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Principles of evolutionary educational psychology

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Abstract

Evolutionary educational psychology is the study of the relation between evolved systems of folk knowledge and inferential and attributional biases as these relate to academic learning in modern society. Following discussion and illustration of the mechanisms of natural selection and their application to human motivational, cognitive, and behavioral evolution, the basic premises and principles of evolutionary educational psychology are outlined. The gist is that the evolved cognitive systems and inferential biases that define folk knowledge are not sufficient for academic learning, but, at the same time, are the foundation from which academic competencies are built. A theoretical frame outlining the relation between folk knowledge and academic development is proposed and implications for motivational issues and instructional practices are detailed. © 2002 Published by Elsevier Science Inc.

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1. Introduction

The principles of natural and sexual selection are being used to guide theoretical and empirical research in the behavioral and social sciences with increasing frequency (e.g., Buunk, Angleitner, Oubaid, & Buss, 1996; Gangestad & Thornhill, 1998; Geary, 1998a; Pinker, 1997; Taylor et al., 2000). Nearly all of this research has focused on social behavior, cognitive mechanisms, and other phenomena that are thought to be evolved and universal adaptations, that is, features of human behavior (e.g., language) that are evident in all cultures (e.g., Tooby &

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Cosmides, 1995). The search for universal adaptations has generated both controversy and substantive theoretical and empirical advances. At the same time, the focus on universal adaptations has directed attention away from an equally important issue, that is, the relation between evolved social and cognitive biases and the expression and acquisition of culturally specific behaviors and cognitions (Flinn, 1997). Of particular relevance to modern society is the relation between evolved social and cognitive biases and children's motivation and ability to learn in school (Geary, 1995), as school-taught competencies influence employability, wages, and the ease of day-to-day living in these societies (e.g., Grogger & Eide, 1995).

Accordingly, the goal here is to develop a theoretical framework that outlines the relation between universal social and cognitive adaptations and academic learning, and provides direction for future instructional research. To fully comprehend the foundations of the model, a primer on the mechanisms of natural and sexual selection in general and as related to human evolution in particular is needed and provided in the first part below. The basic premises and principles of evolutionary educational psychology are provided in the second part, along with discussion of related motivational and instructional implications.

2. Evolution of behavior and cognition

The goal of this section is to provide a basic conceptual frame for understanding the evolved functions of behavior and cognition. The frame provides the needed context for contrasting the academic demands in modern schools with the inherent motivational, cognitive, and behavioral biases of children, as these would be expressed in ecologies more similar to those in which humans evolved (Geary & Bjorklund, 2000). The Section 2.1 provides a primer on selection mechanisms and Section 2.2 outlines a model of evolved motivational, cognitive, and behavioral systems in humans. These evolved systems provide the scaffolding upon which many academic competencies are built.

2.1. Principles of evolutionary selection

2.1.1. Basic mechanisms

The fundamental observations and inferences that led to the insights of Darwin (1859) and Darwin and Wallace (1858) regarding natural selection and evolutionary change are shown in Table 1. Of particular importance is individual differences, which largely result as a consequence of sexual reproduction (e.g., Hamilton & Zuk, 1982; Williams, 1975). "These individual differences are of the highest importance for us, for they are often inherited, as must be familiar to every one; and they thus afford materials for natural selection to act on and accumulate" (Darwin, 1872, p. 34). The process of evolutionary selection occurs when variability in a characteristic, such as beak size (see below), covaries with variability in survival prospects (Price, 1970). If the characteristic is inherited, then the survivors will produce offspring who also have a somewhat shorter (or longer) beak than did less successful conspecifics (i.e., members of the same species). If the characteristic continues to covary with survival prospects in the offspring's generation, then the process will repeat itself. Over many

Table 1
Darwin's and Wallace's observations and inferences

Observation	
(1)	All species have such high potential fertility that populations should increase exponentially.
(2)	Except for minor annual and rare major fluctuations, population size is typically stable.
(3)	Natural resources are limited, and in a stable environment, they remain constant.
Inference	
(1)	More individuals are borne than can be supported by available resources, resulting in competition for those resources that covary with survival prospects.
Observation	
(1)	No two individuals are exactly the same; populations have great variability.
(2)	Much of this variability, or individual differences, is heritable.
Inference	
(1)	Prospects for survival are not random but covary with the heritable characteristics (genetics) of individuals. The resulting differential survival is natural selection.
(2)	Over generations, natural selection leads to gradual change in the population, that is, microevolution, and production of new species, that is, macroevolution or speciation.

Observations and inferences are based on Darwin (1859), Darwin and Wallace (1858), and Mayr (1982).

generations and sometimes in a single generation, there is a change in the selected characteristic, such that the average individual in the population now has a shorter (or longer) beak than did the average individual several generations earlier. This process of natural selection shapes species to their ecology, and will occur whether the trait is physical, physiological, or behavioral.

Whereas natural selection generally refers to factors, such as illness caused by parasites, that influence survival prospects, sexual selection refers to social factors that influence reproductive prospects (see Andersson, 1994; Darwin, 1871; Geary, 1998a). These social dynamics involve intrasexual competition over access to mates, typically male–male competition, and intersexual choice of mating partners, typically female choice. For most species, the combination of male–male competition and female choice influences which males reproduce and which do not. Females choose mates on the basis of indicators of physical or genetic health, and these choices often influence the health of her offspring and thus her lifetime reproductive success (i.e., the number of offspring that survive to adulthood and reproduce). The result is the evolution of traits that facilitate intrasexual competition, such as antlers used by male antelope during male–male competition, or traits that facilitate mate choice, such as the bright plumage (an indicator of physical health) of the males of many species of bird (see Andersson, 1994).

The process of natural or sexual selection acting on variability can be complicated, however. Selection pressures can reduce or eliminate heritable variability, and thus, many traits that have undergone strong selection in the past no longer show heritable variability (e.g., all genetically normal human beings have two legs, an inherited but nonvariable characteristic). Selection pressures can also vary from one generation to the next or from one geographical region to the next. At times, when food is abundant and predators and parasites are scarce, selection pressures are weak and individual differences do not covary with survival or reproductive outcomes. Strong selection results when competition is intense and individual variability in associated traits covaries strongly with survival or reproductive outcomes.

2.1.2. Darwin's finches

The power of natural selection for generating evolutionary change is nicely illustrated by the work of Grant and Grant (1989, 1993) (see Geary, 1998a for examples of sexual selection). For several decades, the Grants have been studying the relation between ecological change on several of the Galápagos islands — Daphne major and Genovesa — and change in the survival rates and physical characteristics of several species of finch that reside on these islands, often called Darwin's finches. As an example of how natural selection acts on variability to produce evolutionary change, consider the medium ground finch (*Geospiza fortis*), a species that resides on Daphne major. Fig. 1 shows that individual medium ground finches naturally vary in beak size. To the left is an individual with a relatively small beak and to the right is an individual of the same age and sex with a relatively large beak. The distributions show that the beak size of most individuals will fall between these two extremes.

