The Cultural Transmission of Technological Skills

Maxime Derex[1] & Thomas J. H. Morgan[2,3]

[1] Institute for Advanced Study in Toulouse, CNRS, University of Toulouse 1 Capitole, France

[2] School of Human Evolution and Social Change, Arizona State University, 900 South Cady Mall, Tempe, 85287, Arizona, USA

[3] Institute of Human Origins, Arizona State University, 951 South Cady Mall, Tempe, 85287, Arizona, USA

Abstract

Human adaptation relies on the multigenerational transmission and accumulation of both skills and knowledge. Nonetheless, there is currently no agreement on which factor, or combination of factors, explains our peculiar ability to do so. Theoretical and empirical work, however, has identified many candidates, that operate at both the individual and population levels. In this chapter, we start by giving a brief overview of these factors that support cultural transmission, before highlighting the relative lack of research on the cultural transmission of skills. We characterize skills as behaviors that rely on fine motor control, and knowledge as mental-states that guide behaviors. Many behaviors require both complex knowledge and skilled actions to be effective. Nonetheless, we argue that the field of cultural evolution has largely studied the transmission and evolution of knowledge, as opposed to skill, raising the possibility it presents an incomplete picture of human adaptation. Drawing on evidence from anthropology and economics, we suggest that the cultural evolutionary dynamics of skill are likely to differ from those of knowledge. Specifically, we argue that (1) skills are less reliant on language for transmission than is knowledge, (2) skills are more costly to transmit than knowledge, (3) skills are transmitted along different pathways than is knowledge, and are more often limited to vertical transmission, and (4) as a result, skills likely evolve more slowly than does knowledge. We conclude that a full picture of human adaptation requires an increased focus on skill, alongside knowledge.

Introduction

A central feature of our species is our unprecedented ability to develop sophisticated technologies that have allowed us to colonize and permanently occupy environments for which we are poorly suited genetically (Boyd et al., 2011). Knives, spears, slings, bows, kayaks and clothes, along with large-scale constructions like houses, weirs and drivelines are only a few examples of the myriad technologies that sustain humans in almost every terrestrial environment on earth.

These technologies, and the skills to use them effectively, are not developed in isolation by especially gifted individuals but result from a cumulative cultural evolutionary process in which skills and knowledge are gradually accumulated across many generations (Boyd et al., 2011; Henrich, 2015). As we shall see in this chapter, our ability to transmit and accumulate skills and knowledge results from a combination of factors that operate at the individual and population levels. In what follows, we start by giving a brief overview of these factors that support cumulative cultural evolution, before highlighting the relative lack of research on the cultural transmission of skills. We describe examples of experimental work that, at first glance, might appear to investigate the cultural transmission of skills, but that we argue actually study the transmission of knowledge. Drawing on evidence from anthropology and economics, we suggest that the cultural evolutionary dynamics of skill are likely to differ from those of knowledge. We conclude that the current focus on knowledge is likely to present an incomplete picture of human adaptation and so a fuller picture requires an increased focus on skill.

Factors contributing to the transmission of cultural information

There is currently no agreement on which factor, or combination of factors, explains our peculiar ability to transmit and accumulate skills and knowledge. Theoretical and empirical work, however, point to two main factors: individual capacities that promote cultural transmission and population characteristics that buffer against cultural loss and foster innovation.

At the individual level, there has been much focus on cognitive abilities supporting high-fidelity social learning. Factors that promote faithful cultural transmission include teaching, language, and prosociality (Laland, 2017). Many studies have investigated this topic using a variety of different methods, including theoretical models and experiments. For instance, Morgan et al (2015) found empirical support for the transmission enhancing effects of teaching and language in the context of modern humans learning to make Oldowan stone tools. Across experimental conditions, participants who were taught, as opposed to learning via passive observation, produced more tools, did so more quickly, and made more efficient use of raw materials. These benefits were further enhanced by verbal, as opposed to gestural, teaching. Such results, however, have not consistently replicated across tool types (Putt et al., 2014; Whiten, 2015; Pargeter et al., 2022) and it is important to note that while teaching and language may enhance transmission, they are unlikely to be strictly necessary (Snyder et al. 2022). Furthermore, the extent to which they help cultural transmission has been shown to vary with tool complexity (Lucas et al. 2020).

From a theoretical perspective, Fogarty et al (2011) examined the conditions under which teaching, defined as a costly ability to increase the efficacy of transmission, will evolve. They found it did so when the inclusive fitness benefits of helping the learner outweigh the personal costs of being a teacher. As a result, teaching evolves when the information being transmitted is neither too easy nor too hard to learn, but rather falls in a middle ground of learnability. This is because easily-learned information would likely be invented anyway, whereas difficult-to-learn information is unlikely to be successfully transmitted even with teaching, and so in both cases the inclusive fitness benefits are small.

