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An Evolutionarily Informed Education Science

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Abstract

Schools are a central interface between evolution and culture. They are the contexts in which children learn the evolutionarily novel abilities and knowledge needed to function as adults in modern societies. Evolutionary educational psychology is the study of how an evolved bias in children's learning and motivational systems influences their ability and motivation to learn evolutionarily novel academic abilities and information in school. I provide an overview of evolved domains of mind, corresponding learning and motivational biases, and the evolved systems that allow humans to learn about and cope with variation and change within lifetimes. The latter enable the creation of cultural and academic innovations and support the learning of evolutionarily novel information in school. These mechanisms and the premises and principles of evolutionary educational psychology are described. Their utility is illustrated by discussion of the relation between evolved motivational dispositions and children's academic motivation, and by the relation between evolved social-cognitive systems and mechanisms that support children's learning to read.

The discovery of the mechanisms of natural selection and thereby the processes that result in evolutionary change within species and the emergence of new species is one of the most important discoveries in the history of the life sciences (Darwin, 1859; Darwin & Wallace, 1858). Empirical support for the theory of evolution is overwhelming and ranges from behavior (e.g., Grant& Grant, 2002) to genes (e.g., Liu, Miyamoto, Freire, Ong, Tennant, Young, & Gugel, 2001). The integration of evolutionary theory into the social sciences has been slow and contentious (Richardson, 2007; Segerstrale, 2000), but nevertheless has been successfully used to frame empirical findings and generate testable hypotheses in areas ranging from mate choice to morality (see Buss, 2005). Cultural influences, such as a parental socialization, mores, and so forth, are a common counter argument to the influence of evolved biases in human behavior (Segerstrale, 2000), but this is unnecessary. Humans have evolved to create culture, that is, a common system of beliefs that facilitate cooperation, a division of labor, formal and informal expectations for the behavior of in-group members, as well as the sharing of information and resources (see Baumeister, 2005; Brown, 1991; Haidt, 2007; Richerson & Boyd, 2005). As with language, the surface structure varies from one culture to the next, but this belies many underlying common features.

I focus on two of these features, the cross-generational or vertical transmission of knowledge and the socialization and preparation of children for adult life within the culture. A full understanding of these features is especially critical for cultures with vast and rapidly accumulating stores of knowledge (e.g., in books). These are cultures in which an ever widening gap has emerged between what children easily learn and what they need to learn to be successful as adults in these societies. Formal and now universal schooling is a cultural innovation was developed in these societies to close this gap. Schools are now the core interface between evolved developmental biases in children’s learning and motivation and the culture of modern society. I provide a précis of this interface between evolution and culture, which can be termed *evolutionary educational psychology*; more extensive treatments are provided in Geary (2002, 2005, 2007a b).

Evolutionary educational psychology is not a framework that is ready for translation into school curricula. Rather, it provides a theoretical foundation for: 1) conceptualizing children's learning in school and their motivation to engage in this learning; 2) generating empirically testable hypotheses about learning and motivation; and 3) discussing implications for understanding and ultimately improving educational outcomes. In the first section, I outline the evolved cognitive, developmental, and motivational foundations for learning in evolutionarily novel contexts, and in the second I overview the premises and principles of evolutionary educational psychology and use these to discuss children's motivation and learning in modern schools. In this final section, I provide several examples that illustrate how an evolutionary perspective can lead to better approaches to facilitating students' motivation in school and to the design of curricular material.

AN EVOLVED ABILITY TO LEARN

Natural selection occurs when individual differences in a trait are partly heritable and influence survival or reproductive prospects in the same way across generations. Many of these traits have evolved such that they can change, within constraints, in response to changing conditions during the life span (West-Eberhard, 2003). Such trait plasticity evolves when core aspects of the ecology or social environment that drove the evolution of the trait fluctuate during lifetimes. When the ability to adapt to these within-lifetime fluctuations influences survival or reproductive prospects, then conditions are set for the evolution of trait plasticity and the corresponding ability to learn (Geary, 2005; Timberlake, 1994).

Proposed sources of the within-lifetime variation that drove human brain evolution and our extraordinary ability to learn include climatic fluctuations (Ash & Gallup, 2007; Kanazawa, 2004), hunting and other ecological demands (Kaplan, Hill, Lancaster, & Hurtado, 2000), and social complexity (Alexander, 1989; Dunbar, 1998; Flinn, Geary, Ward, 2005; Geary, 2005; Humphrey, 1976). This is not an esoteric academic debate, because the source or sources of this trait plasticity are predicted to have resulted in evolved learning and motivational biases. The ease of learning is predicted to be higher for content related to this variation and children are predicted to be motivated to engage in activities that facilitate this learning (for example, attending to cloud patterns to learn how to predict climate change or to facial expressions to learn the nuances of social dynamics). Following Alexander, my colleagues and I have proposed that hominid evolution involved an increasing ability to control the ecology and a ramping up of social competition to control the best ecologies (Flinn et al., 2005; Geary, 2005). The gist is that the evolution of the human mind and brain resulted from the advantages that gradually emerged as a result of our ancestors' ability to modify (e.g., building shelters, dams) and control ecologies and to cope with rapidly changing social dynamics. In the first section, I overview a corresponding taxonomy of folk abilities and in the second section I discuss how these abilities appear to develop during human childhood.

Evolution of Mind

Humans' brain and cognitive systems that have evolved to attend to, process, and guide behavioral response to evolutionarily significant information compose "biologically primary" or core domains of human cognition, and coalesce around folk psychology, folk biology, and folk physics (see also Baron-Cohen, 1995; Geary, 1995; Leslie, Freidman, & German, 2004; Mithen, 1996; Premack & Premack, 1995; Wellman & Gelman, 1992). There is also evidence for an evolved set of quantitative abilities, but discussion is beyond the scope of this article (see Geary, 1995, 2007b; R. Gelman, 1990; Spelke, 2000). These are predicted to be modular to the extent that they are biased to process specific forms of information; and they are predicted to be plastic to the extent that sensitivity to variation in the corresponding information patterns provides an advantage. A bias to orient to the human face and to automatically process key pieces of facial information (e.g., eyes) is an example of a modular primary or core ability (Kanwisher, McDermott, & Chun, 1997). If the ability to discriminate one person from the next affords a social advantage over those who cannot make these discriminations, then this modular system is predicted to involve some degree of plasticity, but within constraints.

Taxonomy of folk modules is presented in Figure 1 (Geary, 2005; Geary & Huffman, 2002). The function of folk domains is to focus behavior in attempts to achieve access to and control of the social, biological, and physical resources that tended to enhance survival or reproductive prospects during human evolution. Achieving control is not an easy task, of course, and if it occurs it is typically without conscious awareness of the corresponding evolved function. To illustrate, the formation of friendships is supported by folk-psychological competencies, but does not appear to be guided by a motivation to control the behavior of these people, or at least there is often no explicit desire to do so. Nevertheless, participating in these relationships and the attendant social support are correlated with physical and psychological health and in some contexts mortality risks (e.g., Taylor, Klein, Lewis, Gruenewald, Gurung, & Updegraff, 2000). These friendships are social resources that can enhance survival (e.g., support during times of social conflict) and reproductive prospects (e.g., a romantic partner) under the types of conditions found in traditional societies and presumably throughout human evolution.