Under some conditions, individual differences in beak size covary with survival and reproductive outcomes because the size and shape of an individual's beak determine which foods can be eaten and which foods cannot (Grant & Grant, 1993). When food sources (e.g., seeds, insects) are plentiful and varied, there is little relation between beak size and survival or reproductive outcomes. When foods are scarce, individual birds that are able to specialize in a relatively abundant food source — due to beak size and shape — survive and reproduce in greater numbers than do individuals whose beak size and shape force them to specialize in a scarce food source. To illustrate, there was very little rain on Daphne major in 1973. The result was an 84% decline in the quantity of foods available to Darwin's finches and a sharp

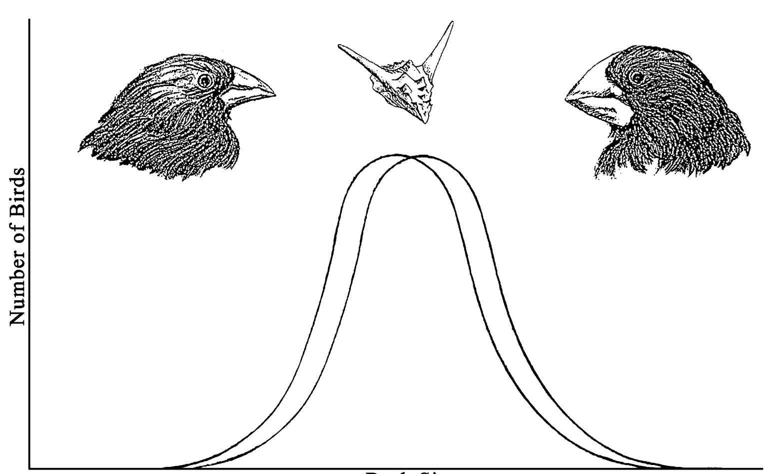

Fig. 1. Cross-generational change in average beak size in the medium ground finch (*G. fortis*). Illustration by Christopher Nadolski.

increase in finch mortality rates (Weiner, 1995). One of the foods that was relatively plentiful during this time was the seeds of the caltrop plant (*Tribulus cistoides*). These seeds are encased in mericarps—shown in the center of Fig. 1—which are armored with spikes and relatively large, at least for a finch. Medium ground finches with relatively large beaks were able to break open mericarps to get to the seeds and thus survived in greater numbers than did those with relatively small beaks.

To make matters worse, survivors with relatively small beaks were at a mating disadvantage. It appears that short-beaked males were weaker than their better-fed large-beaked peers, which appeared to result in a difference in the vigor of their courtship displays: Female medium ground finches choose mates based on the vigor of these displays and thus preferred large-beaked males. The combination of differential survival rates and female choice resulted in a measurable shift in the next generation's average beak size, as illustrated in Fig. 1. The leftmost distribution represents the beak size characteristics before the drought and the rightmost distribution represents these characteristics after the drought. Just after the drought, individual differences in beak size are still evident, but the average beak size has now increased and there are fewer individuals with extremely small beaks and more individuals with extremely large beaks.

For the medium ground finch, having a beak that is larger than average is not inherently better than having a beak that is smaller than average, it is only beneficial during periods of drought. In 1982–1983, an especially strong El Niño event resulted in a 14-fold increase in rainfall on Daphne major (Grant & Grant, 1993). Following this heavy rainfall, the number of caltrop plants and their mericarps decreased significantly and the number of smaller seeds available on the island increased significantly. "Mechanical efficiency of handling small seeds appears to be a feature of finches with small beaks" (Grant & Grant, 1993, p. 114). The result was that small-beaked individuals survived in greater numbers than did large-beaked individuals and small-beaked males were preferred as mating partners. After several generations of differential survival and mating success, the average beak size of medium ground finches was now smaller than it was just after the drought—the distribution had shifted back to the left. In this example, the average beak size covaried, across generations, with ecological change and the resulting change in food availability, but these changes were not consistently in one direction (favoring larger beaks) or the other (favoring smaller beaks).

In other cases, selection is more consistently directional, resulting in more permanent changes in the selected characteristic. Although many issues remain to be resolved, there is now empirical evidence for directional selection in several dozen species (Endler, 1986; Kingsolver et al., 2001). Kingsolver et al. recently reviewed the associated field studies to estimate the strength of the covariation between individual differences in specific characteristics, such as beak size, and evolutionarily relevant outcomes, such as survival probability or number of offspring. It is not surprising that there was considerable variation, across species, contexts, and characteristics, in the strength of the relation between individual differences in these characteristics and evolutionary outcomes. The medium effect size indicated that being 1 S.D. above (e.g., larger beak) or below (e.g., smaller beak) the mean was associated with a 16% increase in fitness (e.g., in probability of mating success). An effect of this size is considered to represent relatively weak selection. Still, if the heritability of any such trait was only 0.25, "then selection of this magnitude would cause the trait to change by one standard deviation in only 25 generations" (Conner, 2001, p. 216), or in 12–13 generations with a heritability of 0.50. When applied to humans, weak directional selection on a trait that showed only modest heritability could result in a 1 S.D. change in the mean of this trait in less than 300 years.

2.2. Evolutionary model for human behavior and cognition

The heritable variability found for most human behavioral and cognitive traits (e.g., Bouchard, Lykken, McGue, Segal, & Tellegen, 1990) indicates that natural and sexual selection will shape these traits to the extent that the associated individual differences covary with survival or reproductive outcomes. There is, for instance, evidence that human reproductive activity and parental behavior have heritable components (e.g., Kirk et al., 2001; Pérusse, Neale, Heath, & Eaves, 1994) and that individual differences in the associated traits (e.g., parental investment) covary with reproductive outcomes in Western society and with infant and child mortality risks in preindustrial and industrializing societies (for reviews, see Geary, 2000; Geary & Flinn, 2001). Under such conditions, human reproductive activity and parental behavior will per force be shaped by evolutionary selection.

Evidence for selection acting on other human cognitive and behavioral biases is less direct, but can be inferred through careful consideration of comparative research and studies of the hominid fossil record (e.g., cranial capacity). With respect to cognition and development, the fossil record suggests substantive evolutionary change in brain size and in the length of the developmental period during the past 2 million years of human evolution. In comparison to our most recent hominid ancestor, *Homo erectus*, both brain size and length of the developmental period appear to have increased by about 50% (see McHenry, 1994; Ruff, Trinkaus, & Holliday, 1997). Comparative research indicates that brain size and length of the developmental period covary with complexity of social relationships across species of living primate (Barton, 1996, 1999; Joffe, 1997). Complex social relationships in adulthood (e.g., mating competition; Sawaguchi, 1997) are associated with a large neocortex and a long developmental period, the combination of which likely enables individuals to learn the nuances of living and reproducing in a complex social system (Geary, in press; Geary & Bjorklund, 2000).

The pattern suggests that the primary section pressures acting on the coevolution of brain size and length of the developmental period involve social demands, such as those required to develop and maintain relationships with a large number of conspecifics and for mate competition (Dunbar, 1993; Barton, 1996). For humans, social demands must be considered in the context of ecological dominance, that is, in most ecologies, human groups have achieved a level of control over essential resources (e.g., food, use of land) that is not evident in most other species (for further discussion, see Alexander, 1989). As noted by Alexander (1989):

> the ecological dominance of evolving humans diminished the effects of 'extrinsic' forces of natural selection such that within-species competition became the principle 'hostile force of nature' guiding the long-term evolution of behavioral capacities, traits, and tendencies, perhaps more than any other species. (p. 458)

Once ecological dominance was achieved, the traits that began to strongly covary with individual differences in survival and reproductive outcomes were those that allowed hominids to socially “outmaneuver” other hominids (Humphrey, 1976). These traits would include sophisticated social competencies, such as language and theory of mind, an accompanying increase in brain size, and other adaptations that facilitated the formation and maintenance of kin-based social coalitions that compete with other coalitions for resource control (Geary & Flinn, 2001). In other words, when the primary selection pressures result from social competition, then natural selection is not simply a struggle for existence, as it is for Darwin’s finches (Darwin, 1859; Darwin & Wallace, 1858). Rather, selection can be conceptualized as resulting from competition with other human beings and coalitions in an attempt to gain access to and control of the resources that covary with survival and reproductive outcomes in the local ecology (Geary, 1998a).

