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Adapted Minds and Evolved Schools

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Evolutionary psychology raises questions about how cognitive adaptations might be related to the emergence of formal schooling. Is there a special role for natural domains of cognition such as folk physics, folk psychology and folk biology? These domains may vary from small fragments of reasoning to large integrated systems. This heterogeneity complicates claims about abilities to inhibit folk sciences and about how formal education exploits such inhibitory abilities. Moreover, formal education often needs to build on intuitive knowledge systems rather than inhibit them. Education must also reduce complex information to the right level of granularity and help students appreciate the limits of their understanding. This involves learning how to outsource understanding to other minds and to read intentions. In his article in this issue, David C. Geary provides an important focus on these issues by suggesting that educational and evolutionary psychologists ask how the patterns found in each field might inform the other.

What significance, if any, do views about the evolution of cognition hold for education? Does our current knowledge of the ways in which the human mind has cognitive adaptations help us understand how to design schools, curricula or methods of instruction? These kinds of questions should make any researcher nervous given the many controversies that exist in both evolutionary psychology and in educational theory and practice. Yet cognitive science has clearly been influenced in recent years by studies of cognition at is earliest points in development and by comparative studies across species (Weiss & Santos, 2006). In addition, there have been surprising predictions arising from evolutionary psychology on such diverse topics as foods avoided by pregnant women and the behaviors of stepparents (Ermer, Cosmides, & Tooby, 2007; Tooby & Cosmides, 2005). In his article in this issue, David C. Geary suggests that we now know enough to be able to take some of the lessons from evolutionary psychology of human cognition and link them to education. This is an important and timely argument well worth considering. In the end, Geary's specific suggestions may not square that well with the current best bets about the nature of adapted human minds and the implications of such adaptations for schooling, but the broader questions he raises are valuable ones that well deserve renewed attention.

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COGNITIVELY NATURAL DOMAINS

Some kinds of information seem to be much easier to learn about than others. We seem naturally gifted in our ability to learn about mechanical causality but have great difficulty learning about rotational dynamics such as the reasons why a spinning top stays upright (Proffitt & Gilden, 1989). We find it easy to learn about contagion of disease but harder to learn about evolution (Keil, Levin, Richman, & Gutheil, 1999; Shtulman, 2006). Moreover, if we look at young infants, we see that they seem to have powerful and often sharply contrasting expectations about the behaviors of inanimate objects (mechanics) and intentional agents (folk psychology). These kinds of phenomena have led many to argue that we have evolved domain-specific adaptations for thinking about certain classes of real-world phenomena. Geary focuses three of the most popular: folk physics, folk biology, and folk psychology. There are good reasons to think that we all do have specializations for guiding learning and thought in each of these areas, but there are two cautions concerning Geary's descriptions of these domains and their implications for education. First, not all the phenomena in these domains are grasped easily and, second, there are many phenomena outside these domains for which we also seem to have specialized learning and reasoning systems.

Certainly, no one really thinks that the child easily grasps all areas of physics given the obvious difficulties adults have with quantum mechanics, electromagnetic fields, and a host of other phenomena. Even in the domain of simple

Newtonian mechanics we seem to have a much better time thinking about some patterns, such as inelastic collisions, than others, such as rotational dynamics. Folk physics seems to be a grab bag of intuitions about a certain subset of mechanics-related phenomena. Indeed, some have suggested that it isn't really a coherent domain at all but rather a collection of small pieces or fragments of understanding (diSessa, Gillespie, & Esterly, 2004). Geary suggests that spatial knowledge is part of a folk physics, but this is definitely not the common view. Knowledge of spatial layout seems to be an independent capacity with its own constraints and can work on layout of shadows and other nonphysical markers of space. Moreover, there are classic ways in which people bias their interpretations of physical events such as trajectories of falling objects (Caramazza, McCloskey, & Green, 1981). Geary is certainly aware of such errors, but there remains a clear need to specify more precisely what domain-specific knowledge in physics really is and how it both hinders and helps learning. Without such specifications, the more substantive claims about the relations between implicit ways of understanding and more conscious ones become empty. We don't really know, for example, the extent to which folk physics really forms a coherent, integrated domain or a more fragmented collection of unintegrated cognitive biases.

