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Cultural Apprenticeship and Cultural Change

Tool Learning and Imitation in Chimpanzees and Humans

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In S. T. Parker, J. Langer, & M. L. McKinney (Eds.). (2000). Biology, brains & behavior (pp. 237-277). Santa Fe: SAR Press.

Often biological evolution is contrasted with cultural process, but the dichotomy is problematic because ultimately the capacity to learn culture is naturally selected. This capacity is critical for humans, and it is tied deeply to the child's potential for cultural learning, which for our species involves the re-creation of cultural traditions in each generation (Lock 1980). This natural ability to acquire (and transmit) culture is actualized through cultural apprenticeship, the subject of this chapter.

Apprenticeship processes are an important key to behavioral ontogeny in a species that must, in the course of a single lifetime, both acquire extensive cultural knowledge from the preceding generation and transmit it to the next. A few other animals participate similarly in socially learned group traditions (e.g., McGrew 1992), but there remains an important question (see Tomasello 1989, 1994): Do species such as chimpanzees learn their cultural behaviors in the same way that humans do, and in particular, are they able to imitate?

One way to explore the imitation controversy is to focus on behavioral ontogeny, which involves coordination between skill development and apprenticeship processes. We do so in this chapter by comparing apprenticeship behavior in humans (acquisition of traditional craft skills) with apprenticeship in chimpanzees (acquisition of tool-use skills in feeding). Our working hypothesis is that chimpanzees may well be capable of imitative learning, both in captivity and in the wild, and that the best way to explore this important question is to compare apprenticeship behaviors of the two species under natural conditions. After considering chimpanzee learning processes, we move on to those of Maya weavers and draw evolutionary conclusions from the comparative studies.

Cultural apprenticeship can be conceptually decomposed into processes of learning and teaching; these take place both between and within generations (Greenfield and Lave 1982; Lave and Wenger 1991; Parker 1996a; Rogoff 1990). Because an important aspect of human culture and its evolution lies in technology, the apprenticeship processes required to learn and transmit technological knowledge are the focus of this chapter. In what follows, we explore apprenticeship in a human tool system (Greenfield 1999; Greenfield, Maynard, and Childs 1997; Maynard, Greenfield, and Childs 1999) and in a chimpanzee tool system (Yut 1994). For this purpose, we utilize two unique data sources: (1) a cross-sectional and historical (long-term diachronic) video study of human tool apprenticeship and (2) a cross-sectional and longitudinal (short-term diachronic) video study of chimpanzee tool apprenticeship. The human tool system is weaving in Zinacantán, a Maya community in Chiapas, Mexico; this is the first microanalytical study of naturally occurring transmission of a human tool system (Childs and Greenfield 1980; Greenfield 1999). The chimpanzee tool system is termite fishing in Gombe National Park, Tanzania (video archives of the Jane Goodall Research Center, University of Southern California, used by Yut 1994), and this is the first microanalytical study of naturally occurring transmission of a chimpanzee tool system. This chapter constitutes the first time these two data sources have been put together for comparative purposes. We supplement our own analysis of the acquisition of chimpanzee tool use with nonhuman primate data from other sources.

The evolution of powerful means of learning and teaching creates culture by providing a way to transmit and transform knowledge from

generation to generation. This is the hallmark of human culture (Bruner 1972; Parker and Russon 1996). The evolution of powerful means of learning and teaching opens the door to behavioral flexibility on the individual level and to cultural change on the social level. In other words, *the phylogenetic evolution of learning and teaching mechanisms creates a biologically based potential for cultural change.*

In recent years, much has been written about the existence of learning biases; these predispose human learning in particular cultural directions such as language and complex social relationships (Boyd and Richerson 1985; Fiske et al. 1998; Pinker 1994a; Trevarthen 1980). Tools and technology constitute another such direction. The focus of this chapter, however, is less on predispositions to learn particular content than on predispositions to utilize particular learning and teaching mechanisms. The role of teaching mechanisms has been relatively neglected in approaches to both the evolution of culture and cultural change; these mechanisms will be central to the discussion that follows.

Pérusse and colleagues (1994:328–29, their emphasis) have pointed out that

> teaching biases (evolved tendencies to convey adaptive information to offspring) are potentially more powerful co-evolutionary forces than learning biases (evolved tendencies to acquire adaptive information) because they capitalize on an *epigenetic* component in parents: the extensive knowledge that comes from experience gained during the long transition to adulthood. If they evolved, such biases could thus have given rise to an almost-endless production of adaptive *and* diverse cultural variants, as the biases, in addition to being naturally selected, would necessarily be context-dependent in their operation. In effect, teaching biases might help reconcile the apparent contradiction between the adaptiveness and the diversity of human culture. A necessary condition for teaching biases to evolve, of course, is that parental rearing be under genetic influence.

The authors then verified this condition empirically (Pérusse et al. 1994). Using a large sample of adult twins, they did a behavior genetics study in which the target behavior was parental child-rearing behavior. Their results established that parenting behavior, in general, is heritable. This finding opens up the possibility that parental teaching style, in particular, is also heritable. Pérusse and colleagues (1994:328) argued for the natural selection of parental teaching techniques: "Genes promoting the transmission by parents of adaptive versus neutral or maladaptive stimuli would likely generate the acquisition of adaptive information by children and, hence, be naturally selected through the process of kin selection."

Knowledge transmission is a defining feature of culture. Indeed, Parker and Russon (1996:432) have defined cultures as "representations of knowledge socially transmitted within and between generations in groups and populations within a species which may aid them in adapting to local conditions (ecological, demographic, or social)." Within the framework of this definition, all that is necessary for culture is some form of social transmission of knowledge—that is, communication. We include in our definition of communication *unintentional* as well as *intentional* communication. For example, a model observed and imitated by another is often an unintentional form of communication. Individuals of the same species must communicate in order to transmit behavioral information—that is, information that affects the behavior of another animal.

Bonner (1980) traced the development of culture through extant animal species, stressing the need for some form of communication, not for a full-blown language capacity. In Bonner's phylogenetic analysis, learning in animals preceded simple forms of teaching, which preceded more complex forms of instruction. Bonner stressed that complex forms of teaching are more recent and are basic to cultural *change* in the human species. These more complex forms are not necessary, however, for cultural *transmission*.

Central to his ideas about cultural evolution is that certain kinds of information are best transmitted by means of social behavior, because genetic transmission would require a complex code and would be nearly impossible. If the transmission of these kinds of behavioral information is adaptive, then there is strong selection pressure for effective social transmission; genes that make this kind of transmission possible will be favorably selected.

In the first part of the chapter, we focus on and compare the tool use and teaching-learning techniques used by chimpanzees and humans. We will also look at within-species variability in cultural traditions and transmission across both space and time. By making a cross-species comparison of teaching-learning processes in humans and chimpanzees, we can learn two kinds of things relevant to the evolution of tool apprenticeship.

First, we can identify similarities in the teaching-learning processes of the two species. These similarities produce knowledge of a possible common evolutionary foundation for teaching-learning processes in the two species before their phylogenetic divergence five million years ago. We present data primarily from chimpanzees *(Pan troglodytes)*, but from time to time we bring in findings from bonobos *(Pan paniscus)*, a species that diverged from *Pan troglodytes* about two million years ago (Caccone and Powell 1989). *Pan troglodytes, Pan paniscus*, and *Homo sapiens* are considered to be sibling species. Our evolutionary case is strongest where we have data from all three sibling species.

Second, we can identify differences in the teaching-learning processes of *Pan* and *Homo*. These differences are evidence for possible evolutionary change in the ontogeny of cultural behavior in the last five million years, after the phylogenetic divergence of chimpanzees and humans.

In the second part of the chapter, we explore the utility of evolved processes of human apprenticeship for adapting to ecocultural change. We focus on weaving, a complex technology, and the means by which skilled use of this technology is transmitted and transformed from generation to generation. The particular ecocultural change on which we focus is the economic transition from agriculture to commerce. Insofar as this change entails changes in learning and teaching, we conclude that certain types of apprenticeship processes will be adaptive and may even be selected for under particular ecological conditions.

THE EVOLUTION OF APPRENTICESHIP AND TECHNOLOGY

Japanese primatologists, starting in the 1950s, began to find evidence in macaques for two key features of human culture, social transmission of information and tool use (Itani and Nishimura 1973; Kawai 1965; Kawamura 1959; Parker and Russon 1996). (For purposes of this chapter, we define a tool as an object that is purposely fashioned to accomplish a task involving at least one other object.) The Japanese research suggested that cross-specific studies could help in reconstructing the evolutionary foundations of human culture.