Section 2.2.1 below describes a model for conceptualizing the associated motivation to control (see also Heckhausen & Schulz, 1995), and Section 2.2.2 provides a taxonomy for evolved domains of the human mind (Geary, 1998a, 1998b; Geary & Huffman, in press). Section 2.2.3 places the propositions outlined in the Sections 2.2.1 and 2.2.2 in a developmental context. The combination of sections provides the foundation needed to derive the basic premises and principles of evolutionary educational psychology.

2.2.1. Motivation to control

Although there is considerable empirical support for the proposal that humans have a basic motivation to achieve some level of control in their life (Heckhausen & Schulz, 1995; Shapiro, Schwartz, & Astin, 1996; Thompson, Armstrong, & Thomas, 1998), there is no empirical evidence that this is an evolved motivational disposition. However, when viewed in terms of the mechanisms of natural and sexual selection, it is necessarily true that any motivational, behavioral, or cognitive mechanism that is directed toward the goal of achieving access to and control of the resources that covary with survival and reproductive outcomes will necessarily evolve, to the extent that individual differences in the fidelity of these mechanisms are heritable (Price, 1970). Stated somewhat differently, a fundamental motivational disposition of human beings, and all other species, will be to gain access to essential resources (e.g., food) and attempt to influence social relationships in ways that enhance the well being of the individual and his or her kin.

The motivational disposition must, of course, be integrated with emotional, cognitive, and behavioral systems that support attempts to achieve access to and control of essential resources. Geary (1998a, 1998b) called the combination *functional systems* and argued that they must be comprised of (1) the motivational disposition that channels the goal-directed activities of the individual; (2) an emotional component that provides feedback to the individual as to the effectiveness of goal-directed activities (e.g., negative affect prompts a change in behavioral strategy); (3) a cognitive component that allows the individual to process goal-relevant information; (4) a psychological component, such as fantasy, that allows the individual to mentally construct and rehearse control-related behavioral strategies; and, (5) a behavioral component that allows the individual to act on the environment and attempt to achieve the goal in question. The relations among these components are

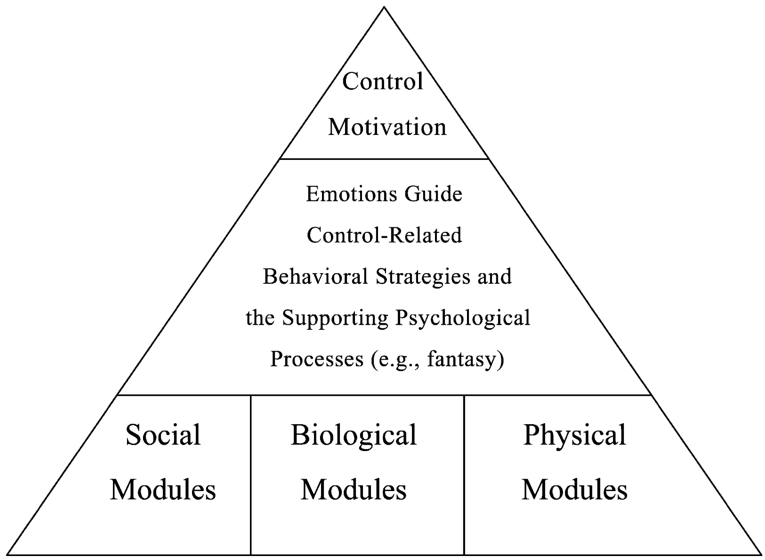

Fig. 2. The motivation–emotion–cognition triangle [Geary, D. C. (1998). *Male, female: the evolution of human sex differences* (p. 160). Washington, DC: American Psychological Association. Reprinted with permission.].

represented in Fig. 2. The apex of the triangle represents the fundamental control-related motivational disposition. The midsection shows that emotional responses to control-related activities act to modify and direct control-related behavioral strategies and the supporting psychological systems (e.g., fantasy). As represented by the base of the triangle, it is assumed that survival and reproduction-related resources fall into three broad categories, social (e.g., competition for mates), biological (e.g., food), and physical (e.g., territory).

2.2.2. Evolved domains of mind

As stated, the cognitive domains associated with the motivation to control are designed to process information regarding social, biological, and physical resources and coalesce around the general areas of folk psychology, folk biology, and folk physics (e.g., Atran, 1998; Baron-Cohen, 1995; Pinker, 1997; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Although there appear to be other evolved functional domains that are of educational relevance — such as for the processing of basic numerical and other mathematics-related information as discussed later (Geary, 1995, 2001) — the position here is that the domains shown in Fig. 3 capture the essential functional competencies of human beings living in natural environments. The extent to which these modular competencies are the result of inherent constraint or patterns of postnatal experience is vigorously debated (e.g., Finlay, Darlington, & Nicastro, 2001; Gallistel, 1995; Pinker & Bloom, 1990; Tooby & Cosmides, 1995), the details of which are beyond the scope of this treatment. It is, however, assumed that these competencies emerge through an interaction between inherent constraint and patterns of developmental experience, that is, through an epigenetic process (Geary & Bjorklund, 2000; Geary & Huffman, in press; Gottlieb, 1992; Hall, 1992).

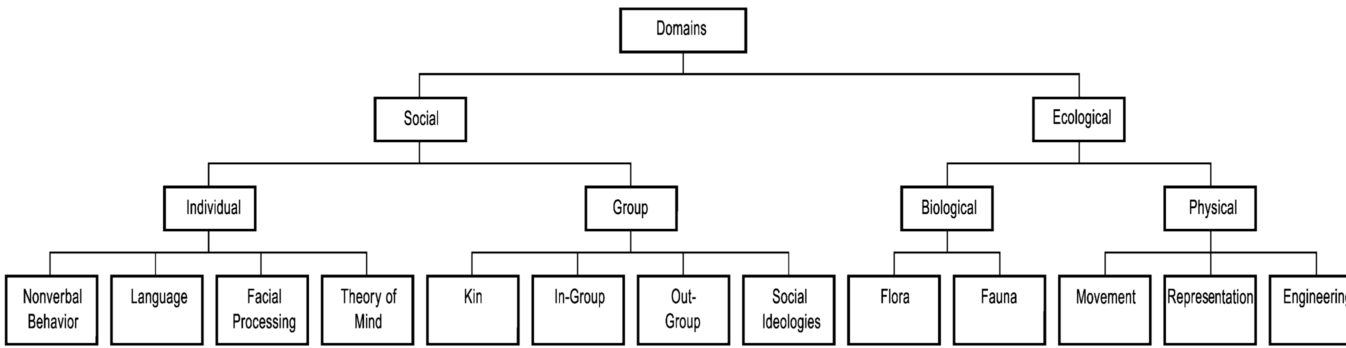

Fig. 3. Proposed taxonomy of evolved domains of the human mind [Geary, D. C. (1998). *Male, female: The evolution of human sex differences* (p. 180). Washington, DC: American Psychological Association. Reprinted with permission.].

