

Feature Review

Imitation and Innovation:
The Dual Engines of Cultural
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Imitation and innovation work in tandem to support cultural learning in children and facilitate our capacity for cumulative culture. Here we propose an integrated theoretical account of how the unique demands of acquiring instrumental skills and cultural conventions provide insight into when children imitate, when they innovate, and to what degree. For instrumental learning, with an increase in experience, high fidelity imitation decreases and innovation increases. By contrast, for conventional learning, imitative fidelity stays high, regardless of experience, and innovation stays low. We synthesize cutting edge research on the development of imitative flexibility and innovation to provide insight into the social learning mechanisms underpinning the uniquely human mind.

Searching for the Foundations of Cumulative Culture

Approximately 7 million years ago humans and chimpanzees shared a common ancestor. Since then, the inventory of human tools has gone from a handful of rudimentary stone implements to a long and diverse list of tools remarkable enough to replicate DNA, support communication across oceans, and build spacecraft that can explore our solar system. In the same evolutionary timespan, there is little evidence that chimpanzees have expanded their rudimentary toolkit beyond what was available to our common ancestor. The technological advances that characterize humans are an outcome of our species' remarkable capacity for cumulative culture; innovations build on each other and are progressively incorporated into a population's stock of skills and knowledge, generating ever more sophisticated repertoires [1–4, 129]. The capacity for cumulative culture has set our genus *Homo* on an evolutionary pathway remarkably distinct from the one traversed by all other species.

Cumulative culture requires the high fidelity transmission of group-specific **instrumental skills** (see [Glossary](#)) and **social conventions** to future generations [5–9]. Instrumental skills and social conventions serve distinct functions in human culture. Instrumental skills are the technological toolkits of social groups. They allow group members to perform the types of tasks required for survival and success within particular cultural contexts. Social conventions are group-specific practices that function to increase cohesion and cooperation among group members. Although the functions of instrumental skills and social conventions are distinct, in practice, all behavior is embedded within social contexts and frequently has both instrumental and conventional elements. Thus, the difference between instrumental skills and social conventions is often a matter of degree rather than of type. For example, many instrumental skills are required to successfully operate a motor vehicle, such as manipulating the accelerator and the steering wheel. The instrumental goal is to travel from point A to point B. Yet, there are also a number of group-specific social conventions associated with driving, such as the side of the road vehicles travel upon and the gestures used to signal to other drivers. The conventional goal is to ensure the cooperation of drivers through a system of shared (although often arbitrary) rules.

Trends

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For conventional learning, imitative fidelity stays high, regardless of experience, and innovation stays low.

We synthesize cutting edge research on the development of imitative flexibility and innovation to provide insight into the social learning mechanisms underpinning the uniquely human mind.

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Young children are well equipped to acquire both types of behaviors from members of their social groups. A rapidly growing literature in developmental and cognitive science, evolutionary anthropology, and comparative psychology has documented children's early developing propensity for **overimitation** or copying actions that are causally irrelevant to achieving an instrumental end goal [10]. Our species-specific proclivity for high fidelity imitation has been linked to **cumulative cultural transmission** [5–9]. For acquired behavior to count as cultural it must disseminate in a social group and remain stable across generations [11–13]. Acquiring the instrumental skills and social conventions of other group members may be the function of an individual-level adaptation for imitation in our species. Thus, the transmission of cumulative culture across generations can be seen, in part, as a byproduct of our propensity for high fidelity imitation.

Yet, imitation alone does not explain the extraordinary cultural achievements of our species. Innovation is necessary to ensure cultural and individual adaptation to novel and changing ecological challenges over time. There is evidence that cultural evolution makes individuals more innovative by allowing for the accumulation of prefabricated solutions to problems that can be recombined to create new technologies. The subcomponents of technology are often too complex for individuals to develop from scratch. Inheriting the cultural technologies of previous generations allows for the explosive growth of human culture [4].