Geary's account suggests that folk psychology is a large three-part domain consisting of self-concepts, individual concepts, and group concepts. Collectively, these are thought to give rise to a larger domain. But are all of these really part of a folk psychology? In particular, cognitions about groups may be of a quite different nature more akin to a folk sociology (Hirschfeld, 2001). Moreover, some aspects of folk psychology interact with Geary's versions of folk physics. For Geary, physics includes both movement and tool use, yet others (e.g., Bloom, 1996) have argued that tool use critically relies on an intentional stance that requires a sense of the intentions of the tool's creator (a folk psychology). In a similar way, Geary's characterization of folk biology as essences, flora, and fauna may not adequately represent the nuances of folk knowledge. After all, quite young children think that inorganic things, such as gold, have essences, and much of the work in folk biology does not find a critical divide between plants and animals (Atran & Medin, 2008; Inagaki & Hatano, 2002). These subtleties matter, because they bear directly on questions of what children bring into the classroom and whether knowledge in one domain, such as folk psychology, supports, interferes, or is independent of development of folk biology.

Domains are also not likely to all be of the same size and degrees of coherence. Evolution gave us a motley collection of information-processing systems that are prepared for certain kinds of inputs. The face perception system may be its own little system largely independent of the rest of folk psychology (Kanwisher, 2006). Taste aversion patterns, phobias of snakes and heights, number, grammar, physical contact causality, and even some notions of economics and fair exchange (Chen, Lakshminaryanan, & Santos, 2006) may also have their own systems. Some may be broad and systematic in scope; others may be small and based on simple heuristics. These details matter greatly for one of Geary's key claims, that humans evolved a second flexible and conscious system to override the knowledge given to us by evolved implicit ones. Overriding a large and systematic set of knowledge structures may be a very different process from overriding a relatively autonomous and local bias.

INHIBITING FOLK THEORIES

Geary suggests that the learning of evolutionary novel information—that is, information that organisms are not naturally prepared to learn—requires a special kind of flexible cognitive architecture along with a motivation to learn the novel and flesh out details. He talks further about gaining "plasticity in folk-modular systems" and about linking these systems in novel ways. To achieve all this, Geary argues that humans have evolved a unique ability to inhibit the folk modular systems.

> 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 learn evolutionarily novel information. . . . [T]he core of these mechanisms is conscious-psychological simulations, and working memory and controlled problem solving. (2008/this issue, p. 182)

At one level, it is indeed a hallmark of human cognition to have richly developed executive control functions, especially in the prefrontal cortex (Miller & Cohen, 2001), and inhibitory processes are certainly a large point of how such functions work. Certainly, there may have been strong selective advantage for such an ability. But the main role of executive systems may not be to inhibit and override the outputs of folk systems, and the most effective educational interventions may not consist of such inhibitions. Although folk systems surely have embodied biases and heuristics that can mislead and cause misconceptions, they have presumably evolved because of the ways in which they have allowed organisms to easily process useful forms of information and act on that information. Folk systems of knowledge should be seen by education as more an asset than as a liability.

The most effective educational practices should build on all the ways in which humans are especially gifted at picking out certain kinds of information and causal patterns. All too often, educational approaches have adopted "deficit models" in which it is assumed that children enter the schools with bundles of misconceptions that need to be overridden and corrected. These kinds of approaches often suffer from a neglect of all that preschoolers do learn and bring to the classroom (Zimmerman, 2007). Geary certainly has some sense of these concerns, but the précis of his work that is offered here runs the risk of being misinterpreted as arguing that our folk systems generate sets of misconceptions that need to be overridden by conscious cognitive executive processes. Instead, the most important role of executive processes and schooling may be learning how to exploit to the largest degree all the implicit knowledge that we do seem to so effortlessly acquire.