Folk Domains

Psychology. The folk-psychological systems are shown in the top part of Figure 1, and represent three sets of modules that process information related to the self, other individuals, and group dynamics, respectively. The first set includes awareness of the self as a social being and awareness of one's relationships with other people (e.g., Harter, 2006). Self awareness is integrally related to the ability to mentally project the self backward in time to recall and relive episodes that are of personal importance and to project oneself forward in time, that is, to create a self-centered mental simulation of potential future states (Suddendorf & Corballis, 1997; Tulving, 2002), as I elaborate below. The individual level modules process the forms of information that guide one-on-one social dynamics and foster one-on-one social relationships (Bugental, 2000). The group-level modules enable individuals to break their social world into categories of people, including kin and members of favored in-groups and disfavored out-groups.

People also have the comparatively unique ability to form in-groups on the basis of ideology, such as nation (Alexander, 1989). These ideologies include moral edicts regarding the treatment of in-group members, as well as mechanisms for their enforcement (Haidt, 2007; Wright, 1994). Ideologies and mores enable the formation of large-scale cooperative communities, provide stability across generations, and support the cross-generational accumulation of cultural knowledge. Ultimately, these biases evolved because they allow the formation of large competitive groups that are better able to control ecologies and social politics than are poorly organized groups.

Biology and physics. The folk biological and physical systems are represented at the bottom of Figure 1. The folk biological modules orient attention toward important features of the biological world, such as movement patterns of potential prey, and support the ability to develop taxonomies of other species and knowledge systems about the behavior, growth pattern, and "essence" of these species (Atran, 1998; Berlin, Breedlove, & Raven, 1966; New, Cosmides, & Tooby, 2007). In traditional societies, these competencies support behavioral activities that are directed toward using ecological resources for survival or reproductive purposes, such as hunting and horticulture (Kaplan et al., 2000). The folk physical systems support navigation, the formation of mental representations of physical features of the ecology, and the construction of tools. Some of these competencies, especially the ability to navigate, are similar to those found in other species and thus are not uniquely human (Tomasello & Call, 1997). The ability to construct and use tools, in contrast, far exceeds the competencies found in chimpanzees (*Pan troglodytes*) and other species (Povinelli, 2000), and the evolution of this ability is almost certainly a component of humans' ability to modify and control the ecologies in which they are situated.

Heuristics. For humans and other species, the behavioral features of folk domains can be described as "rules of thumb" (Gigerenzer, Todd, & and ABC Research Group, 1999). The corresponding information is processed implicitly and the behavioral component is more or less automatically executed (Simon, 1956). Returning to face processing, the pattern generated by the shape of the eyes and nose provides information on 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). These patterns are automatically and implicitly processed by the receiver, who in turn expresses corresponding emotional and other social signals (e.g., smile). 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. Negative feelings, such as fear elicited by an angry expression, may prompt withdrawal; and positive feelings, such as happiness generated by a smile, a continuance of the interaction (Damasio, 2003).

For humans, folk heuristics can also include explicit inferential and attributional biases. People often make attributions about the cause of their failures to achieve desired outcomes, and often attribute such failures to bad luck or biases in other people. An evolved 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 & Schultz, 1995). Social attributional biases that favor members of the in-group and derogate members of out-groups are also well known (Fiske, 2002) and facilitate intergroup competition (Horowitz, 2001). The essence associated with folk biology allows people to make inferences (e.g., during the act of hunting) about the behavior of members of familiar species, and about the likely behavior of less familiar but related species (Atran, 1998). Attributions about causality in the physical world have also been studied. As an example, children and adults have naïve conceptions about motion and other physical phenomena (Clement, 1982).

These biases often 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 does not mean the explanations are necessarily accurate from a scientific perspective. In fact, *descriptions* of psychological, physical, and biological phenomena are often correct (Wellman & Gelman, 1992), but many of the explicit explanations and attributional biases regarding the *causes* of these phenomena are objectively and scientifically inaccurate.

Evolution of Consciousness and Learning

Folk systems evolved to cope with information and conditions that are consistent across generations and within lifetimes. As shown by the left side of Figure 2, these mechanisms guide attention to and enable the quick processing of corresponding information and more or less automatic behavioral rule of thumb responses. The result is that most of the forms of information that were encountered in day-to-day living during our evolutionary history are processed automatically and with little cognitive effort. There are, however, situations in which evolved responses are not sufficient; heuristics often lead to attributional errors (Tversky& Kahneman,

1974) and behavioral strategies do not always lead to the desired outcome. These are represented by the right side of Figure 2: If the evolution of the human brain and mind was driven in part by the need to deal with rapid change in ecological or social conditions, then brain and cognitive systems that function to mentally represent and manipulate dynamic change in information patterns are predicted to evolve.

When social or other dynamics result in situations that cannot be addressed with the use of folk heuristics, the folk systems need to be inhibited (Bjorklund & Harnishfeger, 1995) and the conditions approached using explicit, conscious problem solving (Evans, 2002; Stanovich & West, 2000). The ability to inhibit folk systems and engage in controlled problem solving are defining features of the human brain and mind and are the key to understanding our extraordinary ability to create and to learn evolutionarily novel information. I cannot elaborate fully here (see Geary, 2005, 2007a), but the core of these mechanisms is conscious-psychological simulations, and working memory and controlled problem solving.

Conscious-Psychological

The conscious-psychological system is a fusion of Tulving's (2002) self awareness, Suddendorf and Corballis' (1997) mental time travel, and Johnson-Laird's (1983) mental models. These support the human ability to form an explicit mental representation of situations that are centered on the self and one's relationship with other people or one's access to biological and physical resources. The representations often involve a form of mental time travel, that is, mental simulations of past, present, or potential future states which can be cast as visual images, in language, or as episodic memories, that is, memories of personal experiences. The combination enables people to create a self-aware and self-centered mental simulation of the "perfect world" (Geary, 1998). A perfect world is one in which the individual is able to organize and 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 gist is that people can generate a mental representation of a future life that provides them with more social influence and more resources than is available in their current life. People compare this more perfect world to their current situation, and mentally devise and rehearse strategies that can be used to attempt to reduce the difference between these states (Geary, 2005). Consciousness – awareness of the self – is predicted to be especially important in situations in which the achievement of better future circumstances requires the development of strategies to counter the competing interests of other people. This is because improving ones' social influence or gaining greater access to desired and limited resources often involves social manipulation – getting others to behave in ways that is in your best interest but not always their best interest – and avoiding the manipulative strategies of others. Awareness of aspects of the self (e.g., personality, attractiveness) that may be used by others is an asset in these situations, as is awareness of self-attributes that can be most effectively used to achieve goals (Wright, 1994).

Working Memory and Controlled Problem Solving

The cognitive mechanisms that support the formation of conscious-psychological simulations are working memory, attentional control, and the ability to inhibit automatic processing of folk-related information (Baddeley, 1986; Bjorklund & Harnishfeger, 1995; Cowan, 1995). These are the content-free mechanisms that, among other things, enable the integration of a current conscious-psychological state with memory representations of related past experiences, and the generation of mental models or simulations of potential future states (Alexander, 1989; Johnson-Laird, 1983). Problem-solving mechanisms, such as means-ends analysis or analogical reasoning, are used to simulate strategies that can reduce the difference between the current and desired state (Newell &Simon, 1972).