The notion of culture in nonhuman primates (Parker and Russon 1996) soon spread beyond Japan (Kummer 1971) and became current with works such as those by Wrangham, Goodall, and Uehara (1983), Goodall (1986), McGrew (1992), Wrangham and colleagues (1994), Boesch and colleagues (1994), and Boesch (1996). More specifically, this body of research (recently synthesized by Whiten et al. 1999) showed that chimpanzees have the rudiments of cultural knowledge, the rudiments of cultural variability, the rudiments of intergenerational learning processes for cultural transmission, and the rudiments of cultural change.

Apprenticeship in Tool Use: A Human–Chimpanzee Comparison

Scaffolding. Scaffolding is an interactional process by which an older, more skilled member of the species supplies help to a younger, less skilled one, thus enabling the younger to accomplish a task he or she could not complete independently (Wood, Bruner, and Ross 1976). At a later point in this developmental sequence, the role of the older guide is internalized (Vygotsky 1978) or appropriated (Saxe 1991) by the younger learner, who is now able to carry out the same task independently.

Although Wood, Bruner, and Ross (1976) conducted their research with human children, scaffolding is not unique to humans. Chimpanzee mothers in the Taï forest of Ivory Coast provide a scaffold for their young who are learning to use a hammer and anvil to crack nuts (Boesch 1991, 1993). For example, when a mother goes to gather more nuts, she might leave a nut positioned in the hollow of a tree-root anvil with a hammer stone on top of it. She has prepared and positioned all the necessary materials for nut cracking; all the infant has to do is pound the nut. Chimpanzees without infants have never been observed leaving intact nuts behind when they go to gather more. Mothers leave hammer and/or nut on or near their anvils while collecting additional nuts significantly more often for infants aged three and above than they do for younger infants. Interestingly, three corresponds to the age when chimpanzees first become interested in nuts and in using hammer tools (Boesch 1991). Thus, leaving nuts and hammers behind is not a generalized chimpanzee behavior but is (1) a specific maternal behavior and (2) concentrated in the chronological age window when chimpanzees are maturationally ready to acquire the skill of cracking nuts with hammer and anvil. Thus, this maternal behavior appears to be directed toward the goal of facilitating tool apprenticeship in infant chimpanzees.

Whereas this type of maternal scaffolding is common, there is another, extremely rare type of scaffolding that is much more dramatic because it involves collaborative learning (Tomasello, Kruger, and Ratner 1993). (Later we discuss the potentially important role of infrequent or rare behaviors in the evolutionary process.) In this example, Salomé is cracking nuts with her son Sartre. "After successfully opening a nut, Sartre replaced it haphazardly on the anvil in order to try to gain access to the second kernel. But before he could strike it, Salomé took the piece of nut in her hand, cleaned the anvil, and replaced the piece carefully in the correct position. Then, with Salomé observing him, he successfully opened it and ate the second kernel" (Boesch 1993:177).[1] Collaborative learning is Tomasello, Kruger, and Ratner's (1993) third and last level of cultural learning. Their view is that only humans have this ability (cf. Reynolds 1993). This example, however, albeit a rare one, suggests a preadaptation for collaborative learning that may stretch back five million years.

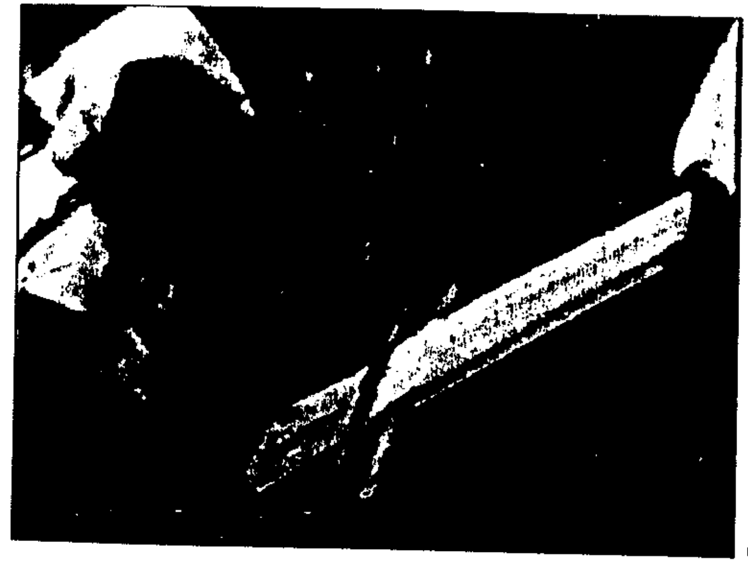
Analogs to these examples of scaffolding and collaborative learning in chimpanzee tool apprenticeship are found among humans. For example, Zinacantec Maya mothers can be observed preparing the materials that their daughters will need in weaving; an example of this phenomenon is shown in the sequence of actions and interactions in figure 9.1. The woman on the right in the first video frame (fig. 9.1A) is using a knife to prepare a stick to be used as a bobbin in the weaving. She hands this stick to one of her daughters (fig. 9.1B), who then uses it as she helps her younger sister learn to weave (fig. 9.1C). The human example is more socially complex than any example of scaffolding observed in chimpanzees: the human mother is dealing simultaneously

A

B

FIGURE 9.1.

Video frames showing the coordinated use of a tool in weaving apprenticeship. A: Mother (hands at right of frame) makes a stick used in the weaving process. B: She hands the stick to her older daughter. C (opposite): The older daughter uses the stick as she helps her younger sister (Katal 1) learn to weave. (First name plus number identifies individual subjects in our complete database of video and other records.) Nabenchauk, Zinacantán, Chiapas, Mexico, 1970. Video by Patricia Greenfield.



C

with two other people, whereas the chimp mothers are dealing with only one other animal. Nonetheless, in these examples both human and chimpanzee mothers are clearly anticipating the needs of their children for aid in successfully completing their respective tool-based tasks. In addition, Salomé, the chimpanzee, appears to take action to prevent an error on her child's part.

Another aspect of scaffolding has also been observed among Taï chimpanzees. They go through the nut-cracking motions more slowly when one of their offspring is present and watching than when a child is not present to watch (Boesch 1991). In Parker's (1996a) typology of teaching techniques, this aspect of scaffolding is called demonstration teaching.

Demonstration teaching is an important part of weaving apprenticeship for the Zinacantec Maya. In the sequence depicted in figure 9.2, demonstration teaching is combined with its complement, observational learning. In the first video frame (fig. 9.2A), a young girl is weaving at a backstrap loom. As she comes to a difficult part of the process, her mother takes over. In the second frame (fig. 9.2B), the mother has begun to weave while her daughter observes. This sequence shows how demonstration can be a part of a scaffolding process: In taking over the weaving, the teacher not only serves as a

FIGURE 9.2.

Video frames showing demonstration teaching. A: *A young girl (Katal 1) weaves on her own as her mother stands nearby.* B: *The mother then steps in and takes over the weaving while the girl observes. Nabenchauk, Zinacantán, Chiapas, Mexico, 1970. Video by Patricia Greenfield.*

model for the learner but also helps the learner get through a difficult part of the weaving process. The learner is also given an opportunity for observational learning.

Keep in mind, as we make our cross-species comparison of tool apprenticeship, that weaving technology is much more complex than termiting technology. Using Piaget's scheme of cognitive development, we could place the former at the level of concrete operations (Greenfield 2000) (completed by many children around age 10), and the latter at the level of sensorimotor intelligence (completed by children around age 2).

Observation and Imitation. In contrast to the Taï chimpanzees (and humans), chimpanzees from Gombe National Park in Tanzania do not use scaffolding to transmit the use of sticks to fish for termites, nor do they scaffold dipping for driver ants, another tool-based activity at Gombe. Gombe chimpanzees use no special techniques whose goal is to help learners achieve mastery of tool use. Instead, learners have opportunities to observe older chimpanzees as the older animals use stems or vines to fish for termites or use sticks to dip for ants in everyday practice. The older animals at Gombe, unlike those at Taï, have never been observed to carry out a deliberate demonstration for the purpose of helping a young chimp to learn. Correlatively, unlike nut cracking at Taï, nut cracking is not part of Gombe culture (Whiten et al. 1999). We conclude that not only is there cross-cultural variability in chimpanzee cultural behavior, but there may also be cross-cultural variability in chimpanzee mechanisms of cultural transmission.

Chimpanzees are exposed to models of tool use, but do they watch and imitate these models? Our observations (as well as those of Custance, Whiten, and Bard [1995] and Boesch [1996]) run contrary to what one would predict from Tomasello's position that chimpanzees can *emulate goals* but cannot *imitate means* of tool use (Tomasello 1989; Tomasello et al. 1987) unless they have received human enculturation (Tomasello, Savage-Rumbaugh, and Kruger 1993). In contrast to Tomasello and colleagues, we studied what chimpanzees *observe*, rather than what they *do*, as a window into the question of observational learning and imitation. Using the Jane Goodall Research Center's video archives at the University of Southern California (USC), we

A

B

Figure 9.3.