At the population level, demography is widely considered as a key factor for the stability of cultural information. The main idea behind demographic models of cultural evolution is that our social learning abilities subtly interact with demography to affect the maintenance of cultural traits (Henrich, 2004; Powell et al., 2009). More specifically, it has been shown that the size of the population within which information is shared can buffer the risk of losing cultural information. Indeed, models have shown that, when populations are large enough, individuals' propensity to learn from successful cultural models creates a selective force that promotes the transmission of beneficial cultural traits and outweighs the degrading effects of learning errors (Henrich, 2004). The plausibility of demographic models has been tested using real-world ethnographic and archaeological data. However, results from studies looking for a correlation between toolkit size and population size have been mixed. Some studies support the hypothesis (Powell et al., 2009; Kline & Boyd, 2010; Collard et al., 2013; Marquet et al., 2012), but others do not (Collard et al., 2005; Collard et al., 2013b; Collard et al., 2013c; Buchanan et al., 2015).

The difficulty with testing demographic models using real-world data is that human populations are typically embedded within extended networks of cultural exchange, making it difficult to gather meaningful estimates of population size (Derex & Mesoudi, 2020). For this reason, cultural evolution researchers have turned to lab experiments, in which groups of participants are tasked to improve a piece of technology, to test predictions from theoretical models. Most experiments provide support for a positive effect of group size on the accumulation of cultural information (Derex et al., 2013; Wisdom et al., 2013; Muthukrishna et al., 2014; Kempe & Mesoudi, 2014; Derex & Boyd, 2015, but see Caldwell & Millen, 2010; Fay et al., 2019). One study, for instance, exposed naïve participants in groups of 2, 4, 8 and 16 to demonstrations showing how to produce virtual arrowheads and fishing nets, and tracked the efficiency of those tools across time (Derex et al., 2013). The larger the group, the less likely tools were to deteriorate, the more likely they were to improve, and the more likely a diversity of tool types were to be maintained. These studies illustrate how decreases in effective population size may result in a loss of technologies and/or skills and can help explain non monotonical trends in cultural evolution.

Along with studies about population size, an increasing number of studies have started to investigate how the structure of the population impacts the transmission and accumulation of cultural information. Human populations are typically embedded within extended networks of cultural exchange and recent work suggests that differences in rates of connectedness strongly affect the transmission and accumulation of cultural information (Derex & Mesoudi, 2020). For instance, experimental studies that assume that existing traits can not only be refined, but also combined with other existing cultural traits have shown that cultural accumulation can benefit from lower levels of connectedness (Derex & Boyd, 2016). This is because high levels of connectedness make individuals more likely to converge on similar solutions, which results in lower levels of cultural diversity and slower rates of innovation compared with less connected groups. When the risk of cultural loss is considered, simulation models show that optimal rates of accumulation are reached for intermediate levels of connectedness (Derex et al., 2018). This is because low levels of connectedness increase the risk of cultural loss by decreasing access to demonstrators, while high levels of connectedness reduce opportunities to innovate by homogenizing cultural behaviors. At intermediate levels of connectedness, groups can accumulate cultural information while remaining culturally distinct, which keeps fueling innovation (Derex & Mesoudi, 2020).

The relationship between knowledge and skill in technology

While the above highlights the progress made in understanding the transmission and accumulation of cultural information, we will now suggest that it has failed to account for how technologies are manifest as complex motor actions, what we will call *skills*. In particular, we suggest that much existing work can be better characterized as studying the transmission of knowledge, as opposed to skill. Let us begin by briefly outlining how we feel these two concepts differ.

The core of our distinction is that skill emphasizes actions, while knowledge emphasizes mental states. For instance, the creation of a colonial knot (as opposed to, say, a French knot) in cross-stitch requires quite fine motor-control to perform highly specific actions and, as such, it is a skill. On the other hand, the ability to read a map and use it to successfully navigate to your destination requires understanding the conventions of map creation (scale, contour lines, location symbols), but does not require any particularly challenging actions, and so it is an example of knowledge.

This is not a dichotomy: in the vast majority of cases both skill/action and knowledge/mental state are at work (you need to *know* how to make a French knot, and holding a map involves *actions*). The interaction between knowledge and action has long been stressed by archaeologists who clearly recognize that both contribute to activities such as toolmaking (Pargeter et al., 2020). Improvements in skill require increased precision of selected actions which leads to higher replicability in achieving a desired goal (Crown, 2001; Stanley & Krakauer, 2013). Individuals, then, may be poorly skilled because they perform appropriate actions with poor precision or because they perform inappropriate actions. Becoming a skilled hunter, for instance, requires more than developing fine motor-control and depends on knowing facts about the local environment and animal behaviour. Kawabe (1983), for instance, has shown that among the Gidra from southwest Papua New Guinea, adolescents vary in hunting success rate because of difference in environmental knowledge. Nonetheless, certain tasks may rely on skills more so than knowledge and so are better characterized as tasks of skill or knowledge.