There are corresponding brain systems that support this controlled problem solving. When folk or learned heuristics are not sufficient for coping with a situation, the anterior cingulate cortex triggers an automatic attentional shift to the corresponding information and a representation of the information in working memory (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The representation in working memory is supported by the dorsolateral prefrontal cortex and attentional areas of the parietal cortex (Damasio, 1989; Kane & Engle, 2002; Posner, 1994) that in turn result in an explicit conscious awareness of the information. Explicitly represented information is then subject to mental modification through the use of problem solving and reasoning. The repeated activation of these systems and associated problem solving enables individuals to learn semantic information and to develop behavioral heuristics for coping with these and similar situations.

Intelligence and Evolutionarily Novel Learning

I have proposed that the just-described conscious-psychological, working memory and controlled problem-solving mechanisms define the core of general fluid intelligence (Geary, 2005). In other words, 100 years of psychometric and cognitive research on general intelligence has identified the evolved mechanisms that enable humans to cope with and learn from evolutionarily novel situations, 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 are beyond the scope of this article, but the result is represented by the arrow at the center of Figure 2, that is, the transfer of information, procedures, and heuristics learned from effortful, controlled problem solving to long-term memory, including semantic and procedural memory.

I am proposing that the ability to learn evolutionarily novel information 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 within lifetimes. The first is plasticity in biologically primary modular systems. As I elaborate below, these have evolved such that they are modifiable during the developmental period, but within constraints. The second type of plasticity 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 can modify primary systems (Damasio, 1989; Geary, 2005). More important, the simultaneous activation of multiple primary systems and the representation of corresponding information in working memory appear to result in the ability to link primary systems in novel ways (Garlick, 2002; Sporns, Tononi, & Edelman, 2000).

Evolution and Cognitive Development

Cognitive development, as contrasted with academic development, is the experience-driven adaptation of biologically primary modular competencies to the nuances of the local social, biological, and physical ecologies (Geary & Bjorklund, 2000). As noted, modular systems are predicted to be open to experiential modification to the extent that sensitivity to variation within these domains has been of potential survival or reproductive significance during human evolution. The mechanisms involved in the experience-driven adaptation of plastic modular systems to local conditions are not well understood. At a macro level, and following the lead of R. Gelman (1990), prenatal brain organization provides the skeletal structure that comprises neural and perceptual modules that in turn guide attention to and the processing of stable forms of information (e.g., the general shape of the human face) in the folk domains shown in Figure 1. Indeed, studies of infants' attentional biases and preschool children's nascent and implicit knowledge are often focused on these three folk domains (S. Gelman, 2003; Keil, 1992; Keil, Levin, Richman, & Gutheil, 1999; Mandler, 1992; Wellman & Gelman, 1992).

The result is biases in early postnatal attentional, affective, and information-processing capacities, as well as biases in self-initiated behavioral engagement of the environment (Bjorklund & Pellegrini, 2002; Scarr, 1992). The latter generate evolutionarily expectant experiences, that is, experiences that provide the social and ecological feedback needed to adjust modular architecture to variation in information patterns in these domains (Greenough, Black, & Wallace, 1987; MacDonald, 1992). These behavioral biases are expressed as common juvenile activities, such as social play and exploration of the ecology. These experience-expectant processes result in the automatic and effortless modification of plastic features of the modular systems. The result is the individual's ability to identify and respond to variation (e.g., to discriminate one individual from another) within these domains, and the ability to create the forms of category described above, such as in-groups/out-groups or flora/fauna.

Folk Psychology

To illustrate modular plasticity, consider that the strong bias of human infants to attend to human faces, movement patterns, and speech reflects, in theory, the initial and inherent organizational and motivational structure of the associated folk-psychological modules (Freedman, 1974). These biases reflect the evolutionary significance of social relationships and recreate the microconditions (e.g., parent-child interactions) associated with the evolution of the corresponding modules (Caporael, 1997). Attention to and processing of this information provides exposure to the within-category variation needed to adapt the architecture of these modules to variation in parental faces, behavior, and so forth (R. Gelman & Williams, 1998). It allows infants to discriminate the voice of their parents from the voice of other potential parents 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, Hains, Lee, Xie, Huang, Ye et al., 2003).

Folk Biology and Folk Physics

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

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

Summary

A long developmental period is an evolved feature of human life history and appears to function in part to enable the fleshing out of folk modules and knowledge. In theory, the necessity of a long developmental period results from the complexity and variability of social relationships and social competition (Alexander, 1989; Geary, 2002b; Geary & Flinn, 2001), and the wide range of biological- and physical-ecological (e.g., mountainous versus desert) niches occupied by humans (Kaplan et al., 2000). In each folk domain, there is evidence for both inherent constraints that guide attention to and the early processing of invariant information patterns, such as human biological motion or human voice patterns (Kuhl, 1994; Freedman, 1974), as well as experience-based modifications of the associated systems to accommodate variation, such as recognition of individual faces, within broader constraints (Pascalis, de Haan, & Nelson, 2002). From this perspective, cognitive development is an integral component of human life history; is centered on cognitive abilities, such as language, that define the folk modules shown in Figure 1; and functions to adapt these inherent modular systems to nuances of the local social group and biological and physical ecologies in which the group is situated.

EVOLUTIONARY EDUCATIONAL PSYCHOLGY

There is a cost to our extraordinary ability to create evolutionarily novel – "biologically secondary" – knowledge and competencies: During the last several thousand years the cross-generational accumulation of cultural knowledge (e.g., through books) has occurred at such a rapid pace (Richerson & Boyd, 2005), that the attentional and cognitive biases that facilitate the modification of folk abilities during children's natural activities do not have evolved counterparts to facilitate the learning of secondary abilities to the same degree. A thorough discussion of the implications are elaborated elsewhere (Geary, 2007a), but I highlight key aspects in the following sections. I begin with the basic premises and principles of evolutionary educational psychology, and then discuss implications for potential motivational and cognitive mechanisms, respectively, that may contribute to the acquisition of secondary knowledge and abilities in school.

Premises and Principles

Evolutionary educational psychology is the study of the relation between folk knowledge and abilities and accompanying inferential and attributional biases as these influence academic learning in evolutionarily novel cultural contexts, especially schools. The fundamental premises and principles of this discipline are presented in Table 1. The premises are that: 1) aspects of mind and brain have evolved to draw the individuals' attention to and facilitate the processing of information that corresponds to the folk domains represented in Figure 1; 2) these primary abilities are modifiable but only within inherent constraints; 3) children are inherently motivated to learn in folk domains, with the associated attentional and behavioral biases resulting in experiences that automatically and implicitly flesh out and adapt these systems to local conditions; and 4) there are evolved aspects of mind and brain whose function is to enable people to cope with within-lifetime variation in social and ecological conditions. These mechanisms operate by enabling people to generate mental representations of potential future conditions and then rehearse behaviors to cope with potential variation in these conditions. These include the core components of fluid intelligence and are the key to understanding secondary learning.