It is also clear that schooling at the elementary and secondary levels at least may be surprisingly ineffective at overriding some of the outputs of folk systems. High school students routinely adopt naive impetus theories of physical mechanics and essentialist assumptions often create misconceptions of evolution that are highly resistant to instruction (Hull, 1965; Keil & Richardson, 1999; Shtulman, 2006). In some cases, the rise of developed cultures and schooling has been accompanied by a "devolution" of knowledge as the opportunity to learn in real-world natural contexts diminishes (Atran & Medin, 2008; Atran, Medin, & Ross, 2004). Thus, suburban and urban children and adults often have atrophied folk biological concepts in comparison to some rural children and adults. For these reasons it may not be quite right to see the triumph of universal schooling as one of overriding and correcting the outputs of folk science systems, as many suburban and urban children may have equal or more extensive immersion of educational systems relative to rural children. The real story is much more nuanced and complicated and may underestimate the power of many informal learning environments (National Research Council [NRC], in press). Moreover, many biases create trade-offs. For example, even as an essentialist bias may be persistently undermining insight into evolution, it may be a cognitively valuable heuristic for children to look for deeper causal structure responsible for surface patterns (Gelman, 2003).

KNOWING TOO LITTLE, TOO MUCH, AND JUST THE RIGHT AMOUNT

We are all confronted with an ever-expanding web of scientific and technical knowledge. The depth and breadth of modern sciences and technologies dwarf what was known even a decade ago. Certainly, as Geary suggests, schools should help children acquire knowledge that goes beyond that which they learn in more intuitive and implicit ways. But schools can't possibly be expected to provide their students with all the details left out by their intuitive understandings. Those details quickly swamp anyone's learning capacities, hence the continuously increasing specializations of scientists and professionals and the compartmentalization and autonomization of subdisciplines. A few decades ago, it was common to be a general orthopedic surgeon. Today, there are wrist surgeons, knee surgeons, spine surgeons, and so on. Some surgeons may specialize in only one kind of knee operation. In the sciences, it is not uncommon for a researcher to specialize in what, appears to the outside world, as an incredibly narrow niche. Such researchers may routinely decline to evaluate research or researchers in what seem to be closely related areas on the grounds that it isn't really in their area of expertise.

The goal of education can't possibly therefore be to fill in all the explanatory details that reside in a society's collective knowledge. Whether it be in an elementary school classroom or a graduate seminar, some details must be left out, some simplifications made, and some slightly wrong generalizations accepted. A primary goal of education is to generate explanatory gists that are at just the right level of detail, the right grain size. We do this all the time implicitly in conversations, trying to provide all the information that we think listeners need and never more than they need (Atlas, 2005). In generating appropriate explanations, this is not an easy challenge to meet. It requires several things: knowing what students know, knowing what they could know after a reasonable period of instruction, and knowing what kinds of new knowledge would do them the most good in expanding their understanding of the world and in enabling them to make more informed decisions and more effective actions in relevant contexts. An understanding of our natural ease at tracking certain kinds of information and coming to certain causal inferences would be a key part of developing appropriate gists, as would an ability to understand how much people can get by with coarse, partial understandings of various types (Keil, 2003, 2006).

Imagine that one is presented with an excessively detailed account of how eating a morsel of food gives an organism energy that enables it to move its muscles. Such an explanation would include vast amounts of information about organic and physical chemistry, cellular function, and anatomy, with tendrils reaching into physical mechanics, thermodynamics, neuroscience, and many other fields. Good teachers who know much of this detailed information may have some pretty accurate hunches of how to distill the information down to just the right coarse grain size. Yet it is very difficult to formalize this ability or to automate it in the larger literature on "text summarization" in computer science. There is one important relevant finding from research on teacher knowledge. Surprisingly rich knowledge may aid optimal simplification for even the youngest target students. Thus, one explanation of the greater success in mathematics teaching at the elementary school in Japan as opposed to the United States is that the average elementary school teacher of mathematics knows far more advanced mathematics. It may well be that deep disciplinary knowledge helps one see what edits in explanations will be most useful (Hiebert & Stigler, 2000). Insights into topics as sophisticated as number theory and linear algebra may help an elementary school teacher tailor in real-time adjustments in the instruction of basic mathematics (Schoenfeld, 2006). There is a clear need to better understand how deep disciplinary insight informs even the most basic levels of instruction and the ability to improvise effectively.

