (2010). *Male, female: The evolution of human sex differences* (2nd ed.). Washington, DC: American Psychological Association.

Geary, D. C. (2012). The evolved mind and scientific discovery. In J. Shrager & S. M. Carver (Eds.), *From child to scientist: Mechanisms of learning and development* (pp. 87–115). Washington, DC: American Psychological Association.

Geary, D. C., Berch, D. B., & Mann Koepke, K. (Eds.). (2015). *Evolutionary origins and early development of number processing* (Mathematical cognition and learning, Vol. 1). San Diego, CA: Elsevier Academic Press.

Geary, D. C., & Bjorklund, D. F. (2000). Evolutionary developmental psychology. *Child Development, 71*, 57–65.

Geary, D. C., & Huffman, K. J. (2002). Brain and cognitive evolution: Forms of modularity and functions of mind. *Psychological Bulletin, 128*, 667–698.

Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and animate-inanimate distinction as examples. *Cognitive Science, 14*, 79–106.

Gelman, S. A. (2003). *The essential child: Origins of essentialism in everyday thought*. New York, NY: Oxford University Press.

Gelman, R., & Williams, E. M. (1998). Enabling constraints for cognitive development and learning: Domain-specificity and epigenesis. In D. Kuhl & R. S. Siegler (Vol. Eds.), *Cognition, perception, and language, Vol. 2* (pp. 575–630). W. Damon (Gen. Ed.), *Handbook of child psychology* (5th Ed.). New York, NY: Wiley.

Gigerenzer, G., Todd, P. M., & ABC Research Group (Eds.). (1999). *Simple heuristics that make us smart*. New York, NY: Oxford University Press.

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin, 138*, 1085–1108.

Grant, P. R. (1999). *Ecology and evolution of Darwin's finches*. Princeton, NJ: Princeton University Press.

Gray, P. (2013). *Free to learn: Why unleashing the instinct to play will make our children happier, more self-reliant, and better students for life*. New York, NY: Basic Books.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development, 58*, 539–559.

Gurven, M., Kaplan, H., & Gutierrez, M. (2006). How long does it take to become a proficient hunter? Implications for the evolution of extended development and long life span. *Journal of Human Evolution, 51*, 454–470.

Hamilton, W. D. (1964). The genetical evolution of social behaviour. II. *Journal of Theoretical Biology, 7*, 17–52.

Harter, S. (2006). The self. In N. Eisenberg (Vol. Ed.), *Social, emotional, and personality development, Vol.* 3 (pp. 505–570). W. Damon & R. M. Lerner (Gen. Eds.), *Handbook of child psychology* (6th Ed.). New York, NY: Wiley.

Heckhausen, J., & Schulz, R. (1995). A life-span theory of control. *Psychological Review, 102*, 284–304.

Hewstone, M., Rubin, M., & Willis, H. (2002). Intergroup bias. *Annual Review of Psychology, 53*, 575–604.

Hindson, B., Byrne, B., Shankweiler, D., Fielding-Barnsley, R., Newman, C., & Hine, D. W. (2005). Assessment and early instruction of preschool children at risk for reading disability. *Journal of Educational Psychology, 97*, 687–704.

Horowitz, D. L. (2001). *The deadly ethnic riot*. Berkeley, CA: University of California Press.

Huffman, K. J., Nelson, J., Clarey, J., & Krubitzer, L. (1999). Organization of somatosensory cortex in three species of marsupials, *Dasyurus hallucatus, Dactylopsila trivirgata*, and *Monodelphis domestica*: Neural correlates of morphological specializations. *Journal of Comparative Neurology, 403*, 5–32.

Humphrey, N. K. (1976). The social function of intellect. In P. P. G. Bateson & R. A. Hinde (Eds.), *Growing points in ethology* (pp. 303–317). New York, NY: Cambridge University Press.

Johnson-Frey, S. H. (2003). What's so special about human tool use? *Neuron, 39*, 201–204.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, England: Cambridge University Press.

Kahneman, D., & Tversky, A. (1982). The simulation heuristic. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment uncertainty: Heuristics and biases* (pp. 201–208). Cambridge, England: Cambridge University Press.

Kaiser, M. K., McCloskey, M., & Proffitt, D. R. (1986). Development of intuitive theories of motion: Curvilinear motion in the absence of external forces. *Developmental Psychology, 22*, 67–71.

Kaminski, V. M., Sloutsky, V. M., & Heckler, A. F. (2006). Do children need concrete instantiations to learn an abstract concept? In R. Sun & N. Miyake (Eds), Proceedings of the 27th Annual Conference of the Cognitive Science Society (pp. 411–416). Mahwah, NJ: Lawrence Erlbaum.

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2008). The advantage of abstract examples in learning math. *Science, 230*, 454–455.

Kaplan, H., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution: Diet, intelligence, and longevity. *Evolutionary Anthropology, 9*, 156–185.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*, 75–86.