In any case, it follows from ecological dominance and social competition that a considerable proportion of human cognitive and brain systems will be designed to process social information. Among the central functions of these sociocognitive competencies are the monitoring and control of dyadic interactions and the development and maintenance of one-on-one relationships (e.g., Bugental, 2000; Caporael, 1997; Geary & Flinn, 2001). Bugental (2000) and Caporael (1997) have recently described universal patterns of dyadic interaction and individual relationship, including parent–child attachments, friendships, spousal and family relationships, and dominance–submissive relationships. There are, of course, some differences across these forms of relationship, such as in the degree of reciprocity comparing parent–child relationships and friendships (Hartup & Stevens, 1997; Trivers, 1971). Still, all of these different forms of one-on-one relationship and dyadic interaction are supported by the individual-level sociocognitive modules shown in the leftmost section of Fig. 3. These modules include those that support the reading of nonverbal behavior and facial expressions, language, and theory of mind (e.g., Baron-Cohen, 1995; Pinker, 1994; Rosenthal, Hall, DiMatteo, Rogers, & Archer, 1979).

Bugental (2000), Caporael (1997), and many others have also argued that a universal aspect of human social dynamics is the parsing of the social world into groups (Alexander, 1979; Geary & Flinn, 2001; Premack & Premack, 1995). The most consistent of these groupings are shown in Fig. 3, and reflect the categorical significance of kin, the formation of in-groups and out-groups, and ideologically based social identification, as exemplified by nationality, religious affiliation, and so forth. The categorical significance of kin is most strongly reflected in the motivational disposition for human beings to form families of one form or another in all cultures (Brown, 1991; see also Hamilton, 1964). In preindustrial societies, nuclear families are typically embedded in the context of a wider network of kin (Geary & Flinn, 2001; Pasternak, Ember, & Ember, 1997). Individuals within these networks cooperate to facilitate competition with other kin groups as related to resource control. As cogently argued by Alexander (1979, 1990), coalitional competition also occurs beyond the kin group and is related to social ideology (for many examples, see Horowitz, 2001). As with kin groups, competition among ideological groups is over resource control.

In addition to managing social relationships, humans living in natural contexts have to secure food and other resources from the local ecology. These demands create selection pressures that would have resulted in the evolution of cognitive and brain systems for processing biological and physical information (Geary & Huffman, in press). As shown in Fig. 3, biological modules are for categorizing and representing the behavior or growth patterns of flora and fauna in the local ecology, especially species used as food, medicines, or in social rituals (e.g., Berlin, Breedlove, & Raven, 1973). Physical modules are for guiding movement in three-dimensional physical space, mentally representing this space, and for using physical materials (e.g., stones, metals) for making tools (Pinker, 1997; Shepard, 1994). It is assumed that these cognitive competencies are an aspect of the motivational disposition to control resources that were of evolutionary significance throughout hominid evolution. In this case, folk biology and folk physics and the associated motivational disposition function to direct the activities of human beings to attempt to achieve ecological dominance.

Within the areas of folk psychology, folk biology, and folk physics, there are also inferential and attributional biases. Social attribution biases that favor members of the in-group and derogate members of out-groups are well known (Stephan, 1985) and facilitate coalitional competition (Horowitz, 2001). In natural contexts, people's elaborate knowledge of the flora and fauna in the local ecology includes knowledge of the "essence" of highly salient species (e.g., those that are hunted; Atran, 1998). Folk knowledge also includes mechanisms that allow inferences to be drawn about the likely future behavior of members of these species as well as about the likely behavior of less familiar, but related, species. Attributions about causality in the physical world have also been well studied. For instance, a series of studies by Kaiser, McCloskey, and Proffitt (1986) and Kaiser, Proffitt, and McCloskey (1985), as well as related research, has shown that both children and adults have natural, naïve conceptions about motion and other physical phenomena (see also Clement, 1982; Shepard, 1994; Spelke et al., 1992).

It is often the case that naïve notions and attributional and inferential biases associated with folk knowledge are scientifically inaccurate, but this is irrelevant from the perspective of natural selection. Selection will operate on attributional and inferential biases that facilitate access to and control of resources that covary with survival or reproductive outcomes, whether or not these biases are scientifically accurate. Attributional and inferential biases in these domains are, however, highly relevant to educational issues, as discussed later.

2.2.3. Evolution and development

A long developmental period is associated with a highly salient risk — death before the age of reproduction — and thus would only evolve if there were benefits that outweighed this risk (Geary, in press). Comparative studies suggest that one function and an important adaptive benefit of delayed maturation is the accompanying ability to refine the competencies that covaried with survival and reproductive outcomes during the species' evolutionary history (Mayr, 1974). The assumption here is that one function of human childhood is to flesh out the cognitive, affective, and psychological systems that comprise folk psychology, folk biology, and folk physics such that these are adapted to the local ecology (Geary & Bjorklund, 2000; see also Bjorklund, 1997), at least the forms of ecology in which humans evolved.

Play, social interactions, and exploration of the environment and objects appear to be the mechanisms through which these emerging competencies are practiced and refined during development. In theory, these child-initiated activities are intimately linked to cognitive and brain development, in that these activities result in the environmental experiences that are an integral part of the epigenetic processes that result in adult competencies (Greenough, 1991; Scarr & McCarthy, 1983). However, these child-initiated activities and associated inherent biases in motivation and in cognitive and brain systems will be focused on recreating the experiences that led to the refinement of competencies that covaried with survival and reproduction during hominid evolution, not necessarily activities that promote academic learning (Geary, 1992, 1995).

3. Evolutionary educational psychology

Evolutionary educational psychology is the study of the relation between folk knowledge and accompanying inferential and attributional biases as these relate to academic learning in modern society. The fundamental premises and principles of this new discipline are outlined in Table 2. The gist of the premises is that folk knowledge and inferential and attributional biases are not sufficient for academic learning in modern society, but, at the same time, are the foundation from which many academic competencies are likely to be built. The implications for academic learning are multifold and outlined in the sections below. Section 3.1 provides brief discussion of the relation between folk knowledge and domains of human intellectual history, which, in turn, provides a broad frame for understanding why folk knowledge is no longer sufficient for successful living in modern society. Section 3.2 provides several examples of the relation between folk knowledge and academic competencies, whereas the Section 3.3 provides discussion of the relation between the motivation to control and the motivation to learn in school. Section 3.4 outlines instructional implications.

Table 2
Premises and principles of evolutionary educational psychology

Premises
(1) Natural selection has resulted in an evolved motivational disposition to attempt to gain access to and control of the resources that have covaried with survival and reproductive outcomes during hominid evolution.
(2) These resources fall into three broad categories: social, biological, and physical.
(3) Cognitive systems as well as inferential and attributional biases have evolved to process information in these domains and to guide control-related behavioral strategies. The combination of cognitive, inferential, and attributional systems defines folk psychology, folk biology, and folk physics.
(4) Children are biologically biased to engage in activities that recreate the ecologies of human evolution. The accompanying experiences interact with inherent but skeletal cognitive and brain systems that define folk psychology, folk biology, and folk physics, and flesh out these systems such that they are adapted to the local ecology.
Principles
(1) Scientific, technological, and intellectual advances emerged from the motivational, cognitive, and inferential systems of folk psychology, folk biology, and folk physics, as well as from other evolved domains (e.g., number and counting). These advances result in a gap between folk knowledge and the theories and knowledge base of the associated sciences and disciplines.
(2) Schools will emerge in societies in which scientific and technological advances create a gap between folk knowledge and the competencies needed for successful living (e.g., employment) in the society. The function of schools will be to organize the activities of children such that they acquire the competencies that close the gap between folk knowledge and the occupational and social demands of the society. These academic competencies are termed biologically secondary abilities and are built from the primary (i.e., evolved) cognitive systems that comprise folk psychology, folk biology, and folk physics, as well as other evolved domains (e.g., number).
(3) Children are innately curious about and motivated to actively engage and explore social relationships and the environment, biases that are directed toward information and activities associated with folk knowledge. The motivational disposition to engage in activities that will develop folk knowledge will often conflict with the need to engage in activities that will lead to the mastery of academic competencies.
(4) The inherent cognitive systems and child-initiated activities that foster the development of primary abilities, such as language, will not be sufficient for the acquisition of secondary abilities, such as reading and writing. It is predicted that the need for instruction will be a direct function of the remoteness of the secondary ability to the supporting primary systems.

