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A joint future for cultural evolution and developmental psychology

Magnus Enquist[a,b,*], Stefano Ghirlanda[c,a,1], Anandi Hattiangadi[d,a], Johan Lind[e,a], Gustaf Gredebäck[f]

[a] Center for Cultural Evolution, Stockholm University, Stockholm, Sweden
[b] Department of Zoology, Stockholm University, Stockholm, Sweden
[c] San Diego, CA, USA
[d] Department of Philosophy, Stockholm University, Stockholm, Sweden
[e] Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden
[f] Department of Psychology, Uppsala University, Uppsala, Sweden

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A B S T R A C T

Developmental psychology and cultural evolution are concerned with the same research questions but rarely interact. Collaboration between these fields could lead to substantial progress. Developmental psychology and related fields such as educational science and linguistics explore how behavior and cognition develop through combinations of social and individual experiences and efforts. Human developmental processes display remarkable plasticity, allowing children to master complex tasks, many which are of recent origin and not part of our biological history, such as mental arithmetic or pottery. It is this potency of human developmental mechanisms that allow humans to have culture on a grand scale. Biological evolution would only establish such plasticity if the combinatorial problems associated with flexibility could be solved, biological goals be reasonably safeguarded, and cultural transmission faithful. We suggest that cultural information can guide development in similar way as genes, provided that cultural evolution can establish productive transmission/teaching trajectories that allow for incremental acquisition of complex tasks. We construct a principle model of development that fulfills the needs of both subjects that we refer to as Incremental Functional Development. This process is driven by an error-correcting mechanism that attempts to fulfill combinations of cultural and inborn goals, using cultural information about structure. It supports the acquisition of complex skills. Over generations, it maintains function rather than structure, and this may solve outstanding issues about cultural transmission. The presence of cultural goals gives the mechanisms an open architecture that become an engine for cultural evolution.

Introduction

Understanding the lifelong development of human mental, social and practical skills, is central to cognitive science (Carey, 2009; Spelke, 2022). Here we argue that the individual development of such skills is inextricably connected with their biological and cultural

* Corresponding author at: Center for Cultural Evolution, Stockholm University, Stockholm, Sweden.
E-mail address: magnus.enquist@su.se (M. Enquist).
[1] Work performed in part while Stefano Ghirlanda was at Brooklyn College, NY, USA.

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evolution, and we call for increased collaboration between the fields of developmental psychology and cultural evolution. Consider, for example, mental arithmetic—the ability to mentally perform calculations such as 11 x 57. This skill is neither inborn nor hardwired: it has emerged through cultural evolution over many generations, and can only be learned in adequate social environments that support long and incremental development of numerical skills (Daucourt, Napoli, Quinn, Wood, & Hart, 2021; Enquist, Ghirlanda, & Lind, 2023). Arithmetic is just one example of a diversity of complex skills that is acquired in childhood.

Developmental psychology and related fields, such as educational science and developmental linguistics, seek to understand how the child develops and acquires skills of many kinds, including complex ones. It is important to acknowledge that there are many different forms of developmental psychology and a wide spread of theoretical perspectives that come together under this umbrella term. When referring to developmental psychology, we focus on perspectives that see development as a learning process that is grounded in the environment around the child and the individual experiences that impact this development; this includes both a dynamic systems approach (Thelen, 1992) as well as embodied (Gredebäck & Falck-Ytter, 2015; Lakoff & Núñez, 2000), cultural (Bronfenbrenner & Evans, 2000; Bard et al., 2021), and pedagogical (Vygotsky & Cole, 1978) approaches to developmental psychology. Evolutionary considerations, both biological and cultural, should be fundamental to developmental psychology because developmental mechanisms in humans, whether inborn or cultural, have evolved to support efficient cultural learning and to maintain functionality. The importance of culture is recognized in both empirical studies (Barrett et al., 2016; Heyes, Bang, Shea, Frith, & Fleming, 2020; Daucourt et al., 2021; Astor et al., 2020) and theoretical work (Bronfenbrenner & Evans, 2000; Haun, Rapold, Call, Janzen, & Levinson, 2006; Vélez-Agosto, Soto-Crespo, Vizcarrondo-Oppenheimer, Vega-Molina, & García Coll, 2017; Kline, Shamsudheen, & Broesch, 2018; Keller, 2018), but explicit evolutionary thinking is rare in mainstream developmental psychology. That is, the field has rarely considered how developmental mechanisms must be designed to support cultural evolution, and how such mechanisms are involved in causing cultural change, including the cultural evolution of parental behaviour.

Mechanisms of individual development are fundamental to cultural evolution because they describe how culturally evolved abilities are acquired. However, references to developmental psychology are uncommon (but see Tomasello, 2016; Heyes, 2018; Legare & Nielsen, 2015) in cultural evolutionary research, despite its potential to solve long-standing problems. One example of such a problem concerns the understanding and modeling of cultural transmission. What is puzzling is that such transmission appears to be more error-prone than expected (Acerbi & Mesoudi, 2015; Heyes & Pearce, 2015; Charbonneau & Bourrat, 2021), yet at the same time, we know that a large amount of cultural information is faithfully transmitted between generations, facilitating the transfer of many complex skills such as crafts, reading, writing, arithmetic, systems of social norms and language. An understanding of the mechanisms of individual development and learning are necessary to shed light on this problem.

A joint research program, combining developmental psychology and cultural evolution, could explore how interactions between individuals, such as children and adults, are shaped by cultural evolution to facilitate cognitive development and give rise to novel practical, social, and mental skills. At the same time exploring how biological goals, such as survival and reproduction, remain central to individual cognition and behavior. This interplay between development and culture is also crucial for understanding the human evolutionary transition: a transition in which culture becomes a dominant route of information transmission in humans alongside genetic information. The importance of developmental psychology to understanding human evolution is further evidenced by the exceptional length of human childhood as a major factor in human evolution (Kaplan & Robson, 2002; Gopnik, 2020; Enquist et al., 2023). For simplicity, we use the term "skill" with a broad meaning, encompassing everything that contributes to performance. In addition to motor skills, this includes knowledge, perceptual abilities, and any other relevant trait.