Kisilevsky, B. S., Hains, S. M. J., Lee, K., Xie, X., Huang, H., Ye, H. H., … Wang, Z. (2003). Effects of experience on fetal voice recognition. *Psychological Science, 14*, 220–224

Klahr, D., & Li, J. (2005). Cognitive research and elementary science instruction: From the laboratory, to the classroom, and back. *Journal of Science Education and Technology, 14*, 217–238.

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science, 15*, 661–667.

Kuhlmeier, V. A., & Boysen, S. T. (2002). Chimpanzees (*Pan troglodytes*) recognize spatial and object correspondences between a scale model and its referent. *Psychological Science, 13*, 60–63.

Leslie, A. M. (1987). Pretense and representation: The origins of "theory of mind". *Psychological Review, 94*, 412–426.

Leslie, A. M., Friedman, O., & German, T. P. (2004). Core mechanisms in "theory of mind". *Trends in Cognitive Sciences, 8*, 528–533.

Lockman, J. J. (2000). A perception-action perspective on tool use development. *Child Development, 71*, 137–144.

Lubinski, D. (2004). Introduction to the special section on cognitive abilities: 100 years after Spearman's (1904) "'general intelligence', objectively determined and measured". *Journal of Personality and Social Psychology, 86*, 96–111.

Macfarlan, S. J., Walker, R. S., Flinn, M. V., & Chagnon, N. A. (2014). Lethal coalitionary aggression and long-term alliance formation among Yanomamö men. *Proceedings of the National Academy of Sciences USA, 111*, 16662–16669.

Maguire, E. A., Burgess, N., Donnett, J. G., Frackowiak, R. S. J., Frith, C. D., & O'Keefe, J. (1998). Knowing where and getting there: A human navigational network. *Science, 280*, 921–924.

Malt, B. C. (1995). Category coherence in cross-cultural perspective. *Cognitive Psychology, 29*, 85–148.

Mann, V. A. (1984). Reading skill and language skill. *Developmental Review, 4*, 1–15.

Markus, H. (1977). Self-schemata and processing information about the self. *Journal of Personality and Social Psychology, 35*, 63–78.

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248*, 122–130.

Meck, W. H., & Church, R. M. (1983). A mode control model of counting and timing processes. *Journal of Experimental Psychology: Animal Behavior Processes, 9*, 320–334.

Medin, D. L., & Atran, S. (1999). *Folkbiology*. Cambridge, MA: MIT Press.

Medin, D. L., & Atran, S. (2004). The native mind: Biological categorization and reasoning in development and across cultures. *Psychological Review, 111*, 960–983.

Medin, D. L., Ross, N. O., Atran, S., Cox, D., Coley, J., Proffitt, J. B., & Blok, S. (2006). Folkbiology of freshwater fish. *Cognition, 99*, 237–273.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. New York, NY: Oxford University Press.

Mithen, S. (1996). *The prehistory of the mind: The cognitive origins of art and science*. New York, NY: Thames and Hudson.

Murdock, G. P. (1981). *Atlas of world cultures*. Pittsburgh, PA: University of Pittsburgh Press.