It may be that evolution has given us the ability to come up with rapid causal construal of phenomena at roughly the optimal grain size of causal analysis for reasoning on the run. We would have foundered long ago as a species if we kept burrowing deeper and deeper in attempts to understand mechanisms, just as we would have if we had taken too shallow a gloss (Keil, 2006). Schools help us go further in explanatory understanding but always in a way still manage to preserve some economy of cognition. We have yet to fully understand how great teachers accomplish this; it seems likely that they are aware of what are the most explanatorily central pieces of information and how they will spread insight to other topics.

Almost paradoxically, our ability to not get overwhelmed by details may be helped by an overconfidence about our own knowledge. Both adults and children are somewhat deluded about how well they understand the world (Mills & Keil, 2004; Rozenblit & Keil, 2002), thinking that they understand it considerably more detail than they really do. This "illusion of explanatory depth" may be a good thing, for it allows us to curb our inquisitiveness when it would bury us in more details than we really need. Thus, the false comfort of insight we fell may be a protection against going too deeper and getting lost (Keil, Rozenblit, & Mills, 2004). We also tend to underestimate how much we construct understandings on the fly with information from the situation at hand and overestimate how much we bring to the situation as a well worked out explanation (Rozenblit & Keil, 2002). More generally, people are not well calibrated to know when they really understand an explanation and have a strong tendency to think they understand far more than they do, a tendency that gets worse in younger children. In education, this means that the effectiveness of expanding on intuitive domain knowledge cannot be assessed solely by children's sincere beliefs that they have gained insight. In short, even from the evolutionary perspective that Geary suggests, there are many layers of complexity to how teaching might expand on explanatory understanding.

LEANING ON OTHER MINDS

It is all too common in cognitive science to characterize the child as acquiring knowledge as an autonomous individual, exploring the world directly and learning it about firsthand. Of course this isn't remotely true (Harris, 2006; Keil, Stein, Webb, Billings, & Rozenblit, 2008). Children acquire most of what they know secondhand, through others. The first animals many urban children learn about are African mammals even though they have never experienced them directly. Books, television, other media, and live people have all conveyed that information to them. Moreover, much of that information has been conveyed informally outside any sort of school setting (NRC, in press).

Even though children acquire vast amounts of information in this secondhand manner, they assimilate it with firsthand information, often so seamlessly, that they are unaware where they initially learned it. Young children are especially poor at source monitoring (Kovacs & Newcombe, 2006; Lindsay, Johnson, & Kwon, 1991) and, as a result, often incorrectly think that information they acquired through indirect sources they learned directly or knew all along (Taylor, Esbensen, & Bennett, 1994). This source neglect may be part of the reason we all underestimate how dependent we are on others for our knowledge. One role of education may be to make such networks of dependency more salient and, if the education is of the right sort, more accessible.

We do not only depend on other minds to develop new bits of knowledge; we also learn pathways of deference to these other minds. That is, we "outsource" much of the explanatory detail to experts, counting on reliable chains to those experts to support our own weak and incomplete understandings. Although often implicit, this process is extremely pervasive and seems to appear early in development. For example, even preschoolers have a rudimentary sense of how some forms of expertise are distributed in the minds of others (Keil et al., 2008; Lutz & Keil, 2002). Cultures depend on this ability to leverage one's own meager knowledge by grounding it in deeper knowledge held by others.

Geary argues that the folk modules are largely concerned with learning and knowledge acquisition as autonomous individuals. Each child is his or her own free agent directly acquiring information for which his folk systems in mechanics, psychology, and biology are prepared. Yet, as Geary repeatedly points out, society is increasingly outstripping that which can be learned as a rugged cognitive individualist. Put differently, human cognition may differ from all other species most dramatically in the ways in which it allows humans to build up knowledge and understanding as a cumulative and communal product that, when accessed, enables us to go far beyond what we can learn on our own with folk modules. This argument is a compelling one and resonates strongly with other claims about how human cognitive capacities are extended into the artifacts we use (Clark & Chalmers, 1997) and into the social communities in which we live (Sterelny, 2004).

A key issue is where schools figure into this system. Geary suggests that schools may have emerged as a uniquely effective way for people to bridge the gap between folk modules and the ways in which cumulative cultural knowledge, especially that in science and technology, is outstripping naïve modular knowledge. He uses reading as an example and contrasts it with the ways in which learning an oral language requires no explicit instruction. Reading is indeed a special case where massive practice and formal structured exposure usually is necessary to gain proficiency, but it may not generalize so easily to other forms of knowledge. Schools do seem to be uniquely effective at teaching reading, basic writing, and parts of computational mathematics, but it is less clear how unique they are in conveying knowledge about science and technology.