The principles in the bottom section of Table 1 represent the foundational assumptions of evolutionary educational psychology. The gist is that knowledge and expertise that prove to be useful in the social milieu or ecology in which the group is situated are retained and transferred across generations. The transfer occurs in the form of cultural artifacts, such as books, or learning traditions, such as apprenticeships (e.g., Baumeister, 2005; Richerson & Boyd, 2005; Flinn, 1997; Mithen, 1996). Across generations, the store of cultural knowledge accumulates. The result is a gap between accumulating cultural innovations and knowledge and the forms of folk knowledge and abilities that epigenetically emerge with children's self-initiated activities. There must, of course, be an evolved potential to learn evolutionarily novel information and an associated bias to seek novelty during the developmental period and indeed throughout the life span. However, the breadth and complexity of the secondary knowledge available in modern societies will very likely exceed any biases to learn in all of the evolutionary novel domains (e.g., reading, algebra) needed for success in these societies. Schools provide a means to winnow this information and to ensure a core set of skills and knowledge common to all members of the society, as well as a venue for teaching these skills and knowledge.

Motivation to Learn

If the complexities of social dynamics are the key to understanding the evolution of the human mind and brain, then a core motivational bias during development will be to engage in activities that flesh out knowledge related to the self, social relationships, and group dynamics; the core folk psychological domains in Figure 1. Many children are also predicted to be inherently motivated to engage in activities that will flesh out folk biological and folk physical competencies, as described in the section Evolution and Cognitive Development. My point is that theoretical and empirical research on children's early attentional biases and activity preferences can be placed within an evolutionary perspective. And, a broader understanding of these preferences and how they are expressed in school settings has the potential to significantly improve our understanding of children's motivation (or not) to learn biologically secondary material.

Motivation in School

The gist is that children's evolved motivational biases are predicted to be focused on learning in folk domains and that children prefer to engage in this learning through self-initiated play and exploration. These preferred activities are predicted to be tied to themes that have been recurrent during human evolutionary history. Children are also predicted to show a preference for the activities that promote the cross-generational transfer of knowledge in traditional societies. These include the use of stories to convey morals (i.e., cultural rules for social behavior) and other themes relevant to day-to-day living, and apprenticeships, that is, learning culturally important skills (e.g., hunting, tool making) through observation of or direct instruction by more skilled individuals (Brown, 1991). The specific content of stories and apprenticeships is predicted to be centered on features of social dynamics or the ecology that children will need to learn before assuming adult responsibilities in the culture. In other words, there will be universal mechanisms that support the learning of culture specific information (e.g., observational learning; Bandura, 1986), in addition to attentional, motivational, and cognitive mechanisms that automatically and implicitly adapt folk modular systems to social and ecological variation that is common across cultures and was recurrent during human evolution; for instance, a bias to form in-groups and out-groups is universal but the dynamics are variable across cultures and contexts. The combination results in human universals, such as face processing and language, as well as many cultural particulars that are variations on these universal themes.

This approach to children's motivation provides a means of interpreting the findings that many school children value achievement in sports – ritualized practice of organized in-group/out-group competition that is related to group-level folk psychological competencies (Geary, Byrd-Craven, Hoard, Vigil, & Numtee, 2003) – more than achievement in core academic areas (Eccles, Wigfield, Harold, & Blumenfeld, 1993). This also includes why students report that in-school activities are a significant source of negative affect (Larson & Asmussen, 1991). For a nationally (U.S.) representative sample, Csikszentmihalyi and Hunter (2003) found that the lowest levels of happiness were experienced by children and adolescents while they were doing homework, listening to lectures, and doing mathematics, whereas the highest levels were experienced when they were talking with friends (see also Csikszentmihalyi & Larson, 1987). For high-school students, the weekend is the highlight of their week, largely because they can socialize with their peers (Larson & Richards, 1998). A preference for engagement in peer relationships may not be useful for mastery of linear algebra, but it follows logically as an evolved developmental bias for a highly social species; it is necessary to learn about one's specific peer group and how to manage and influence dynamics in this group.

More generally, these findings are consistent with the proposal that schools do not emerge from the self-organizing dynamics of peer relationships but rather are a cultural innovation imposed on children and adolescents by adults to facilitate the cross-generational transmission of secondary abilities (e.g., writing) and knowledge (e.g., that a right angle = 90º). As noted, one result is a gap between the abilities and knowledge children are expected to learn in school and their evolved motivational biases. The formalization of schooling is not, however, completely foreign to our evolved learning and motivational biases because the extended length of childhood and adolescence likely co-evolved with an interest in and ability to transfer culturally important information across generations (Richerson & Boyd, 2005; Flinn, 1997;

Henrich & McElreath, 2003). In other words, a species-typical curiosity about and an ability to learn evolutionarily novel information is predicted, but so are substantive individual differences in the motivation and ability to learn this information. My point is, if there were not a gap between the secondary knowledge needed to function well in modern societies and evolved motivational and learning biases, then the motivational dispositions, interests, and abilities of the creative-productive individuals who developed this secondary knowledge (e.g., Murray, 2003; Simonton, 1999) would be mundane and readily duplicated outside of school. As Pinker (1994) has argued, language is an extraordinary ability that is unique to humans, however its acquisition is mundane and effortless for most children. In contrast, this is not the case for Newtonian physics, or even for elementary reading.

Achievement Motivation

Traditional studies of achievement motivation include children's understanding of the relation between effort and ability on academic outcomes (Nicholls, 1984); valuation of academic learning in terms of mastery (i.e., motivated desire for a deep understanding of the material) or performance (e.g., standing relative to others) goals (Ames & Archer, 1988; Dweck & Leggett, 1988); academic self efficacy (e.g., Bandura, 1993); and expectancy of success and attributions regarding the sources of success or failure (e.g., ability vs. bad luck) in achieving academic goals (Weiner, 1990; Wigfield & Eccles, 2000). An integration of these models and the corresponding literature within an evolutionary framework is beyond the scope of this article, but I illustrate how such integration can be achieved by considering Bandura's (1997) model of social and cognitive self efficacy.

"People make causal contributions to their own functioning through mechanisms of personal agency. Among the mechanisms of agency, none is more central or pervasive than people's beliefs about their capabilities to exercise control over their own level of functioning and over events that affect their lives" (Bandura, 1993, p. 118). Self efficacy is an aspect of this personal agency and at its core is a self-referenced appraisal regarding the likelihood of success in various domains and through this influences, among other things, the pursuit of achievement in these domains and persistence in the face of failure. Bandura emphasizes one's explicit appraisal of efficacy and attributions regarding associated outcomes (e.g., cause of failure). From an evolutionary perspective, these map onto the folk-psychological domains of self awareness, self schema, and the ability to explicitly represent associated information in the conscious-psychological system and in mental models; see Geary (2005, 2007a) for a more complete description. The content of mental models will include attributional biases, expectancies, and other social-learning mechanisms that can influence evaluations of future goals and behavioral persistence in attempts to achieve these goals.

In other words, Bandura's (1993, 1997) model of self efficacy is consistent with an evolutionary perspective, but with different points of emphasis regarding children's academic motivations and corresponding self evaluations. One area of difference is with respect to my prediction of domain-specific and inherent learning and motivational biases associated with folk knowledge (Figure 1) and a much weaker motivational bias for academic learning, such as mathematics. Further, the core of the self schema is predicted, from an evolutionary perspective, to be referenced in terms of one's standing vis-à-vis peers and, importantly, more so for traits that have an evolutionary history than for culture-specific knowledge and abilities. The former include physical abilities and attractiveness, social influence, and family status (Geary, 1998). These are predicted to be universal and to have substantial influences on the development of self schemas and self evaluations. This is contrasted with culturally specific activities, such as schooling, that are predicted to be important in these cultures but less central to most children's and adolescents' emerging self schemas and evaluations. In keeping with this view is the finding that self awareness and the emerging self schema are embedded in a web of social relationships and that the best predictor of global self esteem from childhood to adulthood is perceived physical attractiveness (Harter, 1998, 2006) and not, for instance, grades in high school mathematics classes.