Murray, C. (2003). *Human accomplishment: The pursuit of excellence in the arts and sciences, 800 B.C. to 1950*. New York, NJ: HarperCollins.
Newcombe, N. S. (2011). What is neoconstructivism? *Child Development Perspectives, 5*, 157–160.
Newell, A. (1973). You can't play 20 questions with nature and win: Projective comments on papers of this symposium. In W. G. Chase (Ed.), *Visual information processing* (pp. 283–308). New York, NY: Academic.
Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
Newton, I. (1995). *The principia*. Amherst, NY: Prometheus Books. [Translated by A. Motte]. (Original work published in 1687).
O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. New York, NY: Oxford University Press.
Oaksford, M., & Chater, N. (1998). *Rationality in an uncertain world: Essays on the cognitive science of human reasoning*. East Sussex, England: Psychology Press.
Paivio, A. (2007). *Mind and its evolution: A dual coding theoretical approach*. Mahwah, NJ: Erlbaum.
Pinker, S. (1994). *The language instinct*. New York, NY: William Morrow.
Potts, R. (1998). Variability selection in hominid evolution. *Evolutionary Anthropology, 7*, 81–96.
Povinelli, D. J. (2000). *Folk physics for apes: The chimpanzees theory of how the world works*. New York, NY: Oxford University Press.
Richerson, P. J., & Boyd, R. (2005). *Not by genes alone: How culture transformed human evolution*. Chicago, IL: University of Chicago Press.
Rozin, P. (1976). The evolution of intelligence and access to the cognitive unconscious. In J. M. Sprague & A. N. Epstein (Eds.), *Progress in psychobiology and physiological psychology* (Vol. 6, pp. 245–280). New York, NY: Academic.
Scarr, S. (1992). Developmental theories of the 1990s: Developmental and individual differences. *Child Development, 63*, 1–19.
Schneider, D. J. (1973). Implicit personality theory: A review. *Psychological Bulletin, 79*, 294–309.
Schyns, P. G., Bonnar, L., & Gosselin, F. (2002). Show me the features! Understanding recognition from the use of visual information. *Psychological Science, 13*, 402–409.
Sereno, S. C., & Rayner, K. (2003). Measuring word recognition in reading: Eye movements and event-related potentials. *Trends in Cognitive Sciences, 7*, 489–493.
Setoh, P., Wu, D., Baillargeon, R., & Gelman, R. (2013). Young infants have biological expectations about animals. *Proceedings of the National Academy of Sciences USA, 110*, 15937–15942.
Shepard, R. N. (1994). Perceptual-cognitive universals as reflections of the world. *Psychonomic Bulletin & Review, 1*, 2–28.
Shtulman, A. (2006). Qualitative differences between naïve and scientific theories of evolution. *Cognitive Psychology, 52*, 170–194.
Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review, 63*, 129–138.
Simonton, D. K. (2009). Varieties of (scientific) creativity: A hierarchical model of domain-specific disposition, development, and achievement. *Perspectives on Psychological Science, 4*, 441–452.
Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99*, 605–632.
Spelke, E. S., & Kinzler, K. D. (2007). Core knowledge. *Developmental Science, 10*, 89–96.
Spelke, E. S., & Kinzler, K. D. (2009). Innateness, learning, and rationality. *Child Development Perspectives, 3*, 96–98.
Spencer, J. P., Blumberg, M. S., McMurray, B., Robinson, S. R., Samuelson, L. K., & Tomblin, J. B. (2009). Short arms and talking eggs: Why we should no longer abide the nativist-empiricist debate. *Child Development Perspectives, 3*, 79–87.

Sporns, O., Tononi, G., & Edelman, G. M. (2000). Connectivity and complexity: The relationship between neuroanatomy and brain dynamics. *Neural Networks, 13*, 909–922.

Stanovich, K. E. (1999). *Who is rational? Studies of individual differences in reasoning*. Mahwah, NJ: Erlbaum.

Stanovich, K. E., & West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences, 23*, 645–726.

Stanovich, K. E., & West, R. F. (2008). On the relative independence of thinking biases and cognitive ability. *Journal of Personality and Social Psychology, 94*, 672–695.

Sternberg, R. J. (Ed.). (1999). *Handbook of creativity*. Cambridge, England: Cambridge University Press.

Stevens, R. J., Slavin, R. E., & Farnish, A. M. (1991). The effects of cooperative learning and direct instruction in reading comprehension strategies on mean idea identification. *Journal of Educational Psychology, 83*, 8–16.

Suddendorf, T., & Corballis, M. C. (1997). Mental time travel and the evolution of the human mind. *Genetic, Social, and General Psychology Monographs, 123*, 133–167.

Sweller, J. (2012). Human cognitive architecture: Why some instructional procedures work and others do not. In K. R. Harris, S. Graham, & T. Urdan (Eds.), *Educational psychology handbook* (Theories, constructs, and critical issues, Vol. 1, pp. 295–325). Washington, DC: American Psychological Association.

Sweller, J. (2015). In academe, what is learned, and how is it learned? *Current Directions in Psychological Science, 24*, 190–194.

Tinbergen, N. (1963). On aims and methods of ethology. *Zeitschrift für Tierpsychologie, 20*, 410–433.

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology, 53*, 1–25.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192–212.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*, 73–87.

Wellman, H. M. (2014). *Making minds: How theory of mind develops*. New York, NY: Oxford University Press.

Wellman, H. M., Fang, F., Liu, D., Zhu, L., & Liu, G. (2006). Scaling of theory-of-mind understandings in Chinese children. *Psychological Science, 17*, 1075–1081.

Wellman, H. M., Fang, F., & Peterson, C. C. (2011). Sequential progressions in a theory-of-mind scale: Longitudinal perspectives. *Child Development, 82*, 780–792.

Wellman, H. M., & Gelman, S. A. (1992). Cognitive development: Foundational theories of core domains. *Annual Review of Psychology, 43*, 337–375.

Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development, 75*, 523–541.

West, R. F., Toplak, M. E., & Stanovich, K. E. (2008). Heuristics and biases as measures of critical thinking: Associations with cognitive ability and thinking dispositions. *Journal of Educational Psychology, 100*, 930–941.

White, M. (1999). *Isaac Newton: the last sorcerer*. New York, NY: Basic Books.

Zimmerman, C. (2005). *The development of scientific reasoning skills: What psychologists contribute to an understanding of elementary science learning*. Report to the National Research Council's Board of Science Education, Consensus Study on *Learning Science, Kindergarten through Eighth Grade*. Retrieved from http://www7.nationalacademies.org/bose/Corinne_Zimmerman_Final_Paper.pdf.