Frames from a video of a two-year-old juvenile male chimpanzee observing the means by which an adult reaches the goal of feeding on termites. The numerals indicate that the sequence takes 3.85 seconds. A: *In the first frame, the infant's head is oriented toward watching the mother's hands as she engages in the fishing process.* B: *As the mother's hand brings the fishing tool to her mouth, the infant's head adjusts upward as its gaze is directed at the mother's hands and mouth.* C *(opposite): The infant follows through on these adjustments and raises its head further as its eyes continue to track in the direction of the mother's hands and mouth. Video frames courtesy of the Jane Goodall Research Center, University of Southern California.*

C

found that young chimpanzees pay close attention to the means as well as the end when they observe older chimpanzees engaged in fishing for termites. In the sequence shown in figure 9.3, for example, the juvenile's gaze follows the upward trajectory of the termiting tool (fig. 9.3A–C).

We identified 32 instances in which we were able to code the specific focus of attention of the subjects observing an experienced adult's termite fishing. In half of the observations, subjects paid attention to the entire trajectory—that is, to the adult's getting the termites with the stem or vine and transferring them to the mouth (Yut 1994). Indeed, it was relatively infrequent for subjects to focus on the adult's eating the termites (goal) without first observing the adult get the termites on the tool and then visually following the trajectory to the mouth—that is, observing the means (Yut, Greenfield, and Boehm 1995). This close *observation* of means is a prerequisite for the *imitation* of means. In a natural task context, this finding casts doubt on the idea that chimps are generally limited to emulation (replication of ends only) without being able to imitate the means that lead to the end.

These natural behaviors contradict the assertion of Nagell, Olguin, and Tomasello (1993) that captive chimpanzees paid attention to general functional relations in a laboratory task but not to the actual, demonstrated methods of tool use. This is not entirely surprising, because we are analyzing a natural chimpanzee task rather than an artificial human one. In accord with Piaget's (1962) perspective emphasizing the importance of cognitive understanding of the observed model that is to be imitated, we would expect accurate imitation of means to take place in an activity that is part of the lifeway (or culture) of a species or group (and therefore is well understood), as termite fishing is for the Gombe chimpanzees (cf. Boesch 1993). Boesch (1996) provides parallel examples of imitation from chimpanzees in the Taï forest of the Ivory Coast.

Tomasello's first criterion for imitation—rote copying of means—requires some discussion. This is a rather behavioristic approach to the topic of imitation. It stands in stark contrast to Piaget's (1962) cognitive approach to imitation, in which he emphasized not replication but the cognitive transformation of the model in accord with the developmental stage and schema of the imitator. In other words, in an act of imitation, a child (or an adult) will replicate the features of the model as he or she understands them.

For Piaget, therefore, unlike Tomasello, the production of an exact replica could never be a criterion for an imitation. Cognitive transformation of models was also part of Russon's (1996) definition of true imitation and was frequently observed in rehabilitant orangutans. Miles, Mitchell, and Harper (1996) also observed transformation of models in the imitative behaviors of a captive orangutan. Whiten (n.d.) made a similar point in noting that emulation of a model's ends, in combination with creative transformation of the model's means, may actually constitute more intelligent behavior than the (rote) imitation idealized by Tomasello.

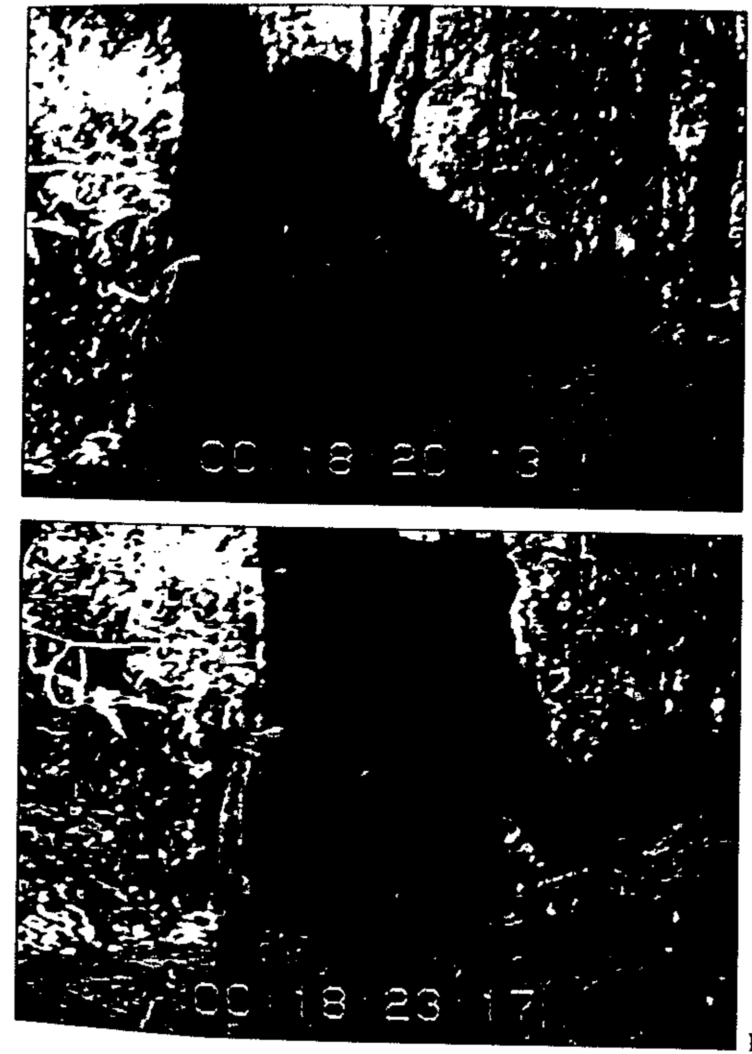
Chimpanzees, however, are indeed capable of replicating a model's means by imitating them. Even accepting Tomasello's criteria for true imitation, we have observed that juvenile chimpanzees translate their close observation of adult tool use into the replication of specific features of the model's activity—for example, a juvenile moves to an adult's termite mound after watching successful termiting there. There is such an instance in the Jane Goodall Research Center video archives at USC used by Yut (1994) in her quantitative study of developmental changes in visual attention to tool activity. In one extended action sequence (fig. 9.4), the young chimpanzee's intentional activity clearly involves taking the same perspective on action as the original model; this is Tomasello's second criterion for true imitation. In this sequence, a juvenile observes an older chimpanzee fishing for termites at a particular location (fig. 9.4A). After the older chimpanzee has left the location, carrying his termiting tool with him, the younger one, swinging from a tree (fig. 9.4B), takes the older animal's tool from his mouth. The younger chimp then returns to the original location (fig. 9.4C) and begins to use the older chimp's tool to fish for termites (fig. 9.4D). The use of the older chimpanzee's tool, location, and activity constitutes the replication of specific features of the elder chimpanzee's methodology. From a learning perspective, this imitation functions, at the very least, to provide practice in fishing for termites. Because goal-directed activity is involved, this imitative sequence also involves some perspective taking: the young chimpanzee assumes the same perspective on the activity that the older chimpanzee had taken a few minutes earlier. As Russon (1996) has found, the imitation lies in the organization of individual elements, not merely in isolated behaviors.

We have observed similar imitative sequences in Gombe with infant and juvenile chimpanzees and their mothers. An infant or juvenile chimpanzee will often grab the mother's abandoned fishing tool when she gets up to leave; the young chimpanzee will then use the tool to fish for termites, often with no success. In one such example, the mother's termite hole and tool were far more productive than the hole and tool the infant had been using earlier. After taking over the mother's hole, the infant began to get a few insects, having assumed a position and posture similar to the mother's. The infant was torn, however, between staying close to its mother, who was moving away, and continuing to fish. The infant therefore whimpered whenever the mother began to move; in this fashion, the infant kept the mother near and continued to fish, using the mother's stick and termite hole with a moderate degree of productivity for about 45 minutes.

In captivity, we have a striking case of adult chimpanzees learning a complicated behavior not found in nature, by immediate imitation. An observation by Desmond Morris (1962) in a captive colony of chimpanzees makes a direct connection between observing and imitating. Morris gave six chimpanzees in the "Chimpanzee Den" of the London

Figure 9.4.