The way in which we are using the terms knowledge and skill here has considerable overlap with the archaeological terms *connaisance* and *savoir-faire* (Pelegrin, 1993) commonly translated as knowledge and know-how, and which refer to the mental images of possible actions and the ability to perform those actions, respectively. There is also similarity with the notions of public/behavioral and private/mental culture (Tamariz, 2019), where the public performance of a behavior is distinguished from its mental representation. Despite this overlap, the intention behind the work is different. Here, we argue that tasks can be characterized as relying to various degrees on skill and/or knowledge.

With the difference between skill and knowledge in mind, let us note that not all technologies (the focus of this chapter) emphasize skill. For instance, the use of programming languages is at the heart of a vast array of contemporary technological developments and learning these languages is a key part of modern-day cultural inheritance. Nonetheless, the successful use of these languages relies almost entirely on an individual's mental state as opposed to their ability to perform certain actions, and so we suggest that a successful programmer is better characterized as *knowledgeable* as opposed to skilled.

Despite this, skills are critical to the ecological success of the human species. Compared to chimpanzees that obtain 95% of their calories from foods that they gather by hand, human foragers obtain 32% of their calories from extracted resources and 60% from hunted resources (Kaplan & Robson, 2002). Technologies that support this subsistence strategy require huge amounts of skill, and this can occur both at the level of production, and at the level of use. As one example, consider the bow hunting of caribou by the Netsilik living along the Arctic coast of North America (Balikci, 1970). To produce a bow requires the skilled manipulation of a musk-ox horn handle and antler limbs, as well as antler splits and blocks, along with sinew to bind them all together. Once a bow is made, several hunting techniques can be implemented to efficiently use the produced tool. One in particular, stalking on open terrain, requires the hunter(s) to approach their prey by standing bent at the waist and imitating the gait of a grazing caribou in order to approach the animal without scaring it off. This approach can last for several hours, and once sufficient proximity is achieved, the hunter would suddenly stand upright and quickly release an arrow. While knowledge is critical to this hunting technique, its successful execution also relies on highly complex motor actions making it a skill.

Cultural evolution typically studies knowledge and not skill

With the distinction between knowledge and skill in mind, we can now return to studies of cultural transmission and ask to what extent the two are present.

For practical purposes, experimental tasks used in cultural evolution tend to be simple and straightforward to solve compared to the ecological problems solved by human cultures (Miton & Charbonneau, 2018; Derex, 2022). Limiting the complexity of tasks is important to effectively study cultural transmission over relatively short period of time. However, it carries the risk of leading to an incomplete understanding of the mechanisms at work, as well as of the resulting cultural evolutionary dynamics. In this section, we argue that most current work focusses extensively on knowledge transmission, leaving relatively little known about the transmission of skill.

As an example, consider an experimental investigation of the transmission of Oldowan stone knapping techniques (Morgan et al., 2015), finding transmission was enhanced by teaching (in particular when gestural teaching was combined with speech). The controlled production of stone tools undoubtedly requires a considerable amount of skill and precise motor control. Indeed, a study comparing the knapping ability of experts (with more than 20 years of experience in stone knapping) against intermediate knappers (several years of experience) and novices (little to no experience) found clear differences between the groups, with only experts being able to precisely predict and control the outcome of strikes (Nonaka et al., 2010). Nonetheless, although the experiment involved such a technology, we suggest it likely did not study the transmission of skill because the experimental timeframe was too short. The expertise study mentioned above shows that the skills underlying stone knapping develop slowly, continuing to improve over decades of practice. The transmission study, however, took under an hour of a given participant's time, with no more than 30 minutes spent making tools. We suggest this time is too short for the meaningful transmission of skill. Indeed, a more recent study involving two hours of knapping was still unable to detect increases in skill (Pargeter et al., 2022). Instead, what was likely transmitted was basic knowledge concerning stone knapping—how to hold the materials, the general characteristics of suitable strike locations, how hard to hit, and so on—which participants put into practice as best they could. Such knowledge allowed participants to make a number of viable flake tools, but their *skill* as knappers likely remained poor.