From an evolutionary perspective, the valuation of academic achievement and the relation between achievement and self esteem is predicted to be highly variable across- and within cultures, and to be heavily dependent on explicit parental and cultural valuation of associated activities and outcomes (e.g., grades; Stevenson & Stigler, 1992), and heavily influenced by peers' valuation of academic achievement (Harris, 1995). From a social-learning perspective (Bandura, 1986), many children will imitate parents and teachers who engage in academic activities (e.g., reading); many will come to focus on these activities because they provide access to culturally valuable resources, such as a job and income; and, many will come to enjoy these activities in their own right, developing a mastery orientation (Winner, 2000). Children and adolescents will also develop a sense of academic self efficacy in cultures with formal schooling. These outcomes also follow from an evolutionary perspective that includes evolved modes of cross-generational knowledge transmission.

One important difference comparing the social learning and evolutionary perspectives is with respect to the specificity of predictions: For instance, with successive grades, academic content will increasingly diverge from its evolved foundation, and thus academic learning is predicted to become more difficult and any motivation to engage in this learning is predicted to decrease; and this is the case (Eccles et al., 1993). Social living also becomes more complex and nuanced as people mature into adulthood, but motivational disengagement from social life is predicted to be far less common than disengagement from academic life. These differences follow logically from an evolutionary perspective, but less readily from a strictly social learning perspective.

If our goal is universal education that encompasses a variety of evolutionarily novel academic domains (e.g., mathematics) and abilities (e.g., phonetic decoding as related to reading), then we cannot assume that an inherent curiosity or motivation to learn will be sufficient for most children and adolescents. Children's and adolescent's explicit valuation of academic learning, the perceived utility of academic skills, and the centrality of self efficacy in these areas to their overall self esteem is predicted to be highly dependent on social-cultural valuation of academic competencies, such as explicit rewards for academic achievement (e.g., honor rolls) and valuation of cultural innovators (e.g., Edison). In contrast, the child's and adolescent's valuation and perceived efficacy of their physical traits or social relationships are implicit features of their evolved folk psychology and will manifest with or without cultural supports, contrary to current assumptions regarding the source of the focus on these traits (e.g. Harter, 1998).

Learning in School

Biologically secondary learning is the acquisition of culturally important information and skills using the mechanisms that evolved to enable people to cope with novelty and change within lifetimes, and that enable the cross-generational transfer of cultural knowledge. As described in the section Evolution of Consciousness and Learning, I argued that these mechanisms include the use of working memory and controlled problem solving – core components of general fluid intelligence – to generate mental simulations of social dynamics and ecological changes and to generate and rehearse behavioral strategies to cope with these fluctuating conditions. The other mechanisms include plasticity within folk-modular systems, and the ability to link these systems in novel ways. I begin with discussion of the first set of mechanisms, and use the relation between language and learning to read to illustrate the second.

Fluid Intelligence and Secondary Learning

The correlation between performance on measures of fluid intelligence and ease of learning in evolutionarily novel contexts, especially schools, has been well demonstrated (e.g., Gottfredson, 1997), but it does not inform us as to how these mechanisms affect the learning process, or more deeply how and why they evolved. I illustrate several aspects of the predicted relation, from an evolutionary viewpoint, between fluid intelligence and secondary learning in my 2005 book.

Inhibition of folk biases. By definition, the folk systems result in an automatic attentional focus on evolutionarily salient information, such as facial expressions, and an automatic and implicit processing of this information. Corresponding emotional and behavioral responses also occur automatically and without the need for conscious, effortful control. These are evolved environment-behavior links (Gigerenzer et al., 1999; Simon, 1956), or links that have been learned during the life span. As described in the section Intelligence and Evolutionary Novel Learning, humans also have an extraordinary ability to inhibit these folk systems and mentally construct evolutionarily novel responses. As the knowledge and abilities children are expected to learn in school become increasingly evolutionarily novel, the importance of these inhibitory mechanisms is predicted to become increasingly important for this learning.

In other words, the cross-generational accumulation of secondary knowledge has resulted in academic disciplines (e.g., mathematics) and other knowledge-based features of modern societies that are becoming increasingly remote from folk systems. The result is a conflict between children’s bias to rely on folk systems and the need to inhibit these systems in order to engage in secondary learning. Thus, the 5th principle in Table 1 states that children’s bias to engage in activities that will adapt folk knowledge to local conditions will often conflict with the need to engage in the activities needed for secondary learning. Indeed, educational research supports the importance of inhibitory control for school-based learning (Duckworth & Seligman, 2005) and is consistent with empirical research on the cognitive components of fluid intelligence – specifically, attentional focus and an ability to inhibit irrelevant information from entering working memory (Engle, 2002; Kane & Engle, 2002). My elaboration is in specifying what needs to be inhibited (e.g., peer play) and why.

Process of secondary learning. Although he did not intend it to be a model for school-based learning, Ackerman's (1988) proposed mechanisms that relate fluid intelligence to learning in some other settings provides a useful framework. The learning is divided into cognitive, perceptual-speed, and psychomotor stages (see also Anderson, 1982; and Sweller, 2004), with these different abilities driving individual differences in academic performance at different points in the learning process. For school-based learning, the cognitive stage refers to the relations among working memory, controlled problem solving, and initial task performance. The prediction is that novel and complex tasks will require an attention-driven, explicit representation of task goals and information patterns in working memory. During this phase, the task goals and the sequence of steps needed to perform the task are learned, and memorized. With enough practice, the eventual result is the automatic, implicit processing of task features and automatic behavioral responses to these features. These phases of learning represent the shift from explicit representations and controlled problem solving to automatic, heuristic-based processing of and responding to the task, as represented by the arrow in the center of Figure 2.

Folk Systems and Secondary Learning

The inhibitory, attentional, working memory, and controlled problem-solving components of fluid intelligence are engaged during the initial phase of biologically secondary learning, but the fully developed secondary competencies reside in a distributed network of cognitive and brain systems that differ from those that support fluid intelligence. These distributed systems are predicted to include those that support folk abilities. I am suggesting that the components of fluid intelligence enable the creation of secondary abilities by modifying folk systems, either through changing the range of information to which these systems respond or by integrating systems that would otherwise remain functionally independent. I cannot provide details as to how these mechanisms might operate (see Geary, 2005, 2007a), but do illustrate the gist with discussion of the relations among folk psychological systems and reading.

Reading and, of course, writing are pivotal in terms of recent cultural history, because they are the primary means through which secondary knowledge has accumulated during the past several thousand years (i.e., through books) and are critical to the acquisition of this knowledge in school. From an evolutionary perspective, reading and writing systems initially emerged from the motivational disposition of people to communicate with and attempt to influence the behavior of other people, and are thereby predicted to engage at least some of the same folk psychology systems. In fact, it has been repeatedly argued that reading is built upon evolved language systems (e.g., Mann, 1984; Rozin, 1976). By fleshing out this argument and extending the learning of how to read and reading comprehension to several folk psychological domains, I hope to illustrate how this form of analysis might be used more generally with an evolutionary educational psychology.