Video frames from a sequence of imitative activity. A: *A two-year-old male juvenile chimpanzee observes an adult male using a stem or vine to fish for termites. About seven minutes later, the adult moves a few steps away from the fishing site, holding the tool in his mouth.* B: *The juvenile, now playing in a tree, takes the tool from the adult's mouth.* C: *Less than a minute later, the juvenile descends with the stolen tool in his mouth and heads toward the location where he had observed the adult fishing for termites earlier.* D: *The juvenile then uses the tool to fish for termites there. The whole sequence takes a little less than eight minutes. Video frames courtesy of the Jane Goodall Research Center, University of Southern California.*



Zoo their first drawing experience. With the first three chimps, each tested alone, Morris provided the chimp with needed instructions in how to hold the pencil. He described what subsequently happened with the last three chimpanzees in this situation:

> But then, when the fourth one, Fifi, came out, to my astonishment she grabbed the pencil from me and started to work without any hesitation. The thought struck me that this must be the

> result of imitation and I turned quickly round to see a dense cluster of young chimps all hanging from the wire of their rest-room at the spot which gave them the clearest view of the drawing Fifi was making. I had been so absorbed in watching the drawings emerge on to the paper, that I had not realized that the Chimpanzee Den was much quieter than usual. I was told afterwards that, behind my back, the silent huddle had hung throughout the tests, intently watching every move, as if their very lives depended on it.
>
> Despite this, the fact that Fifi was the leader of the group made me suspicious. It could just have been that, being the leader, she always took action in a new situation, without waiting for directions. But the fifth chimp, Jubi, answered this doubt. She was small and the least assertive of the group. But, nevertheless, she had seen enough. She did not actually take the pencil from me, but when I handed it to her she straightaway started to draw. (Morris 1962:39)

Chimpanzees are also capable of replicating a model's sequence of functional acts. Whiten (1998) created an experimental test of chimpanzee skill in replicating behavioral sequences. A human model showed humanly enculturated chimpanzees how to open artificial fruit. In line with the greater intelligence of emulating (i.e., copying the goal) rather than imitating (i.e., copying the means) under certain circumstances, the chimpanzees began by imitating model behaviors that were unnecessary to the task; these dropped out over a number of trials (Whiten n.d.). Simultaneously, as subjects experienced repeated cycles of demonstrations and opportunities to perform the task, their behavior gradually converged on the *sequential pattern of the model*, including only those steps that were necessary to accomplish the task (Whiten 1998). Learning over time to replicate a task-relevant sequence of acts demonstrated by a model could be a powerful mechanism in the evolution of cultural transmission. In sum, this array of findings indicates that observational learning (Bandura 1977; Goodall 1986) and imitation are important for chimpanzees, as they are for humans. In both species, they play an important role in cultural transmission.

The Role of Observation and Imitation in Development and Cultural Learning

The research of Bloom, Lightbown, and Hood (1974) on the role of imitation in language development suggests that imitation of models is most frequent with respect to a skill that is already in the process of being acquired but has not yet been mastered. The example of imitation in terimiting reported earlier conforms to this principle: it occurred at the age of two years, when young chimpanzees first start attempting to use objects to fish for termites, a skill that is not completely mastered until the age of five or six years (Yut 1994). Apparently, this principle is general in higher primates; Russon and Galdikas (1995) found that orangutans concentrate their imitation on skills that are on the leading edge of their capacities (Parker and Russon 1996).

As in the human skill of weaving (Childs and Greenfield 1980; Greenfield 1984), close observation of tool use among chimpanzees is a group phenomenon and continues beyond childhood, as is evidenced in the Jane Goodall Research Center archives at USC (Yut, Greenfield, and Boehm 1995). Figure 9.5 depicts close observation of tool use among chimpanzees and humans, respectively. In figure 9.5A, a six-year-old juvenile female chimpanzee is using a tool to fish for termites as two other chimpanzees look on. In figure 9.5B, a young girl is learning to weave as her mother and younger brother stand near to watch.

Other Mechanisms in Chimpanzee Learning and Intergenerational Transmission

Chimpanzees use still other learning and transmission techniques. For example, the Gombe young learn termiting by playful experimentation with objects—specifically, by playing around with the kinds of objects that will later be used as termiting tools (Goodall 1995). Playing with tool-like objects (branches, vines, twigs, stems, and sticks) begins before one year of age (Yut 1994). In figure 9.6, a very young chimpanzee is using a twig, apparently to "termite" in her mother's fur. This playful activity models the real activity of fishing for termites.

A second example of playful experimentation at tool use is particularly creative. On videotape at the Jane Goodall Research Center at

A

B

Figure 9.5.

A: *Two chimpanzees observe another chimpanzee, at far left of frame, probe to fish for termites. Video frame courtesy of the Jane Goodall Research Center, University of Southern California.* B: *Mother and brother observe Rosy 206 learning to weave. Nabenchauk, Zinacantán, Chiapas, Mexico, 1991. Photo courtesy of Lauren Greenfield.*

Figure 9.6.

A two-year-old female juvenile plays with a twig. She has been putting the twig in her mouth, attempting to fish with it, and poking her mother's back with it. In this frame, she is dragging the twig across her mother's back. Jane Goodall remarked that "it looks as if she were fishing [for termites] in her mother's fur" (personal communication, 1995). Video frame courtesy of the Jane Goodall Research Center, University of Southern California.

USC, there is footage of Fifi's infant son as he plays with a small branch with leaves attached, next to a shallow stream. His juvenile sister, Flossi, takes the branch from him and strips a few leaves off, as adults do in making termite probes. She then probes the water for a considerable time, peering into the water as she does so. After repeated reviewing of this footage, it was noted that there were water bugs moving around in the bottom of the stream, which was perhaps six inches deep. That this is indeed playful experimentation is emphasized by the fact that "fishing" for water bugs is never done by adults and has never been otherwise observed in infants or juveniles.

Playful experimentation is an important aspect of the development of technological knowledge by young humans (Piaget 1952). We have observed it in the acquisition of weaving skill when very young girls engage in play weaving on a toy loom (Greenfield 1999). Like play terniting, play weaving models the activity of real weaving. Of course, the play loom of humans is a much more complex tool than a termiting tool used by chimpanzees. But this significant fact does not diminish the important parallelism between the use of playful experimentation in each case.

There is a fourth mechanism for acquiring tool knowledge that is seen at Gombe: independent practice, which is related to opportunity teaching (Caro and Hauser 1992). Independent practice may be stimulated by earlier observation of models, as in Russon's (1996) observations of recurrent rehearsal in rehabilitant orangutans. Our analysis of the Gombe tapes indicates that independent practice occurs for termite fishing between the ages of two and six years, by which time an approximation of adult competence is achieved (Yut 1994).

Similarly, we saw independent practice in videotaped data of young Zinacantec Maya girls learning to weave (Greenfield 1984, 1999). As among the chimpanzees, it was concentrated at the more advanced levels of learning. Again, the technology is much more complex in the human case, but the apprenticeship process and its developmental function are similar.

Cross-species comparison indicates that the human evolutionary legacy includes another important feature of culture: the use of both external and internal representational tools to guide action and to teach. Recently, Savage-Rumbaugh and colleagues (1996) made a startling discovery: in the forests of the Congo Republic (formerly Zaire), bonobo chimpanzees *(Pan paniscus)* use specially prepared branches as pointers to indicate which of two possible paths have been taken. More research on bonobos in the wild is needed to confirm these first observations and to indicate how widespread this practice is. But if these early observations are confirmed, we can note parallels between the bonobo use of branches as pointers and the printed pattern books used by modern-day Zinacantec Maya teenagers and women for embroidery and weaving. In both cases, an external representation indicates a motor path, though in the human case the path is much more complex and is traveled with the hands rather than the feet (Greenfield 1999).

Note that these modes of representation are all indexical or iconic; they are not arbitrary symbols. An index is a representational sign whose interpretation depends on the surrounding context. For example, the act of pointing creates an indexical sign whose meaning depends on what is being pointed to—that is, it depends on context. An icon is a representational sign that resembles its referent; an example would be a photographic image of something, which of course resembles that thing. A symbol is a sign that is arbitrary in the sense that it does not physically resemble its referent. The words of human language generally have this characteristic. Piaget (1962) found that in the first two years of life, these three forms of representation developed in the order index, symbol, and sign.

In the case of bonobo trail marking (Savage-Rumbaugh et al. 1996), the bonobo branches are in context; they are therefore indices of a path. The branches can also be thought of as an image of a path (iconic). The patterns used by the Zinacantec Maya for weaving and embroidery also utilize the iconic mode of representation.

In his work at Gombe, Plooij (1978) provided important insights into the developmental process by which communicative gestures, an internal form of representation, are innovated and developed in chimpanzees in the wild. He documented a developmental process of conventionalization in which mother-child pairs turned interaction into communicative gesture. In figure 9.7 we see how the act of a mother in raising her baby chimpanzee's arm to groom him is subsequently transformed into the baby's raising his arms as an indexical signal to request mother to groom him. Each act of conventionalization creates an innovation in communication for that particular pair of animals.