3.1. Human intellectual history

As shown in the bottom section of Table 2, the first principle of evolutionary educational psychology states that scientific, technological, and intellectual (e.g., philosophy, poetry) advances emerged from the cognitive systems and inferential biases that comprise folk psychology, folk biology, and folk physics, as well as other evolved domains (e.g., number; Geary, 1995). In other words, it is proposed that human intellectual history and the emergence of scientific and academic domains largely coalesced around the areas of folk psychology, folk biology, and folk physics. Academic disciplines in universities do indeed seem to fall into these three categories, with humanities and the social sciences developing from the area of folk psychology; biology, zoology, forestry, medicine, and so on developing from the area of folk biology; and, much of mathematics as well as physics and engineering developing from the area of folk physics. Of course some domains, such as biochemistry, emerged from a combination of areas, folk biology and folk physics in this example. Still other academic domains, such as linguistics, are focused on the study of specific adaptations (i.e., language), and some academic competencies, such as writing and reading, are built from a combination of evolved modules, as described below (Geary, 1995).

The point is that the historical development of scientific and academic disciplines is predicted to have been initially based on the evolved but often times scientifically naïve cognitive, inferential, and attributional biases associated with the domains of folk psychology, folk biology, and folk physics. In some cases, these evolved biases provided a solid frame for the emergence of the scientific discipline and in other cases they led to false starts and scientifically incorrect conceptual models. As examples, implicit knowledge in the areas of folk biology and folk physics was explicitly articulated, codified (often incorrectly), and expanded upon by Aristotle and other Greek intellectuals. Many of these elaborations provided the foundation for the scientific development of academic disciplines, as with Euclid's contributions to geometry (Devlin, 1998). Other elaborations and conceptual models proved to be false starts, as in the Greek system of four basic elements (e.g., Earth, water) which contributed to the development of the pseudo-science of alchemy (e.g., Strathern, 2001). In the 18th century, the early and largely accurate (scientifically) classification systems of naturalists, especially Carl Linnaeus (i.e., Carl von Linné; cf. Frängsmyr, 1983), were almost certainly based on the same cognitive systems and inferential biases that define folk biology, as this Western system for classifying flora and fauna is very similar to that the systems found in preindustrial populations (Berlin et al., 1973).

An important difference is that Linnaeus' taxonomy included more than 12,000 plants and animals and was constructed in a more explicit (rules for classification were codified) and systematic manner than is found in preindustrial societies. Of course, these early scientific taxonomies continue to be expended and refined, and most recently informed by genetic analyses of the relation between species (e.g., Liu et al., 2001). A similar attention to observation, codification, and use of the scientific method resulted in the emergence of physics, chemistry, and other scientific domains, and supports the continued growth of these fields. With the emergence of these disciplines, intuitive biases and naïve conceptualizations of the natural world were tested, evaluated, and often times refuted and replaced with more scientifically accurate conceptual models of the world.

One result of this scientific and technological change was a corresponding change in the type and level of academic competency needed to live successfully (e.g., gainful employment) in the society in which these advances emerged. Today, there is an ever-widening gap between folk knowledge and scientific and technological advances and an accompanying increase in the need for people to acquire novel academic competencies. A crucial implication for education is that that folk knowledge, though necessary, is no longer sufficient for occupational and social functioning (e.g., understanding interest on debt) in modern society (Geary, 1995).

3.2. Folk knowledge and academic competencies

The second principle of evolutionary educational psychology follows logically from the first and states that schools will emerge in societies in which scientific, technological, and intellectual advances have resulted in a gap between folk knowledge and the intellectual (e.g., need to read) demands of the society. It follows that the goal of schools will be to narrow this gap, that is, to ensure that children acquire the academic competencies needed to function successfully (e.g., gainful employment) in the society. The academic competencies that can emerge with schooling are termed biologically secondary abilities and are built from the primary and evolved cognitive systems that comprise folk psychology, folk biology, and folk physics, as well as other evolved domains (e.g., the number–counting–arithmetic system; Geary, 1995, 2001).

The sections below provide several examples of the relation between primary abilities and secondary abilities, for the respective domains of folk psychology, folk biology, and folk physics. Section 3.2.1 illustrates the construction of novel academic competencies, reading and writing, from the cognitive systems that support folk knowledge. Sections 3.2.2 and 3.2.3 provide discussion of the relation between folk knowledge and scientific knowledge and concepts in biology and physics.

3.2.1. Folk psychology, reading, and writing

Because the function of written (and therefore read) material is to communicate with other people, it follows that writing and reading emerged from and currently are based on primary communication systems, that is, folk psychology. Stated somewhat differently, writing is hypothesized to have emerged from the motivational disposition to communicate with and influence the behavior of other people (e.g., morals in the bible) and to engage the same sociocognitive systems, especially language and theory of mind. Secondary activities, such as reading and writing, thus involve coopting primary folk–psychological systems: Cooptation is defined at the adaptation (typically through instruction) of evolved cognitive systems for culturally specific uses (Geary, 1995; Rozin, 1976; Rozin & Schull, 1988). Motivational and instructional issues are discussed in later sections. For now, the issue is the relation between writing and reading and folk psychology, with an emphasis on reading.

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

It is also likely that reading comprehension engages theory of mind, at least for literary stories, poems, dramas, and other genre that involve human relationships (Geary, 1998a). This is because comprehending the gist of these stories involves making inferences about the nuances of social relationships, which by definition involves theory of mind. It is also of interest that some of the more popular forms of literature are focused on interpersonal relationships and dynamics, reproductive relationships in the case of one of the most popular forms of novel, that is, romance novels (e.g., Whissell, 1996). The motivational implications are discussed below.

3.2.2. Folk biology and the biological sciences

As stated, folk biology represents the evolved ability to develop classification systems of flora and fauna and mental models of the essence of these species (Atran, 1998). Although folk biological knowledge provided the foundation for the emergence of the scientific classification system of Western biology, this folk knowledge is rudimentary in comparison to the vast knowledge of modern-day biological science. As an example, people, even young children, infer that living things have "innards" that differ from the innards of nonliving things and that offspring will have the same appearance and "essence" of their parents (Carey & Spelke, 1994; Coley, 1995; Gelman, 1990). The scientific study of "innards" is, of course, anatomy and physiology, and the study of "essence" is behavioral ecology. Through the use of the experimental method and detailed observation, the associated knowledge bases in anatomy, physiology, and ecology have far surpassed people's intuitive understanding of folk biology.