We propose that imitation and innovation work in tandem as dual engines of cultural learning. Both high fidelity imitation and generative innovation are capacities available in the human cognitive toolkit, although the ontogeny of these behaviors has only been studied systematically in recent years. A comprehensive account of cultural learning must explain both how imitation and innovation contribute to cumulative cultural transmission and how they develop over ontogeny. Imitation and innovation are pervasive features of children's behavior, yet an integrated theoretical account of how children flexibly use imitation and innovation has only been developed recently. How do children adjudicate between when to engage in high fidelity imitation, when to innovate, and to what degree? And how does the precocious capacity to use imitation and innovation drive cultural learning?

The objective of this paper is to explain how the unique demands of acquiring instrumental skills and social conventions provide insight into when children imitate, when they innovate, and to what degree. Whereas learning an instrumental skill allows for variability and innovation in methods of execution, learning social conventions requires close conformity to the way other group members perform the actions through high fidelity imitation. New research has demonstrated that the deployment of imitation and innovation is context-dependent and requires early developing flexibility in social learning [14–17].

The Evolution and Ontogeny of Imitation

The capacity to acquire new skills and knowledge by copying others is integral to the development of human cultural learning and is in place early in development [18–20]. By 2 years of age, the tendency to overimitate has become so ubiquitous that children will even imitate causally irrelevant actions that they know are unnecessary to achieving an instrumental end goal. For example, children will tap a stick on the side of a box and then persist in trying to use the stick to manipulate a switch to get the box open because that is what an adult model did, even after having discovered that the switch can be more easily activated by hand [21]. Available evidence suggests other primates do not overimitate [22].

Why faithfully copy all of the actions of a demonstrator, even those that are obviously irrelevant? Given the potentially overwhelming number of objects, tools, and artifacts children must learn to use, it is useful to replicate the entire suite of actions used by an expert when first learning how to

Glossary

Cumulative cultural transmission: technological innovations build on each other and are progressively incorporated into a population's stock of skills and knowledge, generating ever more sophisticated repertoires.

Dual inheritance theory: human behavior is a product of two different and interacting evolutionary processes: genetic and cultural evolution.

Flexible imitation: the use of social and contextual information to infer the goal of behavior (e.g., instrumental or conventional) to adjudicate between when to imitate and to what degree of fidelity.

Instrumental skills: the technical toolkits of a cultural group.

Natural pedagogy: evolved interpretive biases that allow and foster the transmission of generic and culturally shared knowledge to others.

Overimitation: imitation of actions that are causally irrelevant to achieving an instrumental end goal.

Principle of rationality: the assumption that people try to reach their goals.

Ritual: socially stipulated, causally opaque, group conventions that serve an affiliative function.

Social conventions: the traditions, practices, and beliefs of a social group.

Teleological stance: reasoning that is based on the assumption of purpose, design, or function.

Tool innovation: constructing new tools, or using old tools in new ways, to solve new problems.

do something. Some propose that overimitation is an adaptive human strategy facilitating more rapid social learning of instrumental skills than would be possible if copying required a full representation of the causal structure of an event [10,22]. This proposal has much in common with the rational action theory of imitation [23,24]. According to this theory, ostensive communication or ‘**natural pedagogy**’ (i.e., evolved interpretive biases that allow and foster the transmission of generic and culturally shared knowledge to others) coupled with a ‘**teleological stance**’ (i.e., reasoning that is based on the assumption of purpose, design, or function) enables young children to represent the structure of novel actions even when the causal relations between the method and the outcome are opaque and appear to violate the expectation for behavioral efficiency derived from the **principle of rationality** [25].

In line with a ‘copy-when-uncertain’ social learning strategy [26], overimitation may be so adaptive that it is employed at the expense of efficiency [27]. That is, the costs of not imitating with high fidelity in an uncertain situation outweigh the benefits of the reduced effort entailed in imitating with low fidelity. This approach to social learning likely had its foundation in our Pleistocene past [28]. As proponents of **dual inheritance theory** maintain, unless the world is at least somewhat uncertain (or opaque), natural selection would not favor high fidelity imitation [29].