Where do human skills come from?

The core question in development is how children acquire skills, both practical and cognitive, that they do not possess at birth. Behind this question lies a fundamental conflict between the costs and benefits of flexibility. More flexible developmental mechanisms can acquire a wider range of skills, but this leads to increased learning costs because of the larger number of possibilities that need to be evaluated, as we discuss below (Enquist et al., 2023). Even a rather moderate increase in flexibility can lead to an explosion of possibilities (see example below), making it in practice impossible for an individual to acquire even moderately complex skills without guidance.

One possible solution to such combinatorial problems is substantial genetic guidance of developmental processes. Scholars from many fields have also proposed that human skills rest on a number of hardwired mental capacities, from language to social cognition to general intelligence (see e.g. Chomsky, 1957; Gardner, 1983; Tooby & Cosmides, 1992; Pinker, 2003; Sperber & Hirschfeld, 2004). This idea pervades, sometimes implicitly, much of the literature on human behavior and cognition (cognitive psychology: Kurzban & Aktipis (2007); Stahl & Feigenson (2019); Obersteiner, Dresler, Bieck, & Moeller (2019); Meltzoff et al. (2016), social psychology: Hamlin (2013), economics: Brocas & Carrillo (2008), neuroscience: Kriegeskorte & Douglas (2018), moral philosophy: Haidt (2012, 2013, 2015), linguistics: Nowak, Komarova, & Niyogi (2001); Bolhuis, Tattersall, Chomsky, & Berwick (2014), and archaeology: Klein (2008)). Even in the field of cultural evolution, where the independence of culture from genes is often asserted, scholars have posited hardwired cognitive mechanisms evolved to process social information, such as conforming to the majority or to the behavior of prestigious individuals (Boyd & Richerson, 1985; Mesoudi, 2011; Creanza, Kolodny, & Feldman, 2017).

Nativist explanations, however, are hard to reconcile with the recent origin of many mental skills, and to the time and effort necessary to develop them (Enquist et al., 2023). Consider again mental arithmetic. Unambiguous evidence for this skill dates back at most 5,000 years (Chrisomalis, 2010). For most of this time, few people knew this skill (some merchants, philosophers, administrators, and so on). Even in the last hundred years, many individuals have learned mental arithmetic without a single genetic ancestor with this skill. Similarly, skills such as making pottery, playing chess, composing operas, understanding chemistry, driving a car, and programming computers have arisen between a few millennia and a few decades ago. These skills are too recent to have a direct genetic basis, which is at odds with nativist views.

One reason so many researchers have argued that human abilities are primarily hardwired is that the alternatives they considered appeared even more problematic, because many mental skills are so complex that it is implausible that individuals could invent them from scratch during development (Tooby & Cosmides, 1992; Gopnik, 2003). This is an important insight, but it applies only to individuals learning on their own.

What about learning from a cultural environment? Evolutionary psychology has traditionally discounted that culture can significantly affect cognition because this would require cognition to be flexible rather than hardwired, which would incur steep learning costs (Tooby & Cosmides, 1992; Enquist et al., 2023). This argument has been historically influential as it correctly identifies the fundamental cost of flexibility. We can illustrate the argument with some simple math, starting with an example from language learning. Assume that a young individual can, potentially, learn n different grammatical rules to form the plural of nouns. Without any guidance, the individual would have to try rules at random, and discover by trial and error which rule is correct in the local language. On average, this would require trying out $n/2$ rules. Clearly, the argument goes, being flexible (large n) is costly. An individual with hardwired knowledge to search only among fewer rules would be able to learn more quickly. Skills that are made of a sequence of mental or behavioral steps are even harder to learn, because the number of sequences of length l that can be formed with n elements is n^l, thus increasing exponentially with sequence length. For example, if phone numbers had a single digit, one would need only an average of $10/2 = 5$ attempts to guess a phone number by dialing at random. However, with 10-digit numbers, it takes $10^{10}/2 = 500$ million attempts. Likewise, individuals who attempt to learn long sequences of behaviors are faced with an overwhelming number of possibilities to explore.

The learning costs of mental flexibility lend face value to the hypothesis that mental architectures are mostly hardwired. In general, genetic evolution has coped with the difficulties of trial-and-error learning by establishing detailed genetic guidance of behavior, such as a limited repertoire of actions and genetic predispositions to choose actions that are likely to be useful (Enquist et al., 2023). Genetic predispositions also guide learning, such as favoring certain associations over others (Shettleworth, 2009). However, genetic guidance limits flexibility and it is hard to reconcile with the human capacity to learn a diversity of mental and behavioral skills, and thus with cultural evolution on any significant scale.

Some scholars have argued that genetic guidance of human behavior comes in the form of the goals for which we strive, such as prestige, wealth, and reproduction (Boyd & Richerson, 1985; Henrich & Gil-White, 2001). However, human flexibility includes the flexibility to form a variety of goals that did not exist in our prehistory. These include goals that are unrelated to biological reproduction (bird watching, chess playing, orchid cultivation, golf, etc.) or that decrease it, as in lifestyle choices such as chastity and long-term investments in education (Kolk, Cownden, & Enquist, 2014). That individuals can invent these complex goals on their own is also implausible.

The alternative to genetic guidance and self-taught exploration, as a foundation for learning and decision-making, is cultural guidance. That is, culture can serve as a reservoir of useful mental and behavioral skills such that the young individual does not rely solely on trial-and-error learning. This can dramatically alleviate combinatorial problems in a way similar to genetic guidance, and enable even more efficient learning. For example, there are countless possible ways to string and tie shoes, but children can quickly learn efficient ones by demonstration and instruction. A key point for our arguments is that cultural guidance enables substantial mental flexibility without incurring unmanageable learning costs. The fact that we can learn to tie our own shoes by leveraging others' expertise means that we do not need a genetic program for tying shoes and that we can learn different ways for different kinds of shoes and different needs. The argument applies to cognitive skills as well. For example, it may be possible to learn a language with limited genetic support, provided the necessary information is communicated efficiently by the cultural environment (Lyons, 1968; Kirby, Cornish, & Smith, 2008).