Not only is the gap between people's intuitive understanding of the biological world and the knowledge base of the biological sciences widening at a rapid pace, the inferential biases of folk biology may sometimes interfere with the comprehension of scientific models of biological phenomena. The most fundamental of these are the principles of natural selection discovered by Darwin and Wallace (1858). Yet, inferential biases in folk biology, along with religious objections, may conspire to make the basic mechanisms of natural selection sometimes difficult to comprehend. First, one inferential bias results in a focus on similarities across members of the same, and related, species (see Atran, 1998). This bias facilitates the functional goal of being able to predict the behavior (e.g., growth patterns) of these plants and animals, as related to procuring food and medicines. At the same time, the focus on within-species similarities runs counter to the insight that within-species differences, or variability, provide the grist for evolutionary selection. Second, folk biological knowledge is also implicitly focused on the behavior of flora and fauna at different points in a single life span (e.g., maturity of a plant, relative to when it is best to harvest) and not the cross-generational time scale over which natural selection occurs. In other words, people are biased to think about and understand the biological world in ways that are at odds with the observations and principles of natural selection described in Table 1.

3.2.3. Folk physics and the physical sciences

As stated earlier, people have a naïve understanding of certain physical phenomena, and the initial emergence of physics as a domain of conscious intellectual activity was likely to have been based on this folk knowledge. For instance, when asked about the forces acting on a thrown baseball, many people (including many undergraduate physics students) believe that there is a force propelling it forward, something akin to an invisible engine, and a force propelling it downward. The downward force is, of course, gravity, but there is in fact no force propelling it forward, once the ball leaves the player's hand (Clement, 1982). The concept of a forward force, called "impetus," is similar to pre-Newtonian beliefs about motion prominent in the 14th–16th centuries. The idea is that the act of starting an object in motion, such as throwing a ball, imparts to the object an internal force—impetus—that keeps it in motion until the impetus gradually dissipates. Even though adults often describe the correct trajectory for a thrown object, their explanations reflect this naïve understanding of the forces acting upon the object. Although "impetus" is in fact a fictional force, it is a reasonable explanation of most everyday situations.

Nevertheless, this and other naïve conceptions about the workings of the physical world interfere with learning the scientific principles associated with mechanics, as well as many other principles, such as those that represent centrifugal force and velocity (Clement, 1982; McCloskey, 1983). Moreover, as with biology, the knowledge base of the physical sciences is exponentially larger than the knowledge base of folk physics, and in some cases (e.g., quantum mechanics) the accompanying conceptual models bear little resemblance to the naïve concepts of folk physics.

3.3. Motivation to learn

As noted in Table 2, the third principle of evolutionary educational psychology states that children are innately curious about and motivated to actively engage and explore social relationships and the environment—biases that are directed toward information and activities associated with folk knowledge (Geary, 1995; Gelman, 1990; Gelman & Williams, 1998). The motivational disposition to engage in activities that will develop folk knowledge will often conflict with the need to engage in activities that will lead to the mastery of academic competencies. In other words, the gap between folk knowledge and the forms of competency needed for successful living in modern society is predicted to result in an accompanying mismatch between the inherent and preferred motivational and activity biases of children and the forms of activity needed for secondary learning.

For instance, if social competition was in fact a driving force during hominid evolution, then children should have a strong and inherent motivational bias to engage in social activities and these activities should recreate the forms of social competition that were important during hominid evolution (Caporael, 1997; Geary, 2002). The finding that a universal aspect of children's (and adults') self-directed activities is social and very often competitive in nature is consistent with this prediction (Baumeister & Leary, 1995); competition over friends, called relational aggression, is one example (Crick, Casas, & Mosher, 1997). A corollary prediction is that a burning desire to master algebra or Newtonian physics will not be universal, or even common.

There are, of course, many individuals who pursue learning in biologically secondary domains and engage in secondary activities on their own initiative, but this follows from the prediction of a continuity between folk knowledge and human intellectual history. To clarify, scholars in the humanities and social sciences are predicted, and appear, to be fundamentally motivated to understand human social relationships, and biologists and physicists to be motivated to understand the biological and physical worlds, respectively (Roe, 1956). The difference between scholars in these domains and other people is predicted to be related to several dimensions of human individual differences. It is individuals who are at the extreme end of all of these distributions — which makes them very rare — who generate a disproportionate number of scientific and technological advances (Simonton, 1999). Among these individual difference dimensions are (1) the ability to acquire secondary competencies, perhaps indexed by intelligence (Geary, 1998a); (2) intellectual curiosity, a basic dimension of human personality (Goldberg, 1993); (3) the willingness to engage in the long and often tedious training required to master the academic discipline (e.g., Ericsson, Krampe, & Tesch-Römer, 1993); (4) and, perhaps to differences in the degree to which the underlying folk systems are elaborated.

With respect to the latter, Baron-Cohen, Wheelwright, Stone, and Rutherford (1999) found that at least some highly successful mathematicians and physical scientists appear to have an enhanced understanding of folk physics but a poor understanding of aspects of folk psychology. When an enhanced understanding of folk physics and an enhanced motivation to engage in associated activities are combined with high intelligence and high motivation (perhaps due, in part, to social competition with peers in the same discipline), the result can be advances in the associated scientific or scholarly domain. Newton's social isolation and near-obsessive focus on physical phenomena (e.g., optics; White, 1997) and Linnaeus' obsession with flora (e.g., Lindroth, 1983) are but two examples. Of course, the results were scientific revolutions in physics and biology (particularly botany) and a significant widening of the gap between folk knowledge and the emerging scientific disciplines of physics and biology.

For most people, however, the motivational disposition will be expended on rather more mundane activities. These activities are predicted to be largely social in nature, based on the social competition model of hominid evolution (Alexander, 1989; Geary & Flinn, 2001), but can involve more secondary activities. However, the motivation to engage in secondary activities is predicted to be related to evolutionary themes embedded in the content of the activity and not directed toward secondary learning per se. To illustrate, reading is a biologically secondary activity, but many people choose to read. The motivation to read and to engage in other secondary activities (e.g., video games, television) is probably driven by the content of the activities rather than by the process itself. As noted, the content of many stories and other secondary activities reflects evolutionarily relevant themes and it is interest in these themes that motivates engagement in the activity. Geary (1998a) argued that these secondary activities engage the psychological mechanisms, such as fantasy, that allow people to rehearse control-related behavioral strategies (e.g., reading about relationships allows one to refine social knowledge and strategies).

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

3.4. Instructional implications

Considerable effort has been expended in attempts to understand the factors that influence the acquisition of academic competencies (Hirsch, 1996). Almost none of the associated research programs has been informed by evolutionary considerations and, as a result, fail to explain even basic observations, such as why children learn language more readily than they learn how to read and write. The difference in the ease of acquiring language as contrasted with reading and writing is readily understandable from an evolutionary perspective and relates directly to the fourth principle of evolutionary educational psychology, as described in Table 2: The inherent cognitive systems and child-initiated activities that foster the development of primary abilities, such as language, will not be sufficient for the acquisition of secondary abilities, such as reading and writing. A corollary prediction is that the need for instruction will be a direct function of the remoteness of the secondary ability to the evolved functions of the supporting primary systems. The goal of this section is to provide a theoretical frame for conceptualizing the relation between primary and secondary abilities as related to instructional issues.

Following research in cognitive psychology, it is assumed that both primary and secondary abilities comprise three forms of competency: conceptual, procedural, and utilization (Gelman, 1990; Greeno, Riley, & Gelman, 1984; Rittle-Johnson, Siegler, & Alibali, 2001; Siegler, 1996; Siegler & Crowley, 1994). For primary abilities, conceptual competence refers to folk knowledge, procedural competence to the associated behavioral strategies, and utilization competence to knowing where and when the behavioral strategy should be used. Conceptual, procedural, and utilization competencies are linked together because they are designed to achieve the same goal. For primary abilities, these goals are related to the earlier described motivation to gain access to and control of the types of resources that covaried with survival and reproductive outcomes during hominid evolution. For primary domains, such as social discourse, these competencies are automatically and unconsciously engaged, as evidenced, in this case, by the fact that nearly all people have some ability to read the social cues (e.g., facial expressions) of other people and respond accordingly (Geary, 1998a).