Contemporary research on imitation in early childhood has been heavily influenced by research in comparative psychology [7,22,30,31]. Much of what we know about imitation is based on understanding instrumental skill acquisition. One of the inaugural interpretations of overimitation viewed it as overattribution of causal efficacy to redundant elements [10,32]. This interpretation has been challenged by accounts that emphasize the social and normative function of imitation [33–36]. Despite substantial psychological evidence for the early developing and sophisticated capacity to reason causally [37], much of what children need to learn and interpret is not based on understanding physical causality and instead is based on social conventionality.

Causal reasoning does not underpin all imitative behavior [38]. Beyond instrumental skills, children must also learn cultural conventions such as social norms and practices [14,39]. The rituals that children must learn to become competent members of their cultural communities are socially stipulated group conventions, uninterpretable from the perspective of physical causality [40]. We propose that rituals are a crucial subset of conventional behavior with distinctively social functions [14]. They lack an intuitive or observable causal connection between the specific action performed (e.g., ceremonial dance) and the desired outcome or effect (e.g., making it rain) [41,130]. Many rituals, such as forms of greeting, do not entail changes to the physical state of the world in any observable manner. The social stipulation and causal opacity of rituals make them ideally suited to high fidelity cultural transmission, reinforced by a willingness to rely on faith in cultural traditions over personal experience or intuition [14–17].

As cultural novices, children are well prepared to acquire the conventions and practices of their social groups. Children readily adhere to, enforce, and redress violations of the shared behavioral standards of their community [42–44] and will change their behavior to conform to the behavior of others in order to avoid negative social consequences, such as ostracism [45]. The expectation for conformity in the context of social conventions appears to be species-specific and central to the maintenance of cumulative culture.

As specialized cultural learners, children are well equipped to engage in socially motivated, high fidelity imitation, a potential indicator of group affiliation through conformity [15]. New research indicates that high fidelity imitation may have evolved social functions, notably encoding normative behavior [45–47], affiliation with ingroups [48], and detecting ostracism from ingroups [49]. Preschool children are also more likely to engage in high fidelity imitation of an instrumental task

Box 1. The Functions of Ritual in Social Group Behavior

Humans have evolved a variety of psychological adaptations for group living [1–4]. As populations increased in numbers of nonkin over human history, rituals may have allowed social groups to remain cohesive, while reducing the need for physical and social proximity. The adaptive problems presented by living in large groups of nonkin in turn required the evolution of psychological mechanisms to solve them [42,91]. Engaging in rituals serves a variety of functions that help solve adaptive problems associated with coordinated and cooperative group action [91,92]. Rituals mark group members in practically and psychologically powerful ways and hence provide a means of identifying ingroup members. Participating in group-specific practices allows identification of ingroup members, who are more likely to cooperate and less likely to free ride than outgroup members. Engaging in rituals also demonstrates commitment to ingroup values [93]. Rituals often include seemingly costly actions that operate as reliable signals that convey commitment to the group [94]. Individuals who demonstrate commitment to ingroup values through ritual participation are more likely to be trusted in cooperative endeavors [95]. Social group living entails tension or conflict between individual interests and group interests [96]. Rituals might be one way to reduce within-group conflict and facilitate cooperation with social coalitions [97]. Finally, rituals are useful to the groups who perform them because they function as mechanisms of social group cohesion and foster the longevity of social groups [50,51,98,99,130,131].

when primed with ostracism [16,45], suggesting that this behavior may be inherently driven by a motivation to affiliate with social groups through participation in cultural conventions [50–52].

Ritual is a psychologically prepared, species-typical behavior. The evolution of ritual builds upon selective social learning biases that may have become increasingly specialized for affiliative functions within social groups [50,51]. Even infants expect members of social groups to act similarly [53], and are more likely to imitate members of an ingroup than an outgroup [54]. Children as young as 4 years old display distinct preferences for members of their ingroup [55,56]. Preschool children are also acutely sensitive to relations among individuals [57] and particularly to whether two or more individuals act or make judgments in the same way [58]. Children not only conform to a group consensus [59] but they will also disguise their correct opinions to do so [43].