Cognitive mechanisms. Research on the cognitive predictors of children’s reading acquisition, the effectiveness of various types of reading instruction, and sources of individual differences in ease of learning to read provides support for the prediction that many core reading competencies are dependent on language systems (e.g., Bradley & Bryant, 1983; Hindson, Byrne, Shankweiler, Fielding-Barnsley, Newman, & Hine, 2005; Mann, 1984; Stevens, Slavin,

& Farnish, 1991; Wagner & Torgesen, 1987). The crucial components in early reading acquisition include a phonemic awareness – explicit awareness of distinct language sounds – and the ability to decode unfamiliar written words into these basic sounds. Decoding requires an *explicit* representation of the sound (e.g., *ba*, *da*, *ka*) in phonemic working memory and the association of this sound, as well as blends of sounds, with corresponding visual patterns [specifically, letters (e.g., *b*, *d*, *k*) and letter combinations, respectively (Bradley & Bryant, 1983)]. Phonetic working memory has also been proposed as the mechanism that supports vocabulary acquisition during natural language learning (Baddeley, Gathercole, & Papagno, 1998; Mann, 1984), but this form of word learning occurs quickly (sometimes with one exposure) and the associated mechanisms operate *implicitly* (Lenneberg, 1969; Pinker, 1994).

The ease with which basic word-decoding skills are acquired in first grade is predicted by the fidelity of children's phonological processing systems (e.g., skill at discriminating language sounds) in kindergarten (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 the written language. In contrast with natural language learning, the majority of children acquire these 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 on several component skills, such as locating main themes and distinguishing 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).

Another evolution-based prediction is that reading comprehension will be dependent in part on theory of mind and other folk psychological domains, at least for literary stories, poems, dramas, and other genre that involve human relationships (Geary, 1998). Most of these stories involve the recreation of social relationships, more complex patterns of social dynamics, and even elaborate person schema knowledge for main characters. The theme of many of the most popular genre involves the dynamics of mating relationships (e.g., romance novels) and competition for mates, and often, involves use of 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. In addition, some people are predicted to be interested in reading about mechanical things (e.g., the magazine *Popular Mechanics)* and biological phenomena (e.g., the magazine *Natural History*). For instance, the content of children's literature also includes other living things, such as dinosaurs, and thus may capture an inherent interest in folk biology.

Brain mechanisms. The neuroanatomy of language abilities is well known (Price, 2000), and has substantive overlap with the brain regions that support phonological decoding, reading fluency, and text comprehension (Paulesu, Démonet, Fazio, McCrory, Chanoine, Brunswick et al., 2001; Price & Mechelli, 2005; Pugh, Shaywitz, Shaywitz, Shankweiler, Katz, Fletcher, & Skudlarski et al., 1997; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). In a review of neuroscience research on language processing, Price (2000) concluded, among other things, that passive processing of language sounds occurs in the traditional Wernicke's area (part of the temporal cortex); speech production involves Broca's area and areas that support word articulation (part of the frontal cortex); and, the representations of the meaning of spoken and heard utterances is distributed across the temporal and parietal cortices. Prefrontal working memory areas related to language are engaged when the speaker or listener has to make active decisions about the utterances (Poldrack, Wagner, Prull, Desmond, Glover, & Gabrieli, 1999); the need for active decisions suggests that well-learned or evolved heuristics are not sufficient in these circumstances, thus triggering explicit problem solving.

Brain imaging studies of individuals with normal reading acquisition and those with reading disability have provided insights into the areas of convergence and divergence comparing reading and natural language processing. Among other regions, tasks that tap phonological awareness or involve phonological decoding engage Wernicke’s and Broca’s areas (Paulesu et al., 2001; Turkeltaub et al., 2003), as do tasks that involve the reading of single words (Pugh et al., 1997). Word reading also engages areas in the temporal and parietal cortices that support the comprehension of spoken utterances (Price & Mechelli, 2005). Early research on the comprehension of the syntax and the basic meaning of read sentences suggested engagement of the same brain regions that support the production and comprehension of spoken utterances, including Broca’s and Wernicke’s areas (Just, Carpenter, Keller, Eddy, & Thulborn, 1996). Subsequent studies are generally consistent with this finding, but also suggest that involvement of other regions of the temporal cortex and part of the parietal cortex are involved in language comprehension (Caplan, 2004; Price, 2000).

There are also important differences between language processing and reading. Areas at the junction of the temporal and occipital lobes are more likely to be engaged during reading than during natural language processing. This is not surprising because learning to read and skilled reading in adulthood involve the integration of the visual systems that process the orthography of written symbols and those that translate these images into the language-based sounds that support the comprehension and production (e.g., reading aloud) of the read material (Simos, Fletcher, Francis, Castillo, Pataraia, & Denton, 2005; Paulesu et al., 2001). One intriguing exception to this pattern of divergence occurs for natural object naming. Objects are identified visually and their naming with natural language may engage the same temporal/occipital region used during the translation of the orthography of written symbols (Price & Mechelli, 2005). This is intriguing because during the initial phases of reading acquisition, attentional focus on the relation between the sound and written letter or word should result in the amplification of the activity of the brain regions that process these auditory and visual forms of information, and result in their simultaneous representation in working memory.

In other words, this aspect of reading acquisition may be dependent on the modification of the brain areas that evolved for object naming (Price & Mechelli, 2005). The reading of printed words involves integration of two biologically primary systems. The first supports the naming and description of *visually* processed objects in the real world and the second involves the access to concepts associated with these utterances. With repeated simultaneous activation of these visual and auditory pieces of information in working memory, the association becomes represented in long-term memory and thus becomes implicit knowledge, representing Ackerman’s (1988) final stages of learning. When this is achieved, the association between the sound and letter, or letter combination and word sound, is automatically triggered when the letter string is processed during the act of reading and thus no longer requires working memory. In keeping with this prediction, one potential source of reading disability is a poor white-matter connection between these object naming and phonetic/semantic brain regions (Paulesu et al., 2001).

Shall Ever the Twain Meet?

My description of the disconnect between children's evolved motivational biases and the motivational focus needed to excel in modern academic domains and the gap between primary competencies and secondary knowledge that is rapidly accumulating in modern societies is, at first blush, rather discouraging. Our lives and those of our children would be considerably easier, if all children found academic learning as engaging as they find interacting with their peers and as effortless as learning their native language. The value of an evolutionary approach to education is not only to better understand the roots of motivational and learning challenges that children face in modern schools, but also to provide a different perspective on what might be done to facilitate children's engagement of and success in academic learning. In a commentary on a lengthier essay on this topic (Geary, 2007a), Berch (2007) and Bjorklund (2007a) suggested that I have taken the distinction between primary and secondary abilities and knowledge, as well as the attendant motivational distinctions, too far. I agreed (Geary, 2007b), and still do. In the following sections, I suggest a few first steps to moving evolutionary educational psychology from an abstract discipline to one that can help guide educational practice.