There has been a surge of interest in the ways in which knowledge is acquired in informal settings outside the classroom (NRC, in press). This is still knowledge imparted by the culture and not simply that coming from a child, but it occurs in many nonschool settings whether it be through television, museums, toys and other artifacts, the Internet, or even in various games and activities such as chess, cooking, or running a lemonade stand. All of these activities also can lean on cognitive artifacts and expertise in other minds, but they may have little to do with schooling. Thus, our uniquely social nature and our abilities to communicate in groups may well allow us to go beyond knowledge and abilities that we could acquire as individual autonomous agents, but in a great many cases these processes occur outside schools.

The question then remains as to whether schools take children beyond what they can learn on their own in unique ways, or whether they do so in ways that are shared with many other informal learning contexts. As mentioned earlier, we do know that sometimes the culture at large can cause a "devolution" of knowledge, such as the stunting of some aspects of biological thought, and it could be argued that schools only serve to expand on thought by connecting individuals more fully to the cultures in which the live. Some of these increasing connections must surely depend on schooling. The ability to read, for example, can greatly extend one's cognitive powers in many domains. In other cases, education may cause truncation of knowledge and ability as well. For example, curricula that teach "nature" as something that humans seek to control and preserve may blunt an understanding of the extent to which humans are a part of the ecological system as opposed to outside observers of it (Atran & Medin, 2008).

INSIDE INTENTIONALITY

Humans are extremely sensitive to social nuances, reading the intentions of others in ways that no other species can. We have a richly developed intuitive folk psychology that seems to effortlessly attribute beliefs and desires to others and immediately apprehends the goals of many actions that we observe. In addition, we may have evolved a rich repertoire of social cooperation and communication skills that enable us to benefit from shared knowledge resources (Sterelny, 2004). We also, however, have developed systems to guard against cheaters (Cosmides & Tooby, 2005). There are certainly many other social species, but humans seems exquisitely tuned to the intentions of others in ways that make social learning and pedagogy uniquely human activities. Schools may exist more because humans are uniquely endowed with the ability to teach than because of the need for explicit instruction.

Geary suggests that humans may have evolved social and communicative skills that enable them to go beyond what they acquire from their folk modular systems, skills that schools may have explicitly capitalized on. Most important here, however, may be the detection of intentional actions and using that intentionality to strongly guide learning. Children are not able to learn a language merely from listening to the radio, while of course blind children do just fine. The difference is that blind children use whatever cues they can to know the intentional dimensions of an utterance. If a person hands the blind child an object while saying a label, that act suggests an intention to communicate the label of the object, what Csibra and Gergely (2006) called a pedagogical act, one that is uniquely human because of the complex ways in which it relies on tracking of intentions. We are remarkably sensitive to social agents and their mental states and access those states through many routes. Geary suggests that face perception may be a critical core component in folk psychology (2008/this issue, p. 184), yet blind children also clearly develop folk psychology, sometimes with a delay but clearly without relying on the face processing system. It may be that the "intentional stance" (Dennett, 1987) is indeed an evolutionarily advantaged mode of thought that can be triggered by certain cueing contexts (Gutheil, Vera, & Keil, 1998), but there are several routes to eliciting this way of thinking that go beyond any one set of perceptual triggers.

In venue after venue, children assume that intentional actions of adults are vastly more informative than accidental or otherwise haphazard ones. In this sense, they are sensitive to the pedagogical role of those around them in late infancy and long before they start school (Csibra, 2007; Csibra & Gergely, 2006). Consider one rather extraordinary way in which young children differ from other primates: overimitation (Lyons, Young, & Keil, 2007). It has been observed for some time that when chimpanzees watch a human model remove a desired object from a box by manipulating various parts of the box, they will copy only those actions that they think make causal sense for opening the box. In contrast, human children will imitate all the operations including ones that have no apparent causal connection to getting the goal. It was initially thought that the human children copied the irrelevant actions because they thought it was the social "game" to play even though they knew full well that the operations were irrelevant (Horner & Whiten, 2005). Yet when various manipulations check for this possibility of simply following a social convention, it appears instead that young children, in contrast to apes, think that all steps are in fact causally necessary (Lyons et al., 2007).