In summary, it is not clear that a system of inborn modules that evolved in human prehistory can explain the diversity of uniquely human skills (e.g., Pietraszewski & Wertz, 2022). The argument put forward by evolutionary psychology against the importance of culture and cultural evolution ignores that cultural information exists in parents and other individuals around the child. If this information can be transmitted to the next generation, we argue, cultural evolution can avoid the costs of mental flexibility and take place on a grand scale.

The hypothesis that uniquely human skills derive from cultural evolution is supported by the observation that these skills typically do not emerge without social learning, often in combination with teaching (Mermelshtine, 2017; Enquist et al., 2023). If culture were unimportant, human skills would appear reliably without any social input.

Crucial to our arguments, the hypothesis that uniquely human skills are learned from cultural information has logical implications for developmental mechanisms. The first implication is that developmental mechanisms must be powerful and generic enough to acquire a wide range of skills that are not part of our evolutionary history and account for transmission fidelity, and also to generate new culture. We argue that understanding how children acquire skills must consider sequences of learning experiences rather than just single learning events. The reason is that complex skills require incremental learning through a series of intermediate steps, which is typically affected by a combination of social and individual learning.

A second logical implication is that development mechanisms must fulfill biological needs, even when the input they receive is largely cultural. Otherwise, it would be difficult to explain why genetic evolution favored a transition from genetically guided to highly flexible developmental mechanisms that rely on cultural information. This implies that at least some of the goals individuals strive for should continue to promote survival and reproduction.

A third implication is that parents and other suppliers of cultural information must organize learning in steps that can be successfully mastered by the child (Vygotsky & Cole, 1978; Tomasello, 2016; Mermelshtine, 2017). Without such adjustment to a child's current capacity, it would be at a loss when acquiring complex skills. For instance, learning to count and do basic arithmetic is broken down into such steps as learning number words and their sequence, mapping them to sets of objects, and working initially with very small numbers. These activities are crucial for successful skill acquisition, and they must be arranged by parents or other teachers because the child cannot comprehend their ultimate goal. The power of incremental learning guided by parents will be discussed further below, including how it can drastically reduce learning costs for complex skills and circumvent poverty-of the-stimulus difficulties. Cultural evolution is also likely to affect the teaching behaviors themselves, including general ways of interacting with children and task-specific elements. This appears necessary, especially for skills that are not part of our evolutionary history.

The need for strong parental support is a further compelling argument against the view that uniquely human skills are mostly inborn. In fact, if the genes could program the parental behaviors necessary to teach skills to children (which include knowledge of the skills themselves), why not program the skills themselves directly in children?

Incremental functional development

In this section we sketch a developmental machinery that fulfills the requirements discussed in the previous section, and that could serve as a starting point for joint research efforts between cultural evolution research and developmental psychology. We call this conceptual model *Incremental Functional Development* (IFD). The machinery has two fundamental parts, one that develops goals and one that tries to acquire skills that fulfill these goals (Fig. 1). The primary role of goals is to evaluate the results of actions and to learn from these evaluations. In older children and adults, goals can also be used in planning and goal seeking, while in infants and young children, they mainly reinforce behavior. Goals are actively set and continuously updated by the child based on cultural and inborn information as well as its own experiences. The model can accommodate any degree of inborn control from none to complete, and specific applications have to make assumptions about this based on empirical and/or theoretical insights. Throughout this paper, inborn and inborn information refers to both direct and indirect genetic guidance of development. With indirect, we mean that the previous direct actions of genes have formed the individual, so genetic information continues to influence/guide further development. Skills are developed based on cultural information, and own experiences. The extent to which they fulfill current goals is constantly monitored, and improvements are retained (Miller, Galanter, & Pribram, 1960).

A developmental machinery with these properties fulfills the requirements listed in the previous section. First, it can support faithful transmission of complex skills without relying solely on genetic guidance. It does this because it considers both the structure of skills (what actions are involved and how they are combined) and their function (what goals they serve for the individual) (Bornstein, 1995; Tomasello, 2016). Paying attention to the structure of skills decreases learning costs as it allows individuals to imitate what others do or demonstrate. Paying attention to goals keeps skill learning on track by making it possible to detect and correct mistakes. In fact, a developmental machinery that focuses only on the structure of observed skills would keep accumulating mistakes due to necessarily imperfect imitation. Without goals, functional skills can neither be acquired by individuals nor maintained across generations. Focusing solely on the structure of skills would also prevent adaptation to new circumstances, for example, when an action