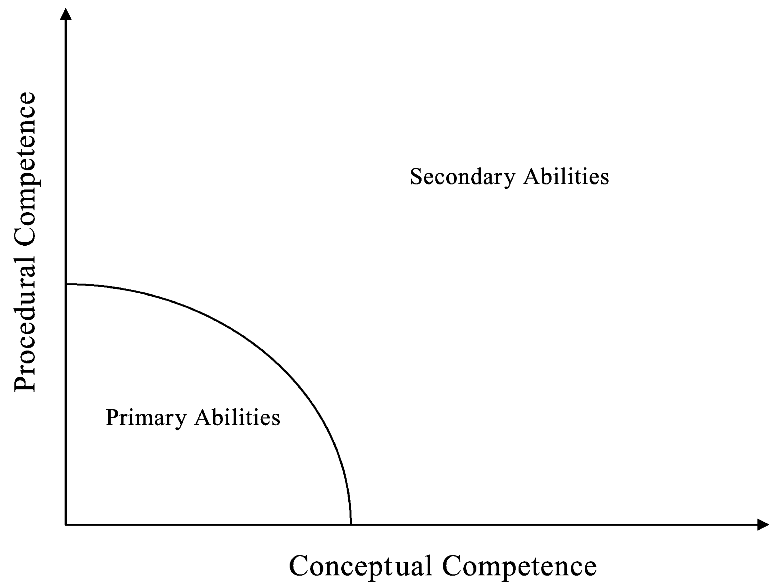

Fig. 4. Theoretical frame for representing the relation between primary and secondary abilities.

Of the three competencies, research in cognitive psychology has focused on conceptual understanding and procedural skill (Siegler & Crowley, 1994), as represented in Fig. 4. A third axis could be used to represent utilization competence, which for secondary domains refers to the issues of transfer and application of conceptual and procedural competencies. The goal here is to sketch a frame of the theoretical relation between primary and secondary abilities, and thus, the focus on conceptual and procedural competencies is sufficient. In any case, the bounded area beyond primary abilities represents scientific, technological, and other advances that have been built upon primary systems. The remoteness of these advances to the supporting primary systems is represented by the distance on the *x*- and *y*-axes from the perimeter that defines primary abilities. The intersection of perpendicular lines projected from the *x*- and *y*-axes represents the relative degree to which the secondary ability is dependent upon conceptual or procedural competence.

The degree to which educational interventions — instructional and motivational — are needed to acquire secondary abilities is predicted to be a direct function of the remoteness of the academic ability from the supporting primary systems. Section 3.4.1 illustrates the concept of remoteness as related to instruction, whereas Section 3.4.2 illustrates the relation between folk knowledge and instruction. Section 3.4.3 lays out basic motivational issues.

3.4.1. Remoteness and instruction

As shown in Fig. 5, there appears to be a primary number–counting–arithmetic system (Geary, 1995; Gelman, 1990; Gelman & Gallistel, 1978). The limits of the associated competencies are not entirely clear, but appear to be restricted to the processing of collections of a small number of items and very simple addition and subtraction. Consider the act of

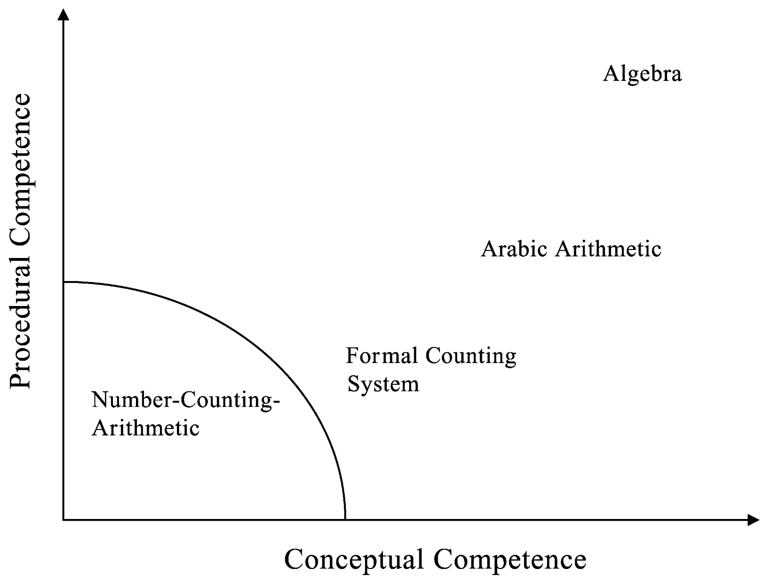

Fig. 5. Example of the relation between the primary number–counting–arithmetic system and secondary abilities that are built upon, at least in part, this primary system.

counting a collection of four items as one example of an associated functional primary ability. The goal of course is to determine the number of items in the collection. The procedure associated with natural counting for children and at least one other species of primate—chimpanzees (*Pan troglodytes*)—typically involves pointing at objects as they are counted; pointing helps the child, and presumably the chimp, keep track of which items have been counted and which still need to be counted (Boysen & Berntson, 1989; Gelman & Gallistel, 1978). The use of counting procedures, in turn, appears to be constrained by an implicit conceptual understanding of several basic features of counting. For instance, the counting behavior of children and chimps is constrained by an implicit understanding that correct counting involves tagging, for example, through pointing, each counted item once and only once (the one–one correspondence principle; Gelman & Gallistel, 1978). Utilization competence is reflected by the fact that counting procedures are only used in contexts where the goal is to enumerate a set of objects.

The historical development of formalized counting systems, such as the system of Roman numerals, was almost certainly based on the same basic procedural and conceptual competencies that support the primary number–counting–arithmetic system. The advance is the development of a formal notational system to represent (e.g., number words, Roman numbers) quantities of various sizes, especially numbers beyond the inherent competence of the primary number–counting–arithmetic system. Once formalized, the notational system allows for commerce, timekeeping, and other number-based activities, and provides the foundation for the development of arithmetic as an academic discipline. At the same time, these advances resulted in a gap between the conceptual and procedural competencies that comprise the primary number–counting–arithmetic system and the formal notational system.

Any individual who wishes to participate in cultural activities that are dependent on this notional system must now receive some type of formal or informal instruction in its use and meaning (e.g., that VI = six items). However, because these early systems are not too far removed, conceptually and procedurally, from the primary supporting system, the amount of required instruction (or first-hand experience) needed to learn the system is predicted to be minimal (for an example, see Saxe, 1988).

The development of the Arabic number system represented another significant advance in the history of arithmetic and mathematics as scientific fields, and made practical activities (e.g., accounting) more efficient (Al-Uqlidisi, 952/1978). As shown in Fig. 5, the underlying conceptual structure, that is, the base 10 system, and associated procedures (e.g., trading from the tens to units column in complex arithmetic) are more complex and removed from the primary counting–number–arithmetic system than are formalized number systems (e.g., the Roman system). As contrasted with natural counting, removed refers to the reliance on abstract and externalized representations of number, that is, Arabic numerals (e.g., 3, 5, 54), and the development of formal procedures for manipulating these abstractions (many examples are found in Al-Uqlidisi, 952/1978). The gap between natural conceptual and procedural competencies and formal mathematics widened further with the later development of algebra and still further with other advances in mathematics (for accessible discussion, see Devlin, 1998).