The role of ritual in cultural evolution raises compelling questions about the process by which the elements of rituals were aggregated and honed to address the adaptive problems of group living. We propose that the performance of rituals increases the early developing and empirically documented preference for ingroup members over outgroup members and that rituals increase social group coordination and cohesion. Rituals are consensual group behaviors that frequently involve group coordination and synchrony [50,51]. There are thus several frequently co-occurring features of rituals that we hypothesize make ritual an ideal candidate for increasing social group affiliation and cohesion (Box 1).

In recent work with children, a novel social group paradigm was used to examine the influence of a ritual versus a group activity control task on a measure of affiliation with ingroup versus outgroup members [51]. The data support the hypothesis that the experience of participating in a ritual increases ingroup affiliation to a greater degree than group activity alone. The results provide insight into the early developing preference for ingroup members and are consistent with the proposal that rituals facilitate ingroup cohesion. We propose that humans are psychologically prepared to engage in ritual as a means of ingroup affiliation.

Adjudicating between Learning Instrumental Skills and Social Conventions

Children use imitation and innovation to acquire both instrumental skills and the conventions of their social groups. We propose that children's flexible use of imitation (i.e., **flexible imitation**) is guided by interpreting behavior as an 'instrumental' versus a 'conventional' act. Children interpret a behavior as an instrumental act if the physical-causal basis of an action is potentially knowable, even if it is currently unknown (as would be the case for novice learners). By contrast, children interpret a behavior as a social act if it cannot be understood from the perspective of potentially knowable physical causality and instead is based on conventionality [14–17].

The key distinction between instrumental and conventional behavior does not hinge merely on causal transparency versus opacity but is based on the interpretation of causal opacity. The distinction often cannot be determined directly from the action alone but requires interpretation by the learner based on relevant social cues and contextual information. For instance, the act of lighting a candle could be interpreted instrumentally (e.g., to find a lost object in the dark) or conventionally (e.g., to commemorate an event or mourn a death). Where ambiguity in interpretation exists, learners may seek out cues to determine how to interpret the primary goal of the behavior. Much of human behavior is a blend of instrumental and conventional acts; in practice, the difference in interpretation of the goal of behavior is often a matter of degree rather than type [14]. Cooking is an example of behavior that frequently has both instrumental (e.g., food preparation) and conventional (e.g., worshiping a deity) goals.

The cognitive demands of instrumental and conventional learning differ in several key respects. Imitating instrumental behaviors allows for innovation and variability, whereas imitating conventional behaviors requires close attention to and reproduction of the way other group members perform the actions [14]. When imitating instrumental behavior, the focal point of imitation is the end goal. This need not implicate an emulation-based approach, as the precise sequence of actions demonstrated may still be copied but the aim is to bring about a tangible, functional outcome. By contrast, when imitating conventional behavior, the focal point of imitation is the process [60] and the way a behavior ought to be executed [61]. Conventional behavior tends to be associated with higher imitative fidelity than instrumental behavior [14–17].

How do children adjudicate between when a task is an instrumental behavior and when it is a conventional behavior? New research has demonstrated that children use social cues to adjudicate between whether a behavior has an instrumental or conventional goal, imitating with higher fidelity for conventional versus instrumental tasks [14–17]. Children attend to the language used to describe a task (i.e., specifying outcome or end goal versus specifying conventionality or process [14,15,17]). They also use the causal opacity of a behavior (i.e., whether or not a behavior has identical start and end states [14,16,52]) to infer the goal. Consensus and synchrony among multiple players [15,62] are also used as social cues to determine whether to interpret a behavior as an instrumental versus conventional act (Table 1).