Boesch (1996) has provided additional evidence for the creation of social conventions in chimpanzee communication in the wild. For example, he noted instances in which the same action had a different communicative meaning in different groups of chimpanzees. And conventionalization has been a long-standing theme in Tomasello's (1989, 1994) longitudinal study of communication in a captive colony.

The genus *Pan* can also use conventionalized symbols to teach. In a videotaped example, Kanzi, a bonobo who uses a lexigram board to communicate with people, attempts to show a younger bonobo, Tamuli, how to slap, hug, and groom him (Ikeo, Jones, and Niio 1993; Tomlinson and Jones 1993). The researcher, Sue Savage-Rumbaugh, asks Tamuli, who has been raised only by his mother and does not understand English, to slap Kanzi. Kanzi then slaps Tamuli. When

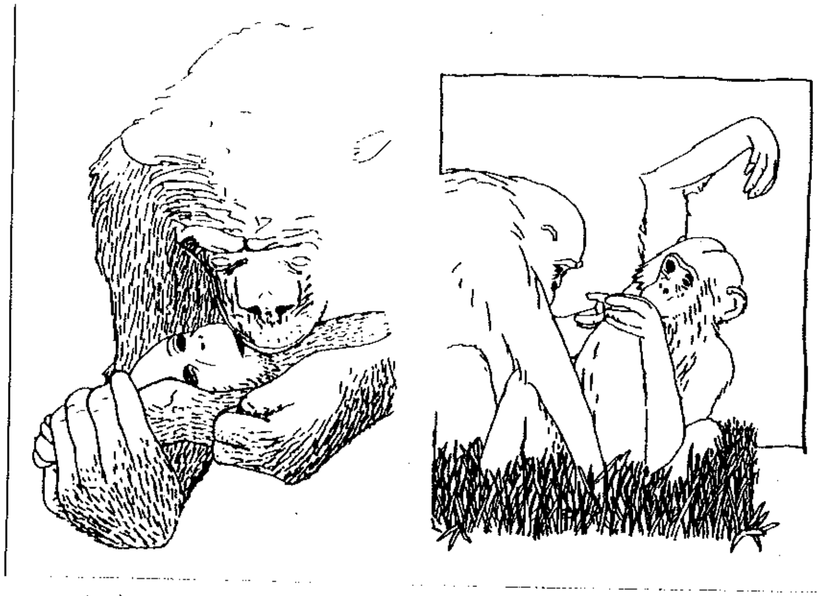


Figure 9.7.

The conventionalization of a gesture, a request for grooming. Left: A mother chimp raises her baby's arm in order to groom it. Right: Later in development, the young chimpanzee raises its arm to request grooming. Reproduced with permission from Plooij 1978:118–19, courtesy of Academic Press.

Tamuli still does not slap Kanzi, Kanzi takes Tamuli's arm and attempts to get Tamuli to slap him. When Savage-Rumbaugh asks Tamuli to groom Kanzi, Kanzi takes Tamuli's arm and hand and shows Tamuli how to groom him. This is a robust example of one chimpanzee's using a communicative gesture to teach another chimpanzee how to do something. Visalberghi and Fragaszy (1996) independently analyzed this scene in the same way.

Not only a bonobo but also a language-trained chimpanzee has been observed to engage in deliberate teaching of symbolic communication (American Sign Language). For a number of years, Washoe and the other signing chimps from the original Gardner study have been collected in a group with no experimental intervention whatsoever, the purpose being to see whether they would use sign language spontaneously in their own interactions. Not only did they use signs frequently in communicating, but also what amounted to an imposed cultural tradition was transmitted to an infant introduced to the group. Some of this transmission was based on unassisted observational learning, but at times deliberate teaching was involved. Fouts, Hirsch, and Fouts (1982) reported a number of occasions in which the chimpanzee Washoe deliberately tried to teach new signs to her adopted infant, Loulis, through a combination of molding—placing the subject's hands in the correct position—and demonstration (Goodall 1986). In the following example, note how Loulis's observational behavior complements Washoe's deliberate teaching: "Washoe was observed to sign *food* repeatedly in an excited fashion when a human was bringing her some food. Loulis was sitting next to her watching. Washoe stopped signing and took Loulis's hand in hers and molded it into the food sign configuration and touched it to his mouth several times" (Fouts, Hirsch, and Fouts 1982:183).

Another example features scaffolded demonstration in which Washoe gradually withdraws the supportive scaffold, just as human mothers do (e.g., Childs and Greenfield 1980): "When Loulis was first introduced to Washoe, Washoe would sign *come* to Loulis and then physically retrieve him. Three days later, she would sign *come* and approach him but not retrieve him, and finally, 5 days later she would sign *come* while looking and orienting towards him without approaching him" (Fouts, Hirsch, and Fouts 1982:183–84). "It is as though because Washoe herself was taught, so she is able to teach" (Goodall 1986: 25).

These examples from *Pan troglodytes* and *Pan paniscus*, because they occurred spontaneously and without coaching, show a preadaptive potential for active teaching. Goodall makes the important point that what may have actualized this preadaptive potential was the animals' experience of having been themselves taught. In other words, environmental stimulation (and functionality) is crucial for transforming a preadaptation into an adaptation. Although a humanly devised language environment is not the "natural" one for chimpanzees, their reaction to it, including the spontaneous teaching of signs, may constitute a model of the way in which the preadaptation for language was transformed into language itself under particular environmental conditions in the course of human evolution.

Note that one aspect of this behavioral adaptation is the possibility of a delayed effect: Washoe was taught signs many years before she taught them to Loulis. Because Washoe's human caregivers had molded her hands to teach her signs many years earlier, her molding of Loulis's hand might even be considered delayed imitation. Indeed, many years had gone by without Washoe's being taught any new signs. This kind of delay might characterize the human mechanism for socialization and culture transmission: one teaches the next generation many years after being taught a skill or piece of knowledge oneself. Because being taught sign language is not normally a part of the chimpanzee environment, the effects of this experience on later teaching suggest a developmental relationship between how one is taught as a child and how one teaches one's children. This may be a key to cultural transmission among humans.

We have seen that chimpanzees in the wild manifest seven of the most basic mechanisms used by humans for the intergenerational transmission and innovation of cultural tools: (1) scaffolding, (2) playful experimentation with objects, (3) observational learning and imitation, (4) independent practice, (5) conventionalization, (6) the use of internal (gestural) and external representations to teach and to guide action, and (7) collaborative learning. Some may become more developed under the influence of human enculturation. Indeed, use of gestures to teach symbol meanings may be an example of such development. We must not, however, underestimate the mechanisms of naturally occurring chimpanzee enculturation. The presence of these mechanisms in both chimpanzees and humans opens up the possibility that these acculturative processes began their evolution in our common ancestor at least five million years ago.

Implications of Cross-Species Contrasts for the Evolution of Human Pedagogy in the Last Five Million Years.

There is one pedagogical complex used by humans but never observed in chimpanzees; it is the use of arbitrary symbolic means to teach a technological skill. This is a strong candidate for the evolution of learning and teaching modalities after humans split from chimpanzees five million years ago. As an example, the arbitrary symbolic means of language is very important in Zinacantec weaving apprenticeship (Childs and Greenfield 1980). Teachers (usually a learner's mother) use language to tell the learner what to do, but not to explain the process. They scaffold their language according to the learner's level of experience. For example, directives are most frequent at the earliest stages of learning, whereas descriptive statements become more frequent with more experienced learners. Language is combined with other modes of teaching, such as demonstrations. The sophisticated use of language, especially commands combined with gestures, in weaving apprenticeship is a skill apes have not evolved.

It may be that linguistic teaching is required by more complex human tool systems such as weaving. Linguistic teaching is clearly unnecessary for simpler tool systems, such as those used to fish for termites or crack nuts. An important hypothesis arises: that technology and teaching (apprenticeship) have co-evolved.

Cross-Cultural Variability and Change in Communicating, Teaching, and Learning among Chimpanzees

There is cross-cultural variability in the symbolic communication of wild chimpanzees. The chimpanzees in Mahale have a different set of communicative gestures from those of the chimpanzees in neighboring Gombe (Wrangham 1995b)—two distinctive nonverbal "dialects" (Goodall 1986:143–45). McGrew (1992) also found cultural variation in the extended arm grasp of chimpanzees.

As we have seen, the different chimpanzee groups do not use methods of intergenerational socialization and learning equally. Just as there is variability in the tools that are used by geographically separated groups in a single species (*Pan troglodytes*), there is also intergroup variability in the learning-teaching mechanisms by which tool knowledge is transmitted and re-created in each new generation.