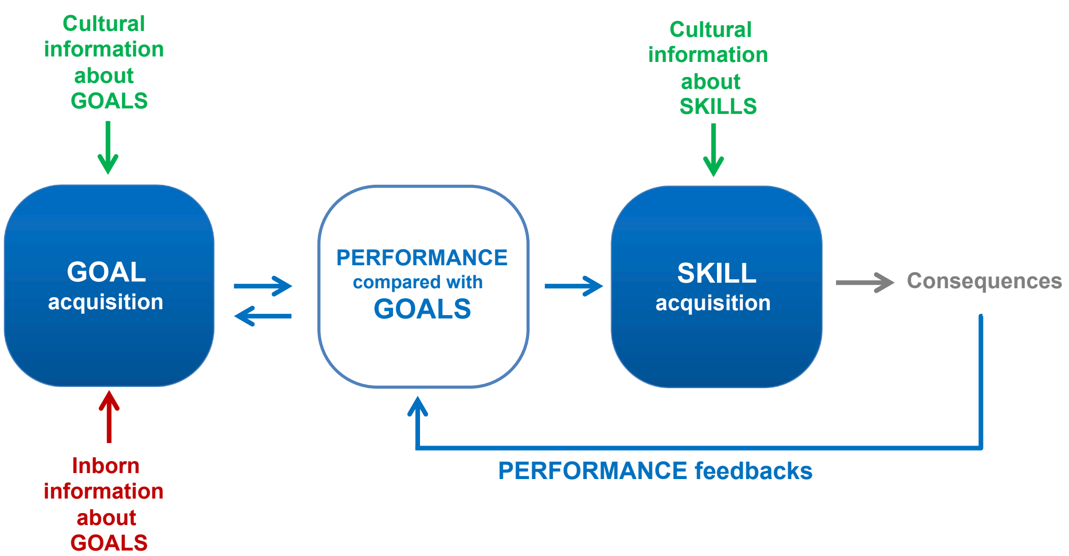

Fig. 1. Incremental Functional Development. The outcome/output (the gray arrow) can be a mental process (private unless communicated) as well as a practical skill or combination of these two. The performance feedback (the error signal) could be internal and/or external and even be feedback from other individuals' judgments. The orange and green arrows refer to observational learning. The arrow from the comparison box to the goal learning box indicates that the goal can be refined as performance improves. Note that the model describes the control of information and not mechanism details, and both skill and goal learning may innovate.

becomes unproductive because of an environmental change. Skill improvement would also be stalled, as without goals there would be no reason to prefer more efficient skills. A developmental machinery that instead focuses on function would be able to discriminate between correct and incorrect actions. However, a focus on goals is not sufficient to manage the learning costs of flexibility. As seen with the example of mental arithmetic, it is unlikely that individuals could, on their own, arrange a sequence of intermediate goals appropriate to support the acquisition of complex skills.

A simple way to fulfill the design in Fig. 1 is to add a filter that rejects unproductive actions to a mechanism that just copies or imitates structure. That such a mechanism that combines structure and function can preserve function from one generation to the next is illustrated in panel A of Fig. 2. Note that function is preserved even when the transmission fidelity is low. In contrast, have mechanism of based on either structure or function difficulties with this, even when the transmission fidelity is high Panel B illustrates what happen when one starts out with a non-competent parental population. Structural imitation cannot learn anything in this situation while the others slowly learn by trial and error. Panel C and D show how a combination of function and structure can support cultural evolution by accumulating learning over generations (see below). Note that this model demonstrates logical consequences common to cultural transmission processes in general. The purpose is not to explore any specific hypothesis about developmental machinery.

The IFD model establish goals by combining inborn and cultural information. This is important for understanding why biological evolution favored a transition from genetic guidance to cultural guidance in our prehistory. We will return to this later in the paper. This ability to negotiate among several individual goals also includes mixtures of cultural goals, some specific to a particular skill but a range of more general cultural goals expressing moral values, norms, and various other preferences. Very early in childhood, inborn