Taking Advantage of Evolved Motivational Biases

Bjorklund (2007b) and Berch (2007) argued that under some conditions children's social play and discourse as well as other natural modes of learning can be used to facilitate the acquisition of academic skills. I am not as enthusiastic about this possibility as they are, but I do believe it has merit, especially during the transition to schooling. The key may be to capitalize on the fuzzy boundary between primary and secondary domains during the early years of schooling (see below) and children's motivation to learn culturally important knowledge and to use these to build academic self efficacy and other beliefs that will help to maintain effort and motivation in school learning in later years (Bandura, 1993; Weiner, 1990). Children's natural interest in novelty and their motivation to learn their culture will get them started but is not predicted to maintain long-term academic learning, contra Rousseau (1979) and other “romantic” approaches to education (see Hirsch, 1996). These approaches have rested on an assumption of a smooth continuity between primary domains, such as language, and secondary domains, such as reading, and thereby assume children are inherently motivated to engage with secondary materials, such as books, and will learn to read automatically and effortlessly during this engagement. I am proposing that this is an educationally fatal error, except perhaps during the transition from primary to secondary learning.

In the Motivation to Learn section, I argued that children’s evolved behavioral biases, such as social play, and their observation of and learning from culturally successful adults results in the automatic and effortless modification of folk systems and the learning of the forms of culturally important activities, such as hunting, that have a long evolutionary history. For these domains and activities, there are corresponding motivational biases that ensure that children engage in the necessary activities. If we assume that children are inherently motivated to learn in secondary domains and learn them as effortlessly as they learn in primary domains, then we risk undervaluing the importance of focus and effort for secondary learning. The necessity of focus and effort follows directly from the attentional and inhibitory working memory mechanisms that I proposed evolved for secondary learning (Geary, 2005). Without an explicit assumption that learning will require effort, we risk having children assume that school learning will occur effortlessly. When effort is required for learning and children begin to experience failure, they are at risk for making attributions that may undermine their later engagement with school.

Many children in the United States, for instance, assume that learning mathematics requires inherent talent or ability and thus disengage when the material becomes difficult. This attributional error may be a direct and harmful consequence of ill-informed educational theories that include an assumption of a smooth continuity between primary and secondary learning. Fortunately, experimental studies show that changing the attributions from ability to effort enhances middle-school children's engagement in mathematics classes and improves their learning (Blackwell, Trzesniewski, & Dweck, 2007). These children would have been better served with a belief in the importance of effort from the beginning of their formal schooling.

During these early years of schooling, including informal instruction during the preschool years, there is necessarily a fuzzy boundary between primary and second abilities: If my proposal that secondary learning is built on primary systems is correct, then this gray area follows as a necessary consequence. I provide an illustration of a cognitive transition from primary to secondary abilities in this boundary area in the next section. This transitional period may also be critical for influencing children's attributions about learning and instilling an expectation that learning often requires effort. During this transition, the novelty and cultural importance (e.g., due to observation of parental reading) of secondary domains (e.g., reading, addition) will motivate children to engage with this material. The transition is also a time when many, if not all, children will consistently experience failure, because the mechanisms that support primary learning will not always be sufficient for secondary learning. My hypothesis is that children will have a greater sense of personal control over their learning and will better sustain their focus and motivation as academic material becomes increasingly remote from primary domains, if we explicitly inculcate a belief that effort is necessary for many types of learning in school.

Indeed, a focus on the importance of effort, as contrasted with ability, for learning in school is common in many countries with high levels of academic achievement (Stevenson, Lee, Chen, Stigler, Hsu, & Kitamura, 1990), and thus my hypothesis may not seem novel. My points are 1) an understanding of children's evolved motivational dispositions will anchor theory and debate in education and may help to stop the pendulum swings in theory and practice that have been occurring in this field for more than a century (Hirsch, 1996); and, 2) this approach predicts that the transitional period between primary and secondary learning may be critical in terms of implementing interventions focused on children's beliefs about academic learning.

Overlap in Primary and Secondary Learning

As many parents know, picture books can serve as a useful introduction to reading, and their use makes sense from an evolutionary perspective for two reasons. First, the initial introduction is in the context of parent-child interactions, a human universal (Brown, 1991). Second, the pictures are of objects that occur in the real world and thus the combination of parental pointing and naming capitalize on evolved object naming and language learning systems. A parent pointing to a picture of an apple in a book and stating "apple" is in the fuzzy boundary between primary and secondary activities. It is very similar to how a parent would name an actual apple when interacting with a child, but it is represented in an evolutionarily-novel format. Motivating children to engage with picture books, especially when this involves social interaction, should not be difficult and provides a natural, so to speak, transition from a primary form of social discourse to the introduction to print material.

However, from an evolutionary perspective the transition from pictures to print is not the same as the transition from naming real objects to naming pictures of objects. This is because print is an arbitrary set of abstract symbols that do not resemble objects in the real world much less resemble the specific objects they – specific words – represent. Of course, the word sounds for objects differ from one language to the next and are also arbitrary, but the language system has evolved to easily develop associations between pronounced words of any human language and objects, people, places, and so forth to which they refer (Baddeley et al., 1998; Pinker, 1994). In contrast to the universality of human language, phonetic alphabets emerged in at most only a few cultures and are a very recent part of human history. Writing appears to have emerged about 5,000 to 10,000 years ago. The first forms are debated but appear to have included tokens that represented something of value (e.g., a quantity of grain) and pictorial representations (e.g., Schmandt-Besserat, 1996). The use of tokens and pictographs provide a permanent record – one that is easily transferred across cultures and generations – of otherwise fleeting utterances and would be a comparatively easy transition from the natural object naming system; although early writing may have also had some phonetic features. In any case, the emergence of complex phonetic languages involved gradual refinements of these early writing systems over the course of several millennia.

Given its cultural origin and recent emergence, the reading of written symbols is by definition a complex evolutionarily novel skill. On the basis of my model, learning how to read these symbols and especially to decode and blend their phonetic features is predicted to require engagement of the systems that have evolved to acquire secondary competencies. The secondary component, as I noted in the Folk Systems and Secondary Learning section, appears to involve the modification of features of the visual object naming system for processing orthographic code and linking these with the comprehension and production systems of natural language. The modification of the visual object naming system and its linking to other natural language systems is predicted to involve the attentional control and inhibitory mechanisms of working memory. The result is the simultaneous and explicit representation of written symbols and corresponding language sounds in conscious awareness, and the eventual formation of letter-sound an letter combination-word sound associations, as I described above.

If this proposal is correct, explicit instruction in phonetic decoding, blending, and other aspects of formal reading are predicted to be necessary for most children. This was concluded by the National Reading Panel (2000), after decades of debate. With a theoretically anchored approach to education, we can avoid these types of debilitating debates for other evolutionarily novel, secondary domains.

Conclusion

Debates over whether children's interests, learning, and motivation are influenced by evolved biases or by social and cultural factors are misguided and result in a false dichotomy. Humans have evolved to create culture – a system of shared ideologies and rules for social behavior that enable the formation of large cooperative groups (Baumeister, 2005; Richerson & Boyd, 2005) – and children and adults have evolved learning and motivational mechanisms that support the retention and cross-generational transfer of culturally useful knowledge. These mechanisms include child-initiated play, observational learning, and adults' use of stories and apprenticeships to teach cultural knowledge to children. However, we are now at a point in human history where the store of cultural knowledge and the array and complexity of evolutionarily novel abilities needed to function in modern societies has outstripped the capacity of these evolved learning and motivational mechanisms. Schools emerged in these societies to address the limitations of these mechanisms and to formalize the cross-generational transfer of knowledge. Said differently, schools are the central interface between evolution and culture – they are the venues in which children's evolved biases in learning and motivation intersect with the need to learn evolutionarily novel abilities and knowledge that have accumulated during the past several millennia.