The behavioral outcomes associated with interpreting a behavior instrumentally or conventionally are distinct. For example, children are better at detecting behavioral variation between multiple players engaging in conventional versus instrumental tasks [14]. They also transmit more of the conventional than instrumental behavior to others in a peer-teaching scenario, despite equivalent memory of the action sequence in a recall task [17]. Transmission chain studies with children (in which a child is taught a behavior and is then asked to teach the behavior to a subsequent series of children) provide insight into the relative contributions of children's

Table 1. Cues to Instrumental versus Conventional Interpretations of Behavior

Contextual Cue	Instrumental	Conventional
Verbal cues [14,15,17]	Outcome-oriented language (e.g., 'The goal is to reach this end state')	Convention-oriented language that emphasizes group norms and/or continuity of performance (e.g., 'Everyone always does it like this')
Causal opacity [14,16,52]	Distinct start and end states or performance of only relevant actions	Identical start and end states or performance of obviously irrelevant actions
Consensus [15,62]	Different behaviors across distinct players	Consistency in behavior across distinct players
Synchrony [15]	No synchrony	Synchrony in performance across players

Table 2. Distinct Behavioral Outcomes Associated with Instrumental and Conventional Interpretations of Behavior

Behavioral Outcome	Instrumental	Conventional
Imitative fidelity [14–17,52]	Lower	Higher
Innovation [14]	Higher	Lower
Difference detection [14]	Less accurate	More accurate
Peer transmission [17]	Lower fidelity	High fidelity
Functional fixedness [17]	Lower	Higher

memory versus task interpretation when imitating a behavior. Even if the first child in a transmission chain is trained by an adult experimenter through demonstrations and subsequent encouragement to reproduce a series of both causally relevant and causally irrelevant actions in a puzzle box task when teaching another child, children in subsequent positions in the chain eliminate the causally irrelevant actions in their demonstrations to subsequent children [63]. This finding is noteworthy in light of research suggesting that children are in fact very capable of transmitting conventional knowledge and work to reinforce norms in contexts where they deem high fidelity imitation as the appropriate means of engaging in a novel behavior [46], and will do so along peer–peer chains [64]. Indeed, there is some evidence that when children interpret the purpose of a task as conventional, they persist in transmitting both causally irrelevant actions [52,65] and inefficient methods for achieving instrumental outcomes [66].

Children also display higher levels of functional fixedness – the inability to override knowledge of an object's intended function in order to use it in novel ways [67] – when using objects previously used in a conventional task than in an instrumental task [17]. These data provide novel insight into the distinct behavioral outcomes associated with interpreting behavior as instrumental or conventional (Table 2). Developmental differences exist in sensitivity to instrumental versus conventional information in guiding imitative fidelity. One possibility is that behavioral differences between imitating instrumental and conventional behavior increase with age and experience. The increase in imitative flexibility may be based on developmental improvements in the ability to infer the goal of behavior [17]. These differences might be attributable to socialization and the timing of cultural inputs, for instance, via experience or training. Another possibility is that an understanding of conventionality develops early. Indeed, there is some evidence that variation in imitative fidelity is detectable even among 3 year olds [68,69]. In line with previous research on age differences in overimitation [27,70], new research has demonstrated that older children are more sensitive to cues to the difference between instrumental versus conventional behavior than younger children, a finding that may be due to increasing understanding of social conventionality with age.

Imitating others thus serves a powerful, adaptive function of facilitating skill acquisition and strengthening social bonds. However, imitation did not, in isolation, take us from being a cultural animal, like our closest living primate relatives [71,72], to a cumulatively cultural one [73]. Also necessary is a powerful inclination to seek novel approaches to old problems and to adapt established means to achieve new outcomes. Thus, to understand how the human mind has become uniquely adapted at creating cultural technologies, we must also consider our capacity for innovation.

The Evolution and Ontogeny of Innovation

Our capacity for tool use has contributed to our remarkable success as a species. Long thought to be a capacity unique to humans, comparative research in the past half century has demonstrated that other species use tools [74]. Nevertheless, the complexity of tool use in humans

remains unsurpassed by other species [75], as does our capacity to generate novel behavioral variation through innovation. Indeed, this capacity for innovation may be something that emerged relatively recently in our evolutionary past.