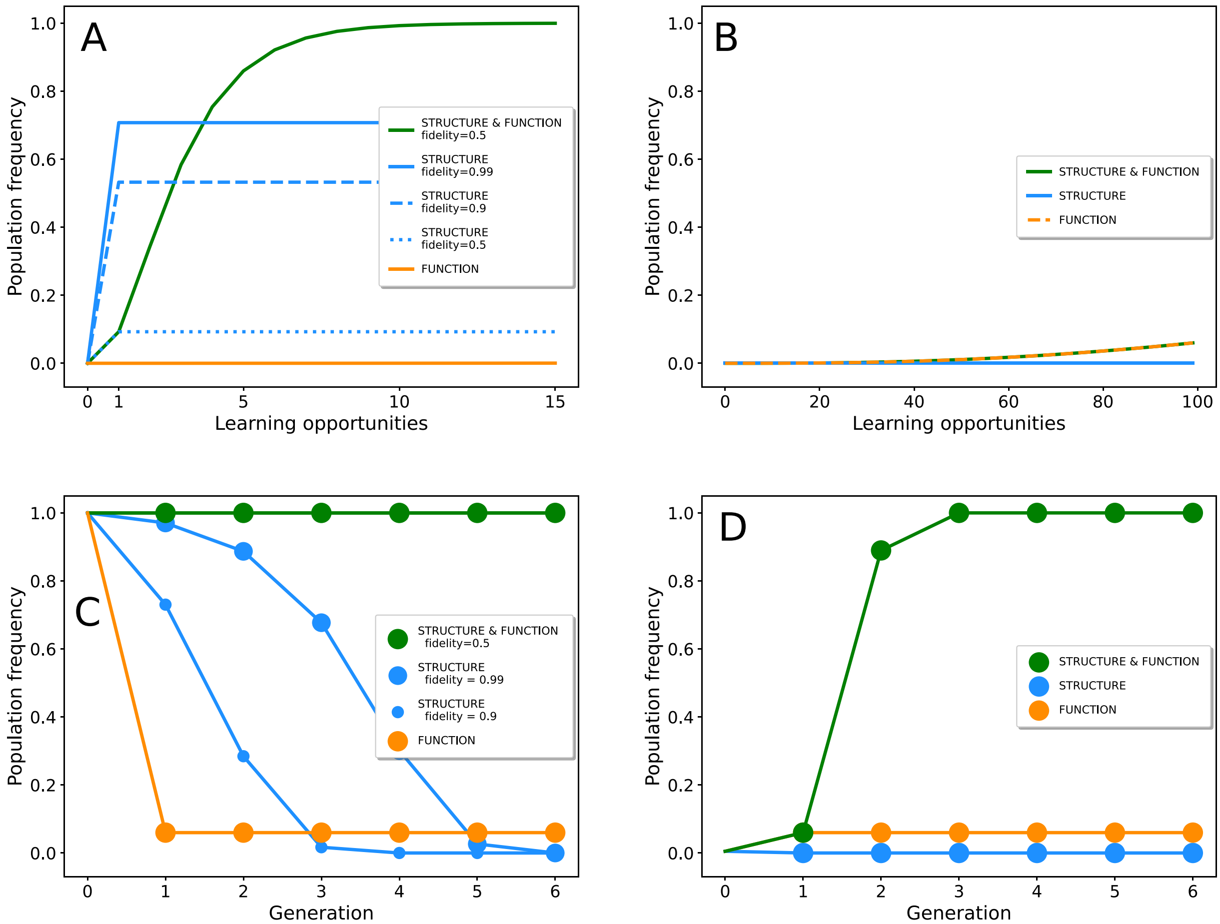

Fig. 2. The power of combining structure and function. Consider the task of combining three different actions into a productive skill, each having its own subgoal, to reach an ultimate goal, assuming that only a few actions are productive out of many possible ones. Three mechanisms are compared, one using cultural information about structure (Blue), one based on function or goals only (Orange), and one that combines structure and function (Green). Panels A and B illustrate individual development and show the frequency of individuals with productive triplets as a function of the number of learning opportunities during development. In panel A, the productive actions are widespread in the parental population (90%), and in B very rare (0.5%). Panels C and D show evolution over a number of generations, with the same starting point as in A and B, respectively. Unless otherwise stated the copying fidelity is 0.5, and the proportion of available action that is productive is 0.5%. The number of learning opportunities is 100 in panel C and D. See the Appendix for the equations used to produce the figure.

information about goals are likely to dominate. For instance, learning to crawl (Adolph et al., 2012) might be driven by experiencing changed or novel stimulation as rewarding.

The IFD model automatically promotes incremental learning, offering an efficient way of acquiring complex cultural traits. Complex goals can be broken down into intermediate steps, and the initial goals can be simple or approximate (Csibra, 2008). For example, a drawing teacher might start by asking pupils to outline simple shapes, and then teach about shading, color, perspective, and so on. There is often a long prefunctional phase before the child is capable of fulfilling the ultimate goal. This machinery for incremental learning sets few limitations to what an individual can learn, and thus on cultural evolution as long as goals and the structure of skills can coevolve flexibly, and there is enough time available. A complete IFD model should also be able to remodel already acquired behavior and mental skills in response to more refined goals (Siegler, 1998; Clark, 2016; Stahl & Feigenson, 2019).

Once a goal is established, IFD can use any combination of social learning, individual learning, and training to acquire a skill. One common problem with the social learning of skills is that they may be difficult to imitate. For example, whereas the goal of winning a game of chess or soccer is easily learned socially, the skills necessary for doing so require extensive individual practice in addition to social skill information. IFD overcomes this problem by integrating individual and social learning.

A goal-directed approach puts emphasis on the child as being responsible for its own development, which can be thought of as the child's main occupation (Baldwin & Moses, 1996; Kline, 2015; Gauvain, 2019; Tamis-LeMonda & Masek, 2023). This has several manifestations that promote efficient development and cultural transmission. First, substantial parts of development processes can be based on individual learning, trying to fulfill goals. This way learning is not just limited to social interactions, as parents and other senders are not always available. Second, the child can actively control the content of social interactions, for instance, by seeking out specific information or rewarding certain parental activities (Blakey et al., 2021). This opens up for variability in developmental trajectories between children, as well as across families and cultures.

Two examples from developmental psychology can perhaps be used to illustrate these points. One complex set of behaviors that children learn early in life, without dependence on social reinforcers, is the ability to locomote, crawl, and later walk. This development can take many different paths, for individual children. Some children crawl, while others roll or use other means to transport themselves before walking onset (Adolph et al., 2012). The goal of walking is not necessarily available to the child at the time of development, instead, local goals, such as a better view of the world achieved by standing up create incentives to continue development. This is not to say that parents and culture cannot impact this development, in fact, the onset of independent sitting and walking varies substantially across cultures, depending on parental practices and cultural affordances (Karasik, Adolph, Tamis-LeMonda, & Bornstein, 2010). Another example comes from the social domain and the many ways in which children and adults can establish joint attention (a precursor of language and social development, Mundy, 2018). In Western contexts parent–child interactions are often governed by face-to-face interactions and eye contact, gaze following (Del Bianco, Falck-Ytter, Thorup, & Gredebäck, 2019), but children also have the flexible ability to follow adult's hands (Deak, Krasno, Triesch, Lewis, & Sepeta, 2014) and anticipate the goal of their actions (Gredebäck & Falck-Ytter, 2015). In other cultural contexts and for other species joint attention is expressed differently, by proximity or touch. In humans, at least, this does not appear to be guided by genetic programs, instead flexibly emerging in a cultural context that the child is raised in (Bard et al., 2021). The ability to set local goals and assess if actions are accurately geared towards these goals are captured by the notion of internal models, feedback loops that assess the distance between assumed and the actually achieved outputs (Miall, 2003; Bardbäck, Lindskog, Juvrud, Green, & Marciszko, 2018) that provide guidance through errors created by the child, in their behavior or through their assumptions about the world. These errors, and the surprise reaction that emerges from the miss-match, have been demonstrated to be linked with development across both social and non-social dimensions (Stahl & Feigenson, 2015; Juvrud et al., 2019; Marciszko et al., 2020).

IFD borrows several ideas that have been discussed and considered within developmental psychology and related fields. Dynamic systems theory emphasizes local processes and variability as a driver in development (Thelen, 1992; Richter, Lins, & Schöner, 2017) whereas social first/ like-me accounts of early interactions emphasize motivation to interact with others (Meltzoff, 2007; Astor et al., 2020). IFD also shares ideas with recent attempts to expand on both cognitive, and situated and embodied accounts for development, highlighting the importance of sequentially and goal seeking (Fantasia & Delafield-Butt, 2023). From a historical point of view early theories of child development also emphasize diversity and cultural adaptation (Bronfenbrenner & Evans, 2000), Vygotsky and also Bruner specify the unique relationship between the child and the more knowledgeable adult, and Piaget targeting exploration and sequential building of knowledge based on experience. A modern, all-inclusive theory that nicely describes the interaction between all of these domains/theoretical pieces is the neuro-constructivist approach that emphasizes a multi-leveled developmental process that involves genetics, experiences, and culture as a system where development emerge, often with variability in the pathways of development (Westermann et al., 2007; Newcombe, 2011; Karmiloff-Smith, 2015).