Evolutionary educational psychology is the study of how inherent bias in children's learning and motivational systems influence their ability and motivation to learn evolutionarily novel academic abilities and knowledge in school. This evolutionarily informed education science has the potential to answer key questions in instruction and learning, such as why many children need explicit instruction to learn word decoding and text comprehension but do not need such instruction to produce and understand natural language. And, why many children value peer relationships more than they value academic learning. Equally important, the mechanisms I outline here and elsewhere (Geary, 2005, 2007a b) 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. As an example, effective instruction in evolutionarily novel academic domains will be dependant on the same attentional control and working memory systems that evolved to cope with variation and novelty within lifetimes, and leads to the hypothesis that many children will need to have any associated problem-solving steps explicitly organized by instructional materials and extensively practiced for long-term retention. I outlined the basic argument for reading, but it also applies, in theory, to all other secondary domains, as illustrated by Sweller's (2004) studies of algebraic problem solving.

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Table 1: Premises and Principles of Evolutionary Educational Psychology

Premises

1. Evolutionarily salient resources fall into three broad categories: social, biological, and physical, which correspond to the respective domains of folk psychology, biology, and physics.

2. Attentional, perceptual, and cognitive systems, including attributional biases, have evolved to process information in these folk domains and to guide strategies that facilitate gaining access to these resources. These systems are largely modular in that they process restricted classes of information.

3. Children are biologically biased to engage in activities that recreate the ecologies of human evolution; these are manifested as social play, and exploration of the environment and objects. The accompanying experiences interact with the inherent but skeletal folk systems and flesh out these systems such that they are adapted to the local social group and ecology.

4. To cope with variation in social or ecological conditions, systems that enabled the mental generation of potential future conditions and enabled rehearsal of behaviors to cope with this variation evolved. The supporting attentional and cognitive mechanisms are known as general fluid intelligence and everyday reasoning.

Principles

1. Culture is built from the cognitive and motivational systems that support folk domains. Cultural innovations (e.g., scientific method) are retained across generations through artifacts (e.g., books) and traditions (e.g., apprenticeships). These advances result in a gap between folk knowledge and the theories and knowledge base of the associated sciences and other disciplines.

(table continues)

Table 1 continued

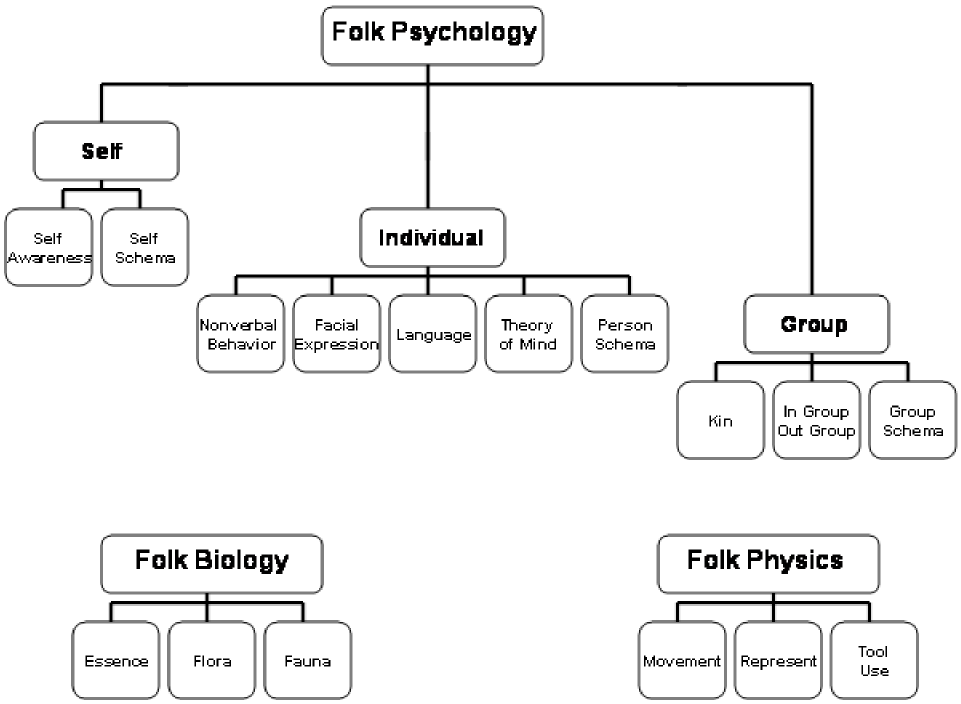
2. Schools are cultural innovations that emerge in societies in which scientific and cultural advances result in a gap between folk knowledge and the competencies needed for living in the society.
3. Schools organize the activities of children so they can acquire the biologicallysecondary competencies that close the gap between folk knowledge and the demands of the society.
4. Biologically secondary competencies are built from primary folk systems and the components of fluid intelligence that evolved to enable individuals to cope with variation and novelty.
5. 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.

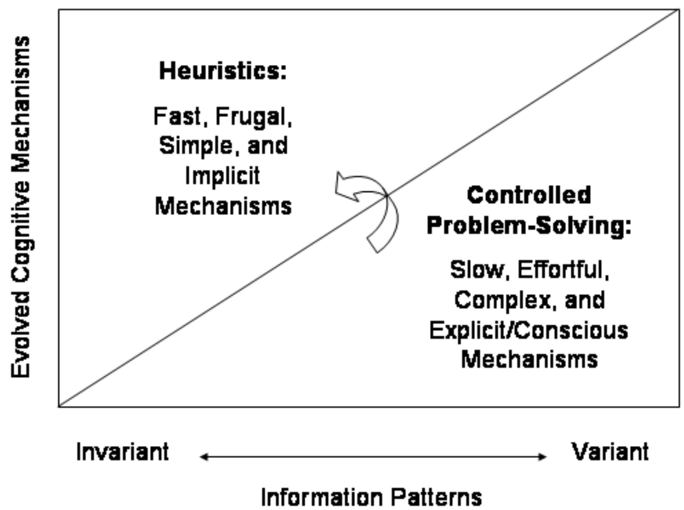
Adapted from "Educating the educating the evolved mind: Conceptual foundations for an evolutionary educational psychology," by D. C. Geary, 2007a, in J. S. Carlson & J. R. Levin (Eds.), *Educating the evolved mind*, p. 35, Greenwich, CT: Information Age.

Figures

Figure 1: Evolutionarily salient information-processing domains, and associated cognitive modules that compose the domains of folk psychology, folk biology, and folk physics.

Figure 2: : 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. 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. Reprinted with permission.


Folk Psychology
Self
Self Awareness
Self Schema
Individual
Nonverbal Behavior
Facial Expression
Language
Theory of Mind
Person Schema
Group
Kin
In Group Out Group
Group Schema
Folk Biology
Essence
Flora
Fauna
Folk Physics
Movement
Represent
Tool Use


Evolved Cognitive Mechanisms
Heuristics:
Fast, Frugal, Simple, and Implicit Mechanisms
Controlled Problem-Solving:
Slow, Effortful, Complex, and Explicit/Conscious Mechanisms
Invariant
Variant
Information Patterns