Beginning around 1.75 million years ago in East Africa our ancestors created the characteristic artifacts of the Acheulean industry: stone hand axes and cleavers [76]. The manufacture of these artifacts represents one of the most significant technological achievements of our evolutionary lineage. Most striking is the unparalleled homogeneity and temporal invariance of the Acheulean. The industry persists for over 1 million years before changes characteristic of Mousterian traditions become evident, suggestive of a social transmission process utilizing high fidelity imitation [28,77]. This million year epoch of relative technological stability stands in stark contrast to it taking less than a century for our more recent ancestors to move from the first manned, powered, heavier-than-air flight to a craft that transported men to the moon.

High fidelity imitation may be crucial to the transmission of skills and technologies refined over generations, but exact copying of others' tool use did not get us from Clément Ader's monoplane (which barely lifted off the ground) to Apollo 11. It was **'tool innovation'** – constructing new tools, or using old tools in new ways, to solve new problems – that proved crucial in making this happen. And it is here that we are faced with something of a paradox. We have argued that there is strong adaptive value to high fidelity replication of others' behaviors and actions. This is a solid foundation for the transmission of skills and technologies that have proven effective in past generations. It has also provided a means by which causally opaque but culturally meaningful behaviors can be maintained. Yet surprisingly, a number of other animals are more sophisticated tool innovators than young children. The tube and floating object tasks designed to assess tool innovation (detailed below) were originally developed to test New Caledonian crows [78] and great apes, respectively [79]. In both cases, the animals passed their respective tests. Tool innovation proclivities have also been reported in chimpanzees [80,81]. This is noteworthy, as there are very few social-cognitive tests that can be passed by members of these species but not by children around 3 years of age and older [82].

The development of innovation in early childhood has received increasing and much needed attention by developmental and evolutionary scientists in recent years, yet much remains unknown about the ontogeny of tool use innovation and the role it plays in supporting cultural evolution and transmission (Box 2). What, then, is the ontogeny of tool innovation?

Although young children's ability to learn how to use tools through observation is well demonstrated, current evidence suggests that directed or systematic tool innovation is challenging for young children. In new research investigating emerging tool innovation capacities [83], children were presented with a narrow vertical tube containing a bucket with a hooped handle [84]. The task was to get the bucket out of the tube in order to retrieve a sticker. By 4 years of age, when given a choice between a straight and hooked pipe cleaner, children will choose the hooked one above chance. When given a choice between a long piece of string, some small matchsticks, or a straight pipe cleaner, the 3 to 5 year olds rarely bent the pipe cleaner into a hook or made any other functional tool. Fewer than half of even the 7 year olds succeeded, with children not performing at high levels until age 9 or 10 years old. By contrast, children in all age groups succeeded at high rates if given the opportunity to imitate an adult's demonstration of what to do. In an analogous study, 4-year-old children were tested on a task where a toy was placed at the bottom of a narrow bottle and the available solution to retrieve it was to add water from a water bottle, causing the toy to float to the top [85]. This task does not require children to construct a new tool, but they do need to use an old tool (the water bottle) in a new way. The children were unable to do this, failing to recognize the solution on their own. They did, however, instantly copy an adult's demonstration of how to succeed.

Box 2. Cross-Cultural Research on Overimitation and Innovation

To better understand cultural continuity and variability in the ontogeny of cultural learning, developmental scientists must conduct research with young children across diverse cultural contexts [100]. To date, only a handful of studies have examined children's imitation in non-Western indigenous cultures [101,102]. There is growing evidence that many aspects of childrearing values and caregiver pedagogical style are culturally variable. For example, there are substantial differences between Western and non-Western indigenous populations in child socialization practices [103,104,132]. Western childrearing practices prioritize child-centered social interaction, encourage independence and autonomy, and segregate children from adult economic and social activity [105]. Western expectations for learning and interactional styles emphasize attention to verbal instruction through didactic pedagogy (i.e., explicit, child-directed formal instruction from adults). Non-Western, indigenous models of childrearing are based upon fostering collective and cooperative values. They are characterized by a strong emphasis on social conformity and an adult-focused social hierarchy. Children outside of Western settings rely more on observational learning and have less experience with didactic pedagogy [106]. Children in many non-Western educated, indigenous cultures use an 'open attentional stance' and routinely engage in third party or intent participation through keen observation of adult activity without being directly addressed or involved [107]. Exposure to Western education also affects caregiving. For example, Western-educated parents are more likely to engage in dyadic interaction and direct instruction with their children than parents without Western education [108].