Similar arguments could be made about most experimental tasks that are commonly used in the cultural evolution literature. Making paper airplanes so that they fly as far as possible or building towers so that they are as tall as possible involve relatively straightforward actions in which individuals are already competent prior to the experiment (such as folding a piece of paper; Caldwell & Millen, 2008). Therefore, cultural transmission in those studies likely concerned knowledge and not skill. The unintended focus on knowledge that we aim to highlight in this chapter is not limited to experimental studies. For instance, one of the rare field studies looking at the interaction between social structure and cultural transmission among traditional populations focused exclusively on the transmission of knowledge (Salali et al., 2016).

That these studies investigate the transmission of knowledge, as opposed to skill, does not mean they are poor studies. The transmission of knowledge is itself a critical part of culture and worthy of study. Experimental studies of knowledge transmission have proved useful tests of theoretical predictions about how individuals learn in groups (Mesoudi, 2011; Morgan et al., 2012) and field studies are extremely valuable to reveal the pathways through which knowledge might flow within actual populations (Migliano et al., 2017). Nonetheless, this work leaves untouched the cultural transmission of skills and we should be cautious about the extent to which current findings generalize.

The cultural evolutionary dynamics of skill likely differ from those of knowledge

The broad focus of the cultural evolutionary literature on knowledge is only problematic to the extent that knowledge does not capture the full spectrum of cultural evolution. Whether skills have different cultural evolutionary dynamics to knowledge is an empirical question that remains to be addressed.

Some findings from the cultural evolutionary literature are likely to be valid regardless of the cultural content involved. For instance, consider the influential finding of theoretical models that population size and connectedness critically affect the transmission and maintenance of cultural traits by buffering the risk of cultural loss (Henrich, 2004; Powell et al., 2009; Creanza et al., 2017; Derex & Boyd, 2016). Although experiments supporting the role of population size on the proper transmission of cultural information have mostly involved the cultural transmission of knowledge (Derex et al., 2013; Kempe & Mesoudi, 2014; Muthukrishna et al., 2014), we should expect to observe similar effects when skills are involved. Indeed, both knowledge and skills are at risk of cultural loss due to our limited learning abilities, and, while the magnitude of the risk may differ, it is plausible that fewer learners will increase the risk of losing cultural information in both cases. Nonetheless, there are multiple reasons to suppose that the cultural evolutionary dynamics of skill might differ from that of knowledge and we shall describe a few examples here.

The role of language

One difference between skills and knowledge is that the transmission of skills is potentially less reliant on, or derives less benefit from, language. For instance, the complex actions involved in skills may be more difficult to put into words, meaning language struggles to transmit them. Similarly, while knowledge is difficult to demonstrate directly (although it can be manifest in behaviors), it may be readily put into words and expressed verbally. As such, without language, knowledge transmission may have been more challenging than skill transmission. However, the evolution of language may have reversed this relationship by greatly facilitating the transmission of knowledge. This suggests that simpler social learning mechanisms, such as imitation, may be more conducive to the transmission of skills than language.

The difficulty of transmitting skills verbally is illustrated by an experiment that compared the acquisition of stone tool-making skills among learners who were taught using speech alone (unassisted by gesture), gesture alone or ‘full language’ (gesture plus speech) (Cataldo et al., 2018). Comparisons of flintknapping performance indicate that individuals who were taught using speech alone performed poorly compared to individuals instructed through either gesture alone or ‘full language’, suggesting that language in the absence of demonstration was poorly suited to transmitting an understanding of the process of tool making.

Costs of transmission

Skills and knowledge are also likely to vary in terms of costs associated with their transmission. Indeed, since skills can be difficult to put into words, they are more likely to require demonstration from teachers. This should be particularly the case for skills that are complex and/or more hazardous. Ethnographic studies, for instance, have shown that complex extractive subsistence skills such as big game hunting and multicomponent toolmaking typically involve direct instruction even within populations where direct, active teaching is relatively rare (Lew-Levy et al., 2017). Thus, even though simpler skills such as trapping small game and pounding grain can be acquired through observation and participation to daily activities, skills involving risks (such as the risk of being harmed or the processing of rare raw material) will tend to involve substantial costs of transmission.

Another difference between skills and knowledge is that skills require extensive practice. To some extent, practice is likely to benefit the transmission of knowledge as well. For instance, in a knowledge-based experiment in which learners received lengthy cultural demonstration on how to build a virtual fishing net by selecting different materials and pointing and clicking on a grid to arrange the materials, 100% of fishing-net builders failed at the first trial (Derex et al., 2013). This illustrates the importance of multiple demonstrations and multiple attempts in the proper acquisition of knowledge (see also Flynn & Whiten, 2010). Yet, ethnographic and experimental evidence indicate that skills are acquired through long apprenticeships during which motor control is progressively developed (Kaplan & Robson, 2002; Pargeter et al., 2020). As noted above, knappers continue to improve in their fine control over flaking outcomes over the course of decades. Similar learning curves are seen in bows and atlatls (Whittaker, 2