For many centuries, the gap between the increasingly formalized and academic discipline of mathematics and the primary number–counting–arithmetic system and other primary mathematics-related systems (e.g., spatial abilities; Geary, 1994, 1995, 2001) was of little relevance to the day-to-day life of most people. This is because there was little need for most individuals for acquire formal mathematical competencies beyond the arithmetic needed for commerce and related activities. And, the acquisition of the associated rudimentary arithmetical competencies probably did not require formal instruction (Saxe, 1988). However, in modern society, occupational opportunity, on-the-job productivity (and thus wages), and more routine activities (e.g., managing finances) require a level of mathematical competence that was once only required of mathematical aficionados (Boissiere, Knight, & Sabot, 1985; Grogger & Eide, 1995; Rivera-Batiz, 1992). The result is an unprecedented — in human evolutionary history — need for large segments of the general population to acquire secondary competencies in the areas of mathematics, science, and so on.

From this perspective, academic instruction is predicted to be an onerous endeavor for students and teachers alike, particularly for domains that are far removed (conceptually and procedurally) from primary domains. To illustrate, for mathematics, it is predicted — and it appears to be the case (Geary, 1994) — that the mastery of the procedural and conceptual competencies defining the base 10 system will require more explicit and formal instruction than the mastery of a formal counting system, but less instruction than the mastery of the fundamentals of algebra. This prediction follows logically from the historical development of the field of mathematics and the accompanying widening of the gap between the associated primary and secondary abilities. In fact, the prediction might seem self-evident, without an understanding of evolution or mathematical history. However, unlike many current educational theories — many of which are based on an assumption that formal teacher-guided instruction is not needed in any area of mathematics (Cobb, Yackel, & Wood, 1992)—the predictions here are explicit and testable: The extent to which formal, explicit, and teacher-guided instruction is necessary for the acquisition of secondary abilities is predicted to be a direct function of the extent to which these secondary abilities are conceptually and procedurally removed from the supporting primary systems.

3.4.2. Folk knowledge and instruction

As noted earlier, folk knowledge and inferential biases may run counter to related scientific concepts. The instructional prediction is that in such cases, folk knowledge will impede the learning and adoption of related scientific concepts or procedures. To illustrate, most people make judgments about the relative risk of various activities (e.g., flying in an airplane) based on how easily they can remember examples of mishaps associated with those activities (e.g., plane crashes). This memory-based method, or heuristic, for determining risk often leads to poor probability and risk judgments in modern societies. This is because mass media (e.g., television) coverage of rare events produces an inaccurate picture of the actual risk associated with various activities. Most people, for example, greatly overestimate the risk associated with flying because they can remember many disturbing plane crashes. Most people have not personally experienced these crashes but were exposed to them through television (Lichtenstein, Slovic, Fischhoff, Layman, & Combs, 1978). The use of this memory-based heuristic probably worked rather well in natural environments—those in which the inferential bias evolved—but it not only leads to poor risk assessment in modern societies, it appears to interfere with the learning and use of formal statistics to make risk assessments (Brace, Cosmides, & Tooby, 1998). Similar biases and instructional impediments have been noted for physics (Clement, 1982; Hunt, 1993; Hunt & Minstrell, 1994).

Folk knowledge and inferential biases may, at other times, facilitate the acquisition of secondary abilities. The primary number–counting–arithmetic system almost certainly provides the springboard for the initial learning of formal arithmetic (Geary, 1995). A relationship between spatial abilities and mathematics, especially geometry, has been posited for thousands of years. In fact, geometry can be defined as the study of space and shape (Devlin, 1998). Primary spatial abilities, especially those associated with navigating in the world, may indeed provide an intuitive understanding of certain features of geometry (Gallistel, 1990; Geary, 1995). Basically, there is order and structure to the physical universe and many of the spatial abilities of humans, and other species reflect the evolution of primary systems that are sensitive to this order (Shepard, 1994). The associated competencies include the ability to navigate in the world and generate a mental map of this world, as well as more basic skills, such as the ability to visually track moving objects. Nearly all of this knowledge of the physical world is implicit, or unconscious, that is, the systems that support moving about in the world work more or less automatically, in the same way that breathing occurs automatically (Geary, 1998a). Some aspects of this intuitive knowledge appear to form the foundation for some aspects of Euclidean geometry. As an example, Euclid's first principle—a line can be drawn from any point to any point, that is, a line is a straight line—reflects the intuitive understanding that the fastest way to get from one place to another is to "go as the crow flies," that is, to go in a straight line (if possible, of course). At the same time, there is little reason to believe that other aspects of formal geometry, such as theorems, are as intimately related to spatial knowledge.

It follows that the goals of instructional research will include identifying folk knowledge and inferential biases that relate to academic competencies and then determining instructional approaches that disabuse students of folk knowledge that runs counter to scientific concepts and capitalizes on folk knowledge (often implicit) that can be used to teach academic concepts. The latter often involves making intuitive implicit knowledge, formalized and explicit; Euclid's first principle is an explicit and formalized representation of an implicit aspect of folk physics.

3.4.3. Motivation

Surveys of the attitudes and preferences of American school children indicate that they value achievement in sports much more than achievement in any academic area (Eccles, Wigfield, Harold, & Blumenfeld, 1993). The result is not surprising as children, especially boys, spontaneously organize their social activities around group-level competition, such as team sports (Lever, 1978). Geary (1998a, in press) interpreted this child-initiated activity as a reflection of an evolved motivational disposition and one that results in the practice of group-level warfare, a feature of the earlier described group-level social modules. In any event, the valuation of this nonacademic activity is in keeping with the prediction that children's inherent motivational and activity biases will often conflict with the goals of academic learning. The instructional implications are especially important in societies in which near-universal education is a goal.

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

A third implication relates to children's attributions about school learning, particularly their attributions regarding the relative importance of ability and effort for success in school. Such beliefs in and of themselves will not result in learning secondary abilities, but will affect the motivation to continue to stick with it once the material becomes difficult. For instance, it has been shown that across cultures, children come to understand that learning in school is related to both effort and ability (Little, Oettingen, Stetsenko, & Baltes, 1995), but the relative emphasis on effort or ability affects the persistence with which students pursue learning in difficult areas, such as mathematics and science; an emphasis on effort rather than ability is associated with greater persistence (Ames & Archer, 1988).

4. Conclusion

The principles of evolutionary educational psychology will provide a much needed anchor for guiding instructional research and practice. An evolutionarily informed science of academic development is in fact the only perspective that readily accommodates basic observations that elude explanation by other theoretical perspectives, such as constructivism (Geary, 1995). For instance, it follows logically from the principles of evolutionary educational psychology that children will learn language easily and without formal instruction, and years later many of these children will have difficulty learning to read and write even with formal instruction. A more novel prediction is that reading and writing will involve the cooptation of the motivational and cognitive systems that define folk psychology, given that reading and writing, like folk psychology, are forms of social communication. Research in cognitive psychology and neuroscience support this prediction (Bradley & Bryant, 1983; Pugh et al., 1997). This is not to say that the principles outlined here are the final word on the relation between evolved social and cognitive biases and academic development. Rather, they should be viewed as the blueprint for conceptualizing academic development and guiding instructional theory and research. There is much to be learned about the specifics of folk knowledge and associated inferential and attributional biases and still more to be learned of their relation to academic learning.

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