Overimitation has been documented at comparable rates in young children living in large Western cities and remote indigenous communities in Southern Africa and Northern Australia [70,109]. By contrast, in a recent study 4- to 7-year-old children living in an Aka hunter-gatherer community of the Congo Basin rainforest in the southern Central African Republic were found not to overimitate [110]. There are many possible reasons for this failure, including lower rates, when compared with other populations tested to date, of contact with Western cultures and limited experience with causally opaque artifacts. There is insufficient empirical evidence to adjudicate among these explanations, highlighting further the need for and value of multisite cross-cultural data collection. There is also a dearth of cross-cultural research on the development of innovation. Only one published study has assessed children's tool innovation in a non-Western community [111]. This study also found low rates of innovation, but many more culturally diverse groups need to be tested before any claims about universality can be staked.

These studies suggest a lack of sophistication in tool innovation in young children and a reliance on being shown task solutions by adults [86]. One possibility is that innovation requires didactic pedagogy and scaffolding from others. Thus, the social context of innovation (i.e., presence of adults and peers) may be a crucial factor in how innovation develops in early childhood.

Yet there are multiple reasons why children should be able to innovate tools much earlier than has been established. In addition to their precocious capacity for imitation, from their second year in life children demonstrate the ability to manipulate and successfully use a variety of tools, and to accurately infer their intended use, design, and basis for categorization. They have an emerging ability to take what is known and extend it to novel situations, the type of inductive reasoning necessary for tool innovation [87]. Younger children may be less functionally fixed than older children [67]. These abilities combined should provide a sufficient cognitive platform for the emergence of tool innovation around the third year. Yet they seem not to be.

One possibility is that innovation increases in systematicity over the course of ontogeny, moving from less systematic 'blind' innovation to more systematic 'directed' innovation. Research on the development of causal reasoning has demonstrated that young children are more exploratory and generate more variation in their behavior than older children [88]. Young children are also capable of generative hypothesis testing through largely unsystematic trial-and-error learning [37]. Thus, the 'blind' innovation that young children engage in may provide the knowledge and experience needed to engage in directed innovation. New research is needed to further examine young children's limited tool innovation proclivities, identify with greater precision their functionality in solving different adaptive problems, and shed new light on this core feature of human cultural learning.

Concluding Remarks and Future Directions

We propose that the unique demands of acquiring instrumental skills and cultural conventions provide insight into when children imitate, when they innovate, and to what degree. Whereas learning an instrumental skill allows for variability and innovation in methods of execution, learning

cultural conventions requires close conformity to the way other group members perform the actions through high fidelity imitation.

The first signs of an overimitation approach to the transmission of technological skills were seen in the construction of Acheulean bifacial hand axes by our *Homo erectus* ancestors who lived in relatively small bands [28,77]. Critically, signs of ritual-like behavior were fleeting in *H. erectus* [89]. This highlights how population size is likely to be a key element in the evolution of cumulative culture (Box 3). As population sizes increase, as they did from the middle Pleistocene, so too does the complexity and total number of tools used in a community [90]. The need to learn how to use increasing numbers of tools thus selected for a cognitive system already adapted to acquire new skills through high fidelity imitation. Also commensurate with increasing population size are new challenges, including issues related to cooperation, allocation of resources, and social living [50]. The need to distinguish devoted ingroup members from imposters, interlopers, and free riders becomes increasingly important, as does the need to gain social acceptance and avoid ostracism. This places adaptive pressure on children to quickly acquire the rituals and cultural practices of their community. To the extent that our knowledge of the Middle Pleistocene provides a window on the evolution of our social learning proclivities, it may be speculated that a drive towards high fidelity imitation came from a need to acquire functional, skill-based abilities that were then exapted for affiliation with social groups. Research with young children is now required to put this speculation to test. The pressure to master functional and cultural behaviors has been profound and may help explain why the tendency for young children to overimitate is strong and the capacity for directed innovation is not. We propose that young children likely begin with blind innovation and become increasingly systematic in their use of directed innovation with age and experience. Children flexibly deploy different exploratory strategies, engaging in a broader or narrower exploratory search depending on the learning context and goals [88]. The social context of early directed innovation is also crucial, as young children typically require pedagogy and scaffolding from caregivers and peers to successfully engage in directed innovation.