A closer look at overimitation reveals that preschool children are exquisitely sensitive to intentional actions of human models and have a strong bias to assume that almost any intentional action on a complex object in the context of a clear goal must be causally necessary. If, however, the same exact action is modeled but in a way that seems unintentional or incidental, children will not assume that irrelevant actions are causally important (Lyons et al., 2007). They use intentional actions as a valuable diagnostic cue to the causal properties of objects upon which an actor intentionally operates.

More broadly, human children seem to be uniquely tuned to intentional actions. The perception of actions as intentional results in a rich array of inferences not just about the actor but about all the things that the actor is acting on or producing, whether those products be manipulations of artifact parts (Lyons et al., 2007), word meanings (Bloom, 2000), or attempts at art (Preisler & Bloom, 2008). In the same way, intentionality may be the central feature of decoding pedagogical actions. For pedagogy to succeed, children need to have some sense of not only the goals but also the intentions and beliefs of those who are teaching. Similarly, teachers must have reciprocal set of senses about the student. The tracking of intention helps narrow the task down to a few critical variables.

Schools may be special in this respect in that formal classroom instruction highlights the intentions of teacher more than many forms of informal learning. Thus, more elaborate use of theory of mind in teacher–student interactions may help refine for the child what matters in instruction. In this way, Geary may be right on the mark in suggesting that uniquely human social information processing is required for learning about complex artifacts and other cultural creations, such as formal science, that go beyond folk belief systems. Schools tend to make the process of cultural transfer of knowledge much more explicit than in other forms of informal learning, a process that critically relies on the tracking of a rich network of intentions.

CONCLUSION

Attempts to link evolutionary theory with psychology are always at risk for describing the obvious in a seemingly post hoc manner. In some ways Geary can be challenged on these grounds as well. Some of his predictions seem to be ones that virtually any theory of learning and education would make, regardless of whether it pays any attention at all to evolutionary issues. For example, Geary suggests that "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" (2008/this issue, p. 186). How is this prediction to be tested in a manner that contrasts with other views of learning? No theory that I know of predicts that children will not, on at least some occasions, show curiosity and motivation to learn about novel and unfamiliar information, a prediction that is weakened even further by the allowance of "substantial individual differences."

In other respects, however, Geary's article is a useful call to ask how human children might be prepared to learn about certain kinds of information and how, as cultures have exploded, schools might have emerged to fill in critical gaps to our native areas of learning expertise. It remains an open question as to whether schools are so dramatically different in what they teach in comparison to informal learning environments in the ambient culture and whether informal learning and schooling interact with more intuitive folk systems in different ways, but Geary is certainly right in pointing out that these questions are critical ones deserving of further research.

In the end, it may be more fruitful to focus on the ways in which cultures in general and schools in particular can leverage and exploit knowledge that is acquired so easily in folk domains rather than to focus on the ways in which the height of human cognition and schooling is seen as inhibiting the outputs of those folk systems. Just as our perceptual systems track and interpret vast amounts of information effectively and appropriately, our folk systems offer a tremendous amount for education to build on. Moreover, in those few cases where folk systems do serve up inaccurate interpretations of the world, those misinterpretations can be surprisingly hard to overcome with instruction.

Humans may differ from other animals not merely because they have domain-general cognitive capacities that enable them to go beyond domain-specific knowledge acquisition systems. The depth and breadth of knowledge that they intuitively acquire within those domain-specific systems may be differ as well. The folk psychology, the folk biology, and the folk physics of the young unschooled child may all be much more articulated than those in other creatures. The same may hold for many other areas, such as economics, sociology, and morality. By granting the possibility of richer untaught knowledge arising from such systems, the need for education to take advantage of such rich knowledge bases becomes more apparent. Geary's perspective may be somewhat different, but in a more general sense he has done a great service by helping us all see the need for considering how the rich array of human cognitive adaptations should be taken into account in understanding the role of formal schooling.

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