Cultural variability carries within it the seeds of cultural change. Clearly, as members of *Pan troglodytes* spread to different ecological niches in historical and evolutionary time, different cultural traditions of tools and communication developed (Whiten et al. 1999). The emigrant chimps must have undergone historical change in cultural traditions (Matsuzawa and Yamakoshi 1996).

Conventionalization, too, carries within it the seeds of cultural change. When a mother-child pair conventionalizes a new signal to use between them (Plooij 1978), cultural innovation on the personal level has taken place. The signal is ripe to be shared with and transmitted to others. And the learning techniques of playful experimentation and independent practice contain within them the potential that individual or dyadic learning can create novelty, thus creating the possibility of cultural change on a broader group level.

Equally important are observational learning from models and symbolic communication. These are mechanisms for the conservative transmission of cultural knowledge from generation to generation or for the spread of tradition from one group to another (McGrew 1992). In the Bassa Islands, Hannah and McGrew (1987) noted the spread of tool use upon the arrival of an adult female chimpanzee who used stones to crack nuts. Where there had previously been no tool use in the host community of chimpanzees, 9 of the 13 chimpanzees began to use stones to crack nuts after observing the behavior of the introduced chimpanzee.

Matsuzawa and Yamakoshi (1996; Yamakoshi and Matsuzawa 1993) have modeled this type of cultural change experimentally by introducing coula nuts into the chimpanzee colony at Bossou, Guinea, in West Africa. An adult female, Yo, most likely a migrant from a colony in which stone tools were used to crack coula nuts, immediately began to use tools to crack and eat the nuts. "When Yo cracked the coula nuts, a group of juveniles gathered around and peered at her while she was cracking and eating the strange nuts. The next day, an unrelated 6 ½-year-old male named Vui cracked open a coula nut without any practice. Four days later, a six-year-old female named Pili did the same. The two juvenile chimpanzees cracked the nuts and sniffed the kernel and chewed and spat it out" (Matsuzawa 1994:364). Although these were the only two juveniles to crack nuts, the utilization of observation and imitation to spread novel behavior is clear. An important point is that the innovative tool use model was copied only by juveniles. Among humans, learning from innovative models is also concentrated in the "juvenile" period (Greenfield 1999).

Tomasello (1989) observed an example of cultural innovation in communication in a captive colony. This occurred when newly introduced wood chips became the basis for a communicative gesture; all of the chimpanzees in the study group began to throw the wood chips at each other in order to initiate play.

Because of the variety of learning mechanisms present in at least a crude form in modern chimpanzee life, the evolutionary foundation for both cultural continuity and cultural change in human groups could have been present in our common ancestor five million years ago, ready to be elaborated in the ensuing millions of years.

One striking change that probably took place in the last five million years is in the cumulative quality of human cultures. Unlike chimpanzee cultures, they cannot be reinvented in the space of a single generation by inter- and intragenerational interaction. Boyd and Richerson (1996) point out that whereas the basic mechanisms of cultural learning are present in nonhuman primates, cultural accumulation is hard to get started because it does not have adaptive advantages until it is quite widespread; at that point, it is easy to keep going. In essence, according to Boyd and Richerson (1996), cumulation is a quantitative, not a qualitative, difference between humans and great apes. The implication is that the common ancestor of *Homo* and *Pan* had the basic psychological mechanisms for cultural transmission. We hypothesize that these mechanisms were then strongly selected for in the hominid line after its divergence from the great apes. This selective process would then have resulted in cultural accumulation.

Contrasting Implications of Behavioral Frequency in Psychology and Evolution

Sometimes the argument is made that chimpanzee behaviors for transmitting cultural knowledge are irrelevant to human culture because they are relatively infrequent in comparison with such behaviors in humans (Tomasello 1994). Frequency is very important in the discipline of psychology, which puts great weight on mean and modal frequencies of behaviors; correlatively, psychology minimizes the significance of infrequent behaviors.

The reverse, however, is true for evolutionary research and evolutionary theory. In evolution, infrequent phenomena often hold the keys to an evolutionary process. This is so because natural selection operates to make adaptive but infrequent characters (including behavioral traits) more frequent in the course of phylogenetic development. Consequently, when we see behavioral traits in common between sibling species, but frequent in one species and infrequent in the other, the most parsimonious explanation is that the behavior was present but infrequent, fragile, and primitive in the common ancestor of the two species; it proved adaptive in one phylogenetic line when it appeared; and it was therefore selected for and became more common, more elaborated, and more robust in the course of that line's evolution. In sum, even rare data are useful in identifying preadaptive potential.

In comparative research, therefore, it is important to acknowledge infrequent phenomena for their potential evolutionary significance. For example, there is potential evolutionary significance in the minority of conventionalized gestures that spread to the chimpanzee group as a whole (Tomasello 1989).

If modern-day chimpanzees share with humans the basics of tools and the basics of intergenerational transmission of tool knowledge, then it is more than likely that the ancestor that preceded the phylogenetic split between hominids and chimpanzees also knew how to use tools and how to induct the young into this knowledge. In this pedagogical knowledge lies the evolutionary foundations not only of human culture and human cultural transmission but also of human cultural change.

CULTURAL CHANGE AND TOOL APPRENTICESHIP IN HUMANS

Given the evolution of this wide range of apprenticeship mechanisms, the possibility arises that different mechanisms would be useful under different ecocultural conditions. A change in the importance of various apprenticeship processes could therefore be a key to successful adaptation to ecocultural change. This hypothesis was tested through a long-term study of weaving apprenticeship conducted by Greenfield and Childs in the Maya community of Zinacantán. We explored the relations between sociohistorical transformations and apprenticeship processes in a direct way: by following a group of families over two generations, studying their processes of weaving apprenticeship before and after processes of important ecological change.

The study site of Zinacantán is a community in which the basis of the economy is in transition, from agricultural subsistence to commercial entrepreneurship and cash. In 1969 and 1970, Greenfield and Childs (1977; Childs and Greenfield 1980) conducted studies of culture, learning, and cognitive development in Nabenchauk, a Zinacantec hamlet. At that time, a subsistence lifestyle based on corn and beans was almost universal in the community, although corn was also sold as a cash crop. One focus of our research was on the apprenticeship processes involved in the important cultural technology of weaving, the most complex skill in the culture and one that is acquired by virtually all Zinacantec girls. In 1991 we returned to a community that had expanded its economic basis to commerce and in which cash had taken on a much greater importance. We repeated our study of weaving apprenticeship with the next generation of girls (Greenfield 1999; Greenfield, Maynard, and Childs 1997).

Our major theoretical proposition was that not only do cultures change over historical time, but the importance of particular processes of cultural learning and cultural transmission also changes. More specifically, a somewhat different set of teaching and learning processes may be emphasized when cultures are in a more stable state compared with when they are in a more dynamic state. Correlatively, particular processes of apprenticeship should be highlighted in connection with the dominant ecocultural system of a particular time and place.

Insofar as the process of socialization prepares the next generation to participate in society, it should change when the conditions faced by that next generation differ from the environment in which their parents grew up. Socialization is intrinsically future oriented—it prepares children for an adulthood that still lies in the future. A key question, however, is this: Under conditions of change, do parents merely recreate the apprenticeship process they underwent as children (as Washoe did), or is there a capacity to develop new methods and processes as societal conditions—in this case, economic conditions—change? Pérusse and coworkers (1994:334) hypothesized that evolution has selected for the (unconscious) rule of parental teaching (which has its roots in childhood teaching [Maynard 1999]): "Teach what is most adaptive for your children." Is this the case in situations of sociocultural change?

Weaving was the focus for studying processes of informal education, teaching, and learning in a society in which education does not traditionally take place in school. Weaving, considered to be the essence of Zinacantec womanhood, is the means by which most clothing is made. In 1969 and 1970, woven artifacts, like other parts of the culture, were stable and unchanging, limited by tradition. Woven patterns were limited to two red-and-white striped configurations, one multicolor stripe, and one gray-and-white basket-weave pattern.

On the basis of our research in 1969 and 1970 (Childs and Greenfield 1980; Greenfield 1984; Greenfield, Brazelton, and Childs 1989; Greenfield and Childs 1977, 1991), we concluded that the implicit goal of Zinacantec education and socialization was the intergenerational replication of tradition: learning to weave meant learning to weave about four specific patterns. According to our findings, the particular way in which weaving was taught fostered this goal. The learning process was a relatively error-free one in which the teacher, usually the mother, sensitively provided help, a model for observation, and verbal direction in accord with the developmental level of the learner. The mother as a teacher provided a scaffold of help that allowed the learner to complete a weaving she could not have done by herself. There were no failures; every girl learned to weave. Because the process was highly structured by the older generation and allowed no room for learner experimentation and discovery, the method of informal education (or apprenticeship) was well adapted for the continuation of tradition, the status quo. Such respect for tradition, as embodied in the older generation, is an effective adaptation to agricultural techniques and ecology, a system in which land is controlled by the older generation (Collier 1990).