Box 3. Grandmothers and Population Dynamics

Cumulative culture is the result of many individuals making qualitative and quantitative improvements to available technologies while serving as models for the next generation [90]. This process functions more effectively as population size grows, which expands the pool of available experts, increasing learners' access to skill variations, thereby allowing greater opportunity to evaluate relative success and popularity [112,113]. Increasing population size also protects against loss – the more members of a community possessing mastery of a skill the less likely it is for that skill to be lost in the face of a catastrophic event [114]. Similarly, the success of any innovation is reliant on its uptake. In small populations, cultural variants can be lost if inventors are not copied [115].

Evolutionary trends towards increasing brain size and bipedalism has led human children to be born at an earlier stage of brain development than other primate species [116]. Further, breastfeeding is usually discontinued around 36 months of age in preindustrial societies [117], resulting in a much shorter infancy period than our primate relatives. Humans thus have an extended juvenile period characterized by dependence on parents and older members of the social group for nourishment [117–120]. Increasing population size by reducing interbirth interval thus relies on mothers having reliable sources of help to take care of their children [121]. The most reliable source is likely to be their mothers. Whereas other ape females become frail in their thirties and usually die during the cycling years, human females past the childbearing years make up substantial fractions of the population [122]. Critically, it has been shown that grandmothers help their offspring leave more descendants than mothers whose own mothers are no longer around [123–126]. Grandparents also serve as a repository of cultural information, providing an additional source from which to learn and seek counsel [4,127]. Menopause may have evolved because the benefits of care provision outweigh costs of further direct reproduction.

A cognitive system favoring high fidelity imitation while affording innovation will work best when there are multiple models to copy and multiple individuals to support change (whether by allowing new ideas to spread widely or ensuring retention of skills when others experiment with novel ways). We propose that cumulative cultural transmission has been facilitated by sufficiently large population sizes, potentially facilitated in our recent evolutionary past [128], by the appearance of a postmenopausal life stage.

At an age when children can learn elaborate action sequences by watching others execute them, they fail to recognize that simply bending a pipe cleaner into a hook will provide them access to a desirable object. But perhaps this is precisely how cumulative culture works. The majority continue to act as those before us have acted, while an imaginative and potentially status-seeking few pursue new ways of doing things. But because there is stability when innovations fail, costs are not likely to be catastrophic. And because the majority perpetuates the norm, nonutilitarian cultural practices that provide ingroup binding are maintained without corruption. Future research is needed to examine variation in imitation and innovation by conducting research in cultural contexts that represent key aspects of the diversity of human childrearing practices (Box 2). Research of this type will inform our understanding of what drives imitation and what stimulates innovation and ultimately provide insight into how best to foster ingroup harmony while ensuring the capacity to confront new problems (see Outstanding Questions).

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Outstanding Questions

To what extent do imitation and innovation vary by culture?

How do diverse childrearing practices and cultural variation in child socialization impact the ontogeny of imitation and innovation?

How limited are young children's tool innovation proclivities?

What is the function of tool innovation in solving different adaptive problems?

To what extent does participating in ritual increase ingroup affiliation in childhood?

How does the use of imitation and innovation vary as a function of different lifespan adaptive problems individuals face?

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