Mechanisms for social transmission have also been central to cultural evolution research (Boyd & Richerson, 1985; Tomasello, Kruger, & Ratner, 1993; Sperber, 1996; Acerbi & Mesoudi, 2015). However, the aim is typically to understand how these mechanisms promote and shape cultural evolution, rather than to understand development (Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Mesoudi, 2011; Creanza et al., 2017). Two issues have received the most attention. The first one is how cultural transmission can be sufficiently faithful to maintain cultural adaptations (Sperber, 1996; Tomasello, 1999; Lewis & Laland, 2012; Acerbi & Mesoudi, 2015; Charbonneau & Bourrat, 2021). The focus has mainly been on copying or imitation of structure while less attention has been given to cultural goals and function (but see (Whiten & Ham, 1992; Call, Carpenter, & Tomasello, 2005; Caldwell & Millen, 2009; Galef, 2013; March, Dames, Caldwell, Doherty, & Rafetseder, 2020; Blakey, Atkinson, Rafetseder, Renner, & Caldwell, 2022) and error-correcting mechanisms (but see e.g. Boyd & Richerson, 1985; Enquist & Ghirlanda, 2007; Enquist, Eriksson, & Ghirlanda, 2007). How to account for cultural innovations when transmission is faithful has also been analysed (Caldwell, Cornish, & Kandler, 2016; Jagiello, Heyes, & Whitehouse, 2022). The other main issue is understanding what factors determine the outcome of cultural evolution. Here, most focus has been on inborn biases or social learning strategies (Boyd & Richerson, 1985; Rendell et al., 2010; Mesoudi, 2011; Henrich, 2016; Creanza et al., 2017).

Recent work has suggested a wider scope for cultural evolution as some authors in this field have considered development more in detail and argued that cognitive skills are significantly shaped by culture (Tomasello, 1999; Heyes, 2018; Wertz & Moya, 2019; Enquist et al., 2023). For example, Heyes musters empirical evidence to show that the celebrated human capacity for imitation requires extensive learning, rather than being inborn as often assumed. The open architecture of IFD could serve as a general model of cultural transmission, combining error-correcting processes with goals (biases) determined by a combination of inborn and cultural information (see below) into a more general framework for cultural evolution.

Cultural parents can replace genes

If a skill is too complex for individual learning, and if its development is not guided genetically, then it must rely on information from "cultural parents", here any individual capable of influencing the learner, including parents, teachers, peers (Lew-Levy et al., 2023), and even younger individuals (Gauvain, 2019). When properly structured, interactions with cultural parents can foster the development of complex skills and bypass combinatorial dilemmas, using such strategies as breaking down long sequences into shorter ones, providing feedback, and enabling children to practice and progress partly on their own.

In these activities, cultural parents set appropriate goals and communicate them to the child (Rogoff, 1990; Rogoff, 2003; Sterelny, 2012; Tomasello, 2016; Tamis-LeMonda & Masek, 2023). For example, when learning to add, one goal may be to learn the sums of single-digit numbers, in order to later use them to add larger numbers. By the time they are taught addition, children are generally capable of internalizing goals provided by cultural parents and practicing partly on their own. However, children would not be able to devise these intermediate steps on their own (Vygotsky & Cole, 1978; Lakoff & Núñez, 2000).

Crucially, cultural parents can introduce only mental and behavioral elements that are relevant to the skill at hand, as well as learnable by children. For example, when learning addition, children are given functional information such as $2 + 2 = 4$. They do not have to rule out non-functional statements such as $2 + 2 = 0$, $2 + 2 = 7$, and so on. They would not be able to do that because they do not know how addition is supposed to work. Indeed, the goal of learning addition makes sense to children only because it is presented as worthwhile by cultural parents. Furthermore, addition can only be successfully taught after the child has mastered preliminary skills, such as the sequence of numerals from 1 to 10 and how numerals are used to count objects. In parallel, children actively seek information they can process and learn from by selecting among cultural parents and communicating and interacting with them (Tamis-LeMonda & Masek, 2023).

We believe that the selective presentation of mental and behavioral elements in highly functional sequences may be the most important strategy in enabling children to acquire skills they cannot invent individually. Perhaps, this is currently underappreciated just because it is commonplace and almost synonymous with teaching. Any time cultural parents provide feedback, information, or a functional path toward a goal, they are effectively decreasing the space of possibilities that children have to search in order to develop a skill.

There is ample evidence that parents and teachers adapt their interactions to the child's level of mastery (Mermelshtine, 2017; Tamis-LeMonda & Masek, 2023; Fantasia & Delafield-Butt, 2023). Even language, which traditionally was regarded as developing under strong genetic guidance (Pinker, 1994), requires extensive practice, correction of mistakes, and a succession of increasingly complex steps in production and comprehension (Bohannon & Stanowicz, 1988; Fazekas, Jessop, Pine, & Rowland, 2020).

That cultural parents can structure a productive learning environment for children begs the question of where their knowledge comes from. Given that the skills to be taught are cultural inventions, it is implausible that adults have specific genetic knowledge about how to teach them. While an inborn motivation to interact with children is necessary, the content and structure of interactions must themselves have a cultural origin. This means that the behavior of cultural parents must also be subject to inter-generational transmission and cultural evolution (Van Ijzendoorn, 1992; Chen & Kaplan, 2001). For example, schools can teach young children mental and behavioral skills that took hundreds or thousands of years to invent, such as reading and writing, arithmetic, geometry, how to read maps, and how to use computers. We also deem it likely that humans learn informal teaching skills, such as breaking down tasks into easy-to-follow steps, stating goals clearly, and communicating ideas in ways that children can understand.

Caldwell et al. 2018 demonstrated that direct active teaching is necessary for transmitting complex knot-tying skills while simple knot-tying skills can be transmitted through emulation (i.e., observation of the end-state) or imitation (i.e., observation of intermediate states) alone.