Our follow-up study two decades later (Greenfield 1999; Greenfield, Maynard, and Childs 1997) was based on the fact that by the 1990s, the ecocultural environment had changed. Men who formerly farmed were now in the transport business. They had become commercial entrepreneurs, running a van service back and forth to the former colonial city of San Cristóbal de las Casas. Other men were involved in trucking, and many either drove or owned their own trucks for transport businesses and commerce, the buying and selling of agricultural products.

In accord with our theory, a coordinated change had taken place in the apprenticeship process. The emphasis in weaving apprenticeship had shifted in many families (specifically, those families most involved in commerce) from scaffolding toward independent practice. A second shift was from teachers in the maternal generation to teenage teachers.

FIGURE 9.8.

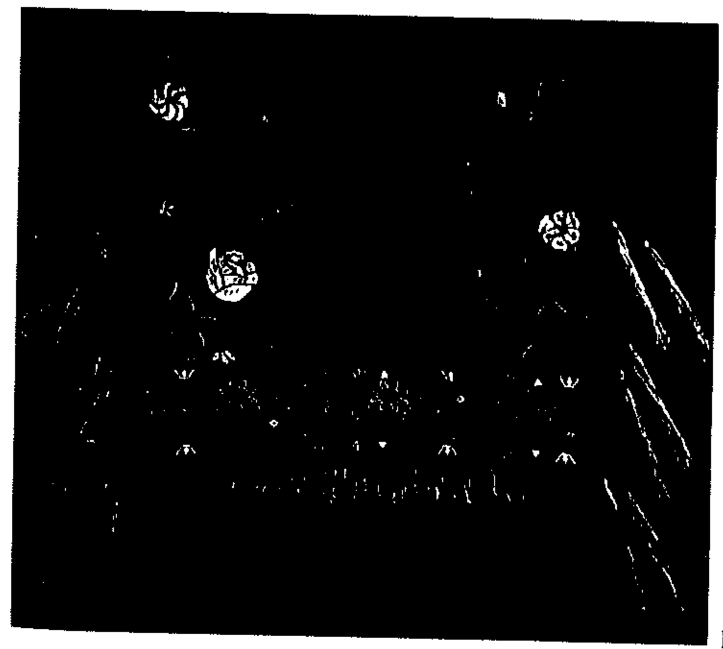
Mother and daughter (Katal 1) work at the loom together. Four hands on one loom are often a part of Zinacantec weaving apprenticeship. Nabenchauk, Zinacantán, Chiapas, Mexico, 1970. Video by Patricia Greenfield.

As with chimpanzees (Matsuzawa and Yamakoshi 1996), innovation was concentrated in the younger generation. Compare a video frame of a girl learning to weave in 1970 (fig. 9.8) with a video frame of her daughter learning to weave at the same age (nine years old) in 1991 (fig. 9.9). In 1970, weaving instructors stayed close to their pupils, often resulting in four hands on a loom, with the teacher and the pupil working to keep the weaving going together (fig. 9.8). In the 1990s, the learner was often weaving more independently; weaving teachers were often away from their pupils and had to be called over for help (fig. 9.9) (Greenfield, Maynard, and Childs 1997). Collaborative activity still took place in the apprenticeship process, but, in comparison with a generation earlier, it was initiated more by the learner and less by the teacher. In figure 9.8, the learner is being taught by her mother. In figure 9.9, the mother is not teaching her own daughter but has assigned a teenage sibling to serve as teacher. Both independent practice and teenage teachers are better adapted to discovery learning and innovation, a value implicit in commercial entrepreneurship.

FIGURE 9.9.

A teenage sister stands near a girl (Loxa 1 201) who is learning to weave, but she does not offer assistance until she is summoned. These girls are the daughters of Katal 1, the learner in figures 9.2 and 9.8. Nabenchauk, Zinacantán, Chiapas, Mexico, 1991. Video by Patricia Greenfield.

A



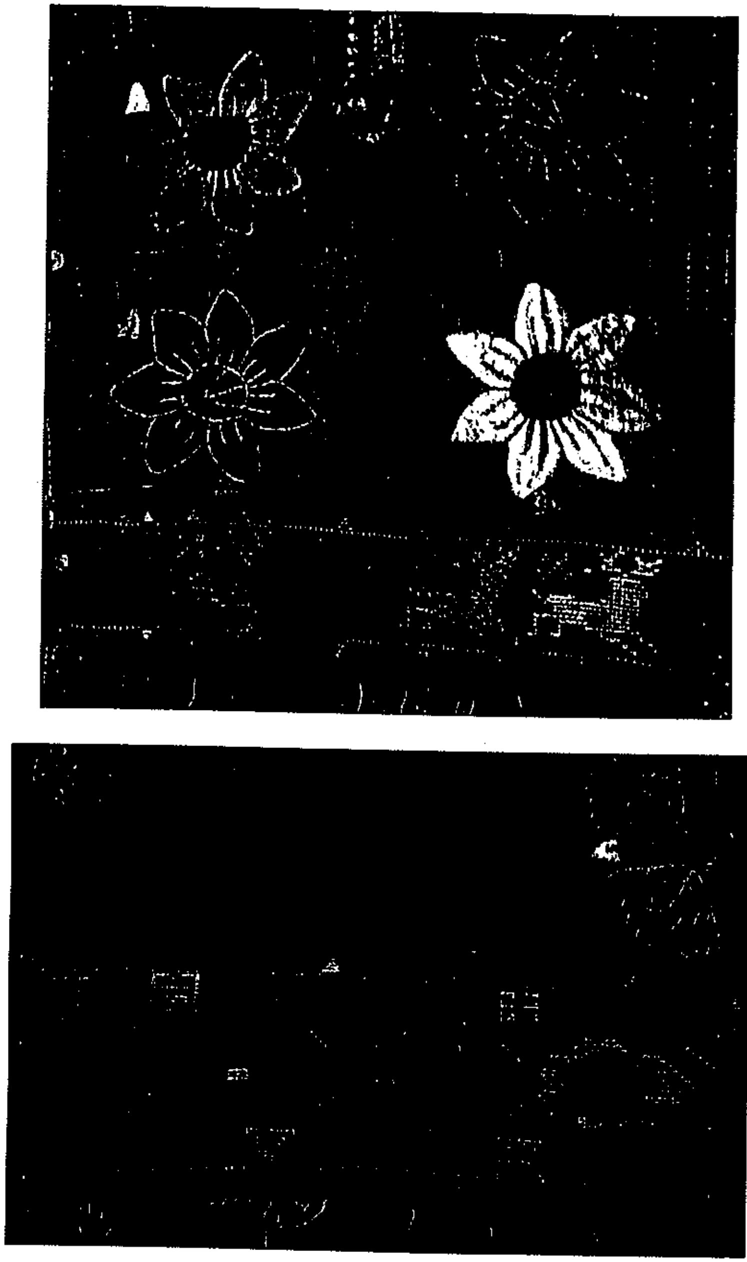
B

FIGURE 9.10.

A: *Two Zinacantec brothers dressed almost identically, 1970. Photo courtesy of Sheldon Greenfield.* B *(above),* C, D *(next page): Three men's ponchos representing the variety and invention found in Zinacantec textiles in 1991. Photos courtesy of Lauren Greenfield.*

Indeed, innovation was rampant in weaving and embroidery in 1991. Unlike the 1970 weavers (Childs and Greenfield 1980; Greenfield and Childs 1977), weavers of the 1990s were engaging in a constant process of pattern creation. No two pieces of clothing or other woven items were exactly alike. We saw both new motifs and new recombinations of old motifs. Both geometric designs and figurative representations had entered the scene. There had been no figurative representations in Zinacantán two decades earlier. Figure 9.10A depicts two brothers dressed almost identically in 1970. Examples of the variety of woven and embroidered patterns created in 1991 are depicted in figure 9.10B–D. As in chimpanzee culture (Matsuzawa and Yamakoshi 1996), innovation was concentrated in the younger generation (Greenfield 1999).

Here, then, as hypothesized, was a correlated historical change in ecocultural environment (from agriculture to commerce) and techniques of apprenticeship (from emphasis on scaffolding to emphasis on independent practice). Changes in the material culture of woven



C

D

FIGURE 9.10 (CONT.).

C, D: *Close ups of men's ponchos from Zinacantán, 1991. Photos courtesy of Lauren Greenfield.*

artifacts to an innovative mode entailed change in the method by which weaving was taught and learned. The mode of cultural learning changed from one adapted to maintaining an unchanging stock of traditional artifacts to one adapted to creating cultural innovation and novelty. Thus, change in emphasis in cultural apprenticeship was interrelated with both general ecocultural change and further change in textile design.

Each mode of cultural learning contributes to maintaining a distinctive cultural environment. Hence, we find that certain methods of apprenticeship—such as closely guided participation by the older generation—are more culturally conservative. They tend to transmit the cultural status quo. In contrast, other methods—notably independent practice and teenage teachers—tend to lead to more rapid and radical cultural transformation.

As Pérusse and colleagues (1994) had hypothesized, Zinacantec mothers taught in a way that would maximize their children's fitness under current conditions. They did not simply repeat the way they had been taught weaving as children. Because the historical change was uneven (some families were still involved in agriculture and not commerce, some were involved in both, and some were involved in commerce alone), the change in apprenticeship was also uneven. One would expect that as the economic change became more complete, the techniques of apprenticeship would become more uniform again, as they had been in 1970.

Thus, Zinacantec weaving apprenticeship serves as an example of how cultural transitions may often begin as adaptive alternatives within a given group. If so, this would mirror phylogenetic evolution, in which "phenotypic transitions often begin as adaptive alternatives within species" (West-Eberhard 1988). Variability may be as important in processes of cultural change as it is in biological evolution. Insofar as there is a genetic basis for the more adaptive variants, they can be selected for over a long period of time. In this way cultural change has the potential to become biological in nature (Baldwin 1902).

CONCLUSION

Cultures provide models for the growth and survival of their members that are transmitted from one member to another. There are many aspects of cultural transmission that are shared between *Homo sapiens* and *Pan*. These include scaffolding, observational learning and imitation, experimentation with objects, independent practice, the use of both internal and external symbolic communication, and collaborative learning. In both species (albeit not with equal frequency), these techniques have been incorporated into deliberate teaching.

In terms of the evolution of cultural transmission, perhaps most impressive is the finding that a chimpanzee mother will spontaneously teach her child what she was taught and the way she was taught (by humans) during her own childhood. Although our example comes from a special captive situation, we emphasize that the potential of *Pan* is almost as important, in terms of preadaptations for becoming human, as what *Pan* actually does in the wild. While we can never know the special environmental circumstances that led humans to develop as they did, we can at least identify types of behavior in the wild and in captivity that enable us to speak about likely preadaptations.

In most instances, we have information on humans and on *Pan troglodytes*; in one instance (the use of external symbolic tools), we have information on humans and *Pan paniscus*. In only one instance (instruction about symbolic communication) do we have information for all three species. The evolutionary implications would be much clearer if all aspects of cultural transmission had been explored among all three sibling species. Cladistic methodology posits that when all sibling species share a trait, that trait is highly likely to have been possessed by the ancestor of those sibling species. When traits have been investigated in only two of three sibling species, as is often the case with mechanisms for cultural apprenticeship, the evidence is weaker. Nonetheless, our positive cross-species findings of shared features of cultural apprenticeship indicate that these features are strong candidates to be part of *Homo sapiens'* evolutionary heritage, going back five million years to the common ancestor of *Homo* and *Pan*. The more research that can be done in which the same behavioral features are investigated in all three species, *Homo sapiens, Pan troglodytes,* and

Pan paniscus, the surer the phylogenetic basis for these traits will become.

Unique in human cultural transmission is technical instruction by means of arbitrary symbols, such as language. But note that this unique feature results from a combining of elements that are shared with *Pan*: we have seen that technical instruction occurs in stone tool apprenticeship in the jungle of Ivory Coast (Boesch 1991, 1993) and that instruction incorporating arbitrary symbols occurs spontaneously in captive chimpanzees exposed to a human language environment (Fouts, Hirsch, and Fouts 1982; Ikeo, Jones, and Niio 1993; Tomlinson and Jones 1993).

In addition, of course, human technologies are much more complex than chimpanzee technologies, and the complexity of teaching must increase proportionately. Indeed, in industrial societies, human tool apprenticeship now requires a specialized institution, the school. Hence, the last five million years of human evolution have involved, among other things, the coordination of symbolic communication with collaborative learning and the elaboration of apprenticeship techniques to induct the young into a high level of technological complexity. After examining the evidence, however, we come to the unexpected conclusion that the last five million years of evolution of human tool apprenticeship seem not to have produced major differences in kind. Instead, they have involved the elaboration and combination of learning mechanisms that may go back at least as far as the split of *Pan* and *Homo* five million years ago.

We believe there is a co-evolutionary process in the development of technology, teaching, and cognition. As the complexity of technologies increases, the complexity of apprenticeship to use those technologies must also increase. The evolution of apprenticeship processes must also be coordinated with ontogeny and its evolution. That is, there must also be coordination between the skill development of the learner and the nature of the apprenticeship process across species. Current work on the development of teaching in young children indicates that children as young as six years are able to provide stage-sensitive instruction that is adapted to the developmental capacities of their pupils (Maynard 1999). This research also shows that apprenticeship itself has an ontogeny (Maynard 1999)—that is, skills in cultural teaching develop with age.

Processes of apprenticeship provide mechanisms for both the re-creation and the transformation of culture from one generation to the next. Given a pool of apprenticeship techniques, changes in emphasis on particular processes of learning and teaching provide ways of both responding to and creating cultural change or cultural continuity. While both human and chimpanzee cultures show constancy and change over time as a result of these apprenticeship modes, evidence for cultural accumulation is found only in the human species. Perhaps the combination of complex technology and symbolic instruction is responsible for the cumulative quality of human culture.

Human cultural change holds an implication for the evolution of ontogenies: it is not adult stages that evolve but rather ontogenies that must evolve in response to new tool systems or changing ecocultural conditions. Even across species, it must be *ontogenies* that evolve (Gould 1977; McKinney, this volume) and get transmitted genetically in response to new ecological niches. Given the absence of a fossil record of behavior and its development, the comparative study of human and nonhuman development and socialization is prerequisite to reconstructing the evolution of human behavioral development, including sequences and rates of development (Parker, this volume). A key contribution of the present chapter is that behavioral development must include the development of teaching processes as well as the development of learning processes.

Studying chimpanzees and humans in the transmission of tool systems furthers our understanding of the biological and historical basis of culture, cultural transmission, and cultural change. We gain knowledge of which features of teaching and learning were most likely present in the common ancestor we share with *Pan*; we understand how we humans are both similar to and different from our closest primate relatives; and we gain insight into how cultures themselves are transmitted and transformed from one generation to the next. When we examine cultural apprenticeship across species, factors essential for cultural transmission and for cultural change become more evident, ultimately deepening our understanding of both.

Notes

We would like to acknowledge the School of American Research, the Wenner-Gren Foundation for Anthropological Research, the Fogarty International Center of the National Institutes of Health (Minority International Research Training Program to UCLA–El Colegio de la Frontera Sur, TW00061, Steven Lopez, principal investigator), and UCLA for supporting the preparation of this manuscript. We thank the Jane Goodall Research Center archives at the University of Southern California, the Spencer Foundation, the National Geographic Society, the UCLA Latin American Center, the UCLA Center for the Study of Women, the Center for Cognitive Studies (co-directed by Jerome Bruner), the Harvard Chiapas Project (directed by Evon Z. Vogt), the Radcliffe Institute, and the Milton Fund of Harvard Medical School for supporting the research on which this chapter is based. We also thank Carla Childs, Leslie Devereux, Hanna Carlson, and Lauren Greenfield for collaborating in the collection of the Zinacantec Maya data and Matthew Greenfield for managing the video database. Christopher Boehm thanks the H. F. Guggenheim Foundation for support of research that enabled him to assemble a substantial archive of videotaped footage of wild chimpanzee behavior, which is housed at the Jane Goodall Research Center at the University of Southern California. Ashley Maynard was supported by graduate fellowships from the National Science Foundation, the UCLA Center for the Study of Evolution and the Origin of Life (CSEOL), and the University of California Office of the President.

Portions of this chapter were presented as a poster on chimpanzee tool apprenticeship by Yut, Greenfield, and Boehm at the annual symposium of the Jean Piaget Society for the Study of Knowledge and Development, held in Berkeley, California, in June 1995 (Yut, Greenfield, and Boehm 1995).

1. Whiten (1999) concludes that lowland gorilla mothers (observed in a zoo) manifest in a basic form almost all of the features of scaffolding identified by Wood, Bruner, and Ross (1976). Boesch (1991) concludes that all of these features are present in chimpanzee apprenticeship for nut cracking with hammer and anvil.