Teaching abilities are often viewed as part of our inborn capacities (Fogarty, Strimling, & Laland, 2011; Csibra & Gergely, 2011; Burdett, Dean, & Ronfard, 2018), and sometimes referred to as natural pedagogy in contrast to cultural pedagogy (Heyes, 2016). Natural pedagogy has been criticised in developmental psychology on conceptual and empirical grounds (Szufnarowska, Rohlfing, Fawcett, & Gredebäck, 2014; Gredebäck, Astor, & Fawcett, 2018) but even without this criticism the natural pedagogy cannot explain how we can teach skills of recent invention, like mathematics, reading and writing, and many crafts. Cultural coevolution of cultural phenomena and cultural adaptations can explain why cultural parents can efficiently transmit complex domain-specific cultural information (Chen & Kaplan, 2001). Peer interactions may also be subject to cultural evolution (Ronfard, Was, & Harris, 2016; Lew-Levy et al., 2023), such that children's play and games may be cultural products promoting cultural transmission (Lew-Levy & Boyette, 2018).

Cultural and biological evolution

IFD entails an open mental architecture that supports unbounded cultural evolution by providing an efficient mechanism for the cultural transmission of complex cultural traits. These include the behavior of cultural parents and the goals individuals strive for. Parental behavior can enable the organization of more productive learning trajectories for individuals. The cultural evolution of goals has the potential to create new phenomena, as emergent goals typically require the co-evolution of a host of skills necessary to fulfill them. For example, producing and enjoying music has led to the flourishing of many professions, such as singers, instrumental players and makers, teachers, and composers. Each of these is supported by culturally evolved skills and also by its own goals. For example, a violin maker's craft may entertain such goals as acquiring appropriate wood and other raw materials, carving the wood according to a design, and finishing the instrument with varnish. This power of IFD in supporting cultural evolution is illustrated in panels C and D of Fig. 2 showing that it can both evolve and maintain competence over generations requiring a set of skills.

Because of its focus on goals, we expect IFD to preserve function across generations, but not necessarily structure. When a goal can be fulfilled in many different ways, how it is actually fulfilled can change over time. Language evolution is an example: languages can change to the point of being unintelligible within a few hundred years, yet their communicative function is entirely preserved (Lyons, 1968; Kirby et al., 2008). One can argue that maintaining function is what is important rather than perfect copying of structure. Finer analyses of the outcome of cultural transmission often reveal small differences in structure between the sender and the receiver (Acerbi & Mesoudi, 2015; Charbonneau & Bourrat, 2021). For this reason some variation in structure is expected, and also often observed, among individuals that have been subject to the same cultural environment. An example of this is variation strategies of mental arithmetic (Lemaire & Arnaud, 2008). In addition, IFD can also support the generation and spread of new or modified complex skills through both active exploration of behavior and mental operations, and through invention of new goals or subgoals (see Fig. 2). A classic example is when metals replaced stone as the raw material. In these transitions, the endgoals, in terms of tools with different functionality, were maintained, for instance, knives, arrows, and axes, while the production technology completely changed with completely different subgoals. Evolutionary psychology has been criticized for confusing modularity and functional specialization (Pietraszewski & Wertz, 2022). The latter can be transmitted between generations by developmental mechanisms that use goals and

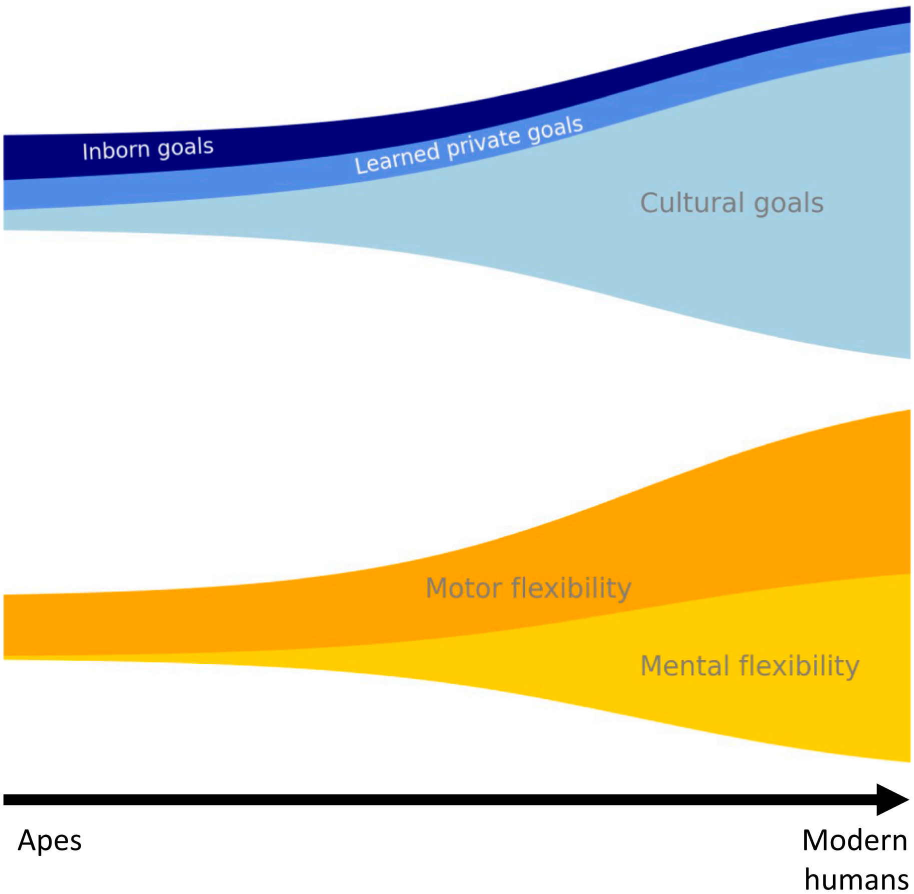

Fig. 3. Suggested changes during the human evolutionary transition from a typical ape to modern humans. Learned private goals refer to goals that develop through individual learning and associative processes, which are widespread among animals (Williams, 1994; Enquist et al., 2023).

error correction like IFD.

The focus on function is also important for understanding the genetic evolution of human cultural capacities. The basic machinery behind these capacities must be inborn and the start of its evolution can be traced to our early ancestors, as illustrated in Fig. 3. We speculate that sometimes during primate evolution, learned goals became more important, social information more prevalent, and motor programs more flexible. Only humans, however, have substantial mental flexibility that evolved in conjunction with culturally transmitted goals and skills of increasing complexity.

What circumstances could have triggered these changes? Consider a situation in which the social environment has become an increasingly valuable source of information. We will not discuss why this happened, which has been the subject of much research, but ask what kind of developmental mechanisms would evolve in such an environment.

Studies of the genetic evolution of cultural capacities often assume that skills can be simply copied from the social environment (Acerbi & Mesoudi, 2015; Boyd & Richerson, 2005). However, we argued above that complex skills cannot be learned just by observing others and by verbal instruction. It is here that goal learning becomes important. Incremental acquisition of culturally evolved skills requires subgoals that themselves have little value, and these must be learned from the cultural environment. Individual perfection of culturally evolved skills will also require goals in order to evaluate performance. Even imitation can be more accurate if complemented with a mechanism for error correction that is aware of the goal to be accomplished. We speculate that new opportunities to learn productive skills from the social environment arose during human evolution and that these were the initial selection pressure that fueled the evolution of the inborn mechanisms for goal learning, and subsequently of the complete IFD machinery.

One emergent consequence of goal learning is that cultural evolution now can establish goals that are in conflict with biological needs, as cultural evolution does not always favor the same things as genetic evolution (Campbell, 1975; Smolla et al., 2021). Biological evolution would only support cultural capacities that increase biological reproduction (fitness). For this to be the case, biological goals like feeding, reproducing, and surviving must be sufficiently safeguarded even when a majority of goals and skills are learned. We hypothesize that, to this end, inborn information influence the formation of goals, rather than directly influencing the development of skills that serve biological goals. For instance, an inborn mechanism for hunger motivation would promote the cultural evolution of foraging skills, while inborn fear mechanisms would promote safe foraging practices. The IFD model can integrate inborn and cultural information if the former retains some control over the latter. By letting inborn factors operate through goals rather than skill predisposition, biological needs could be sufficiently safeguarded at the same time allow cultural evolution to occur on a grand scale. This idea can be integrated with the ideas of inborn receiver biases in contemporary theory of cultural evolution (see above). That inborn mechanisms for motivation and emotions guide human behavior has also been highlighted in evolutionary psychology (Cosmides & Tooby, 2000) but it has not been recognized that this allows for non-modular control of development (Pietraszewski & Wertz, 2022) and that it can promote biological evolution of flexibility and cognitive capacities for culture.

Since cultural skills could evolve to be more productive than inborn skills, the genes underlying IFD could be favored in human evolution even as they relinquished direct control of behavior. This, at the same time, left plenty of room for cultural evolution to shape goals and skills in ways not expected under genetic evolution alone. For example, if IFD resulted in securing 10% more resources, it would be sufficient that 1% be devoted to genetic goals for the underlying genes to spread. The remaining 9% of resources could serve purely cultural goals like building soccer stadiums, opera houses, or the 920-page book that describes dog breed standards according to the American Kennel Club (2017).

Conclusions

We have argued above that goal acquisition is a fundamental part of human development. We also argued that goal learning is accomplished socially, as the child interacts with caregivers, and that it is at least as important, if not more, than the social learning of specific actions. We have dubbed this broad characterization of development “incremental functional development” in order to emphasize the child’s internalization of increasingly complex goals as the primary driving force in human development. We believe that this perspective may offer a solution to the puzzle of how humans can learn complex skills without any specific guidance, which we regard as a deep question about human development. Further, incremental functional development suggests that the interaction between development and cultural evolution is fundamental to human nature, because the goals of development can themselves evolve culturally, and because only cultural elements that are learnable during development can evolve. We therefore suggest that developmental psychology and cultural evolutionary studies can fruitfully team up in a joint effort to understand more fully human development and cultural evolution. These efforts would include:

1. Investigating development as a process of cultural transmission, and vice versa.
2. Focusing on childhood as a primary window for cultural transmission.
3. Striving for a much needed understanding of how complex culture is incrementally transmitted, including the role of parental behavior.
4. Researching how parental behavior evolves culturally.
5. Understanding how the extraordinarily long human childhood makes complex human culture possible.

Accomplishing these goals requires new empirical research, for example, to elucidate how goals are transmitted, as well as new theoretical approaches that integrate developmental processes and cultural evolution.

Author contribution

All authors contributed to conceptualization, formal analysis, writing and visualisations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Equations used to produce Fig. 2

Transmission based on structure:

$$x_{t+1} = \lambda x_t + (1-\lambda)q$$

where x_t and x_{t+1} are the proportion of productive actions at the end of generation t and $t+1$ respectively. The parameter λ is the copying fidelity and q is the likelihood that a randomly explored action is productive. In this case, the individual cannot assess whether the action is productive or not, and x_{t+1} decreases with decreasing copying fidelity (decreasing λ) and increased flexibility (decreasing q). Conformity, not modeled here, could improve the transmission of a productive action but could never increase or maintain (unless transmission is perfect) the frequency of x.

Transmission based on functions:

$$x_{t+1} = q + (1-q)q + (1-q)^2 q + \cdots + (1-q)^{k-1} q = 1 - (1-q)^k$$

where k is the number of learning opportunities. In this case, individuals get no cultural information about structure and explore actions on their own, and stop when a productive one is found.

Transmission based on a combination of structure and function:

$$x_{t+1} = A + (1-A)A + \ldots + (1-A)^{k-1} = 1 - (1-A)^k$$

where $A = \lambda x_t + (1-\lambda)q$. In this case, cultural information is inherited about structure that can significantly reduce learning cost associated with flexibility, while cultural information about goals allow correction of errors emerging from both transmission infidelity and attempt at innovating.

Sets of actions:

If a set of n different actions is required to fulfill an overall goal, and each action is learned independently resulting in a probability of p of get each action right, the probability of getting all n productive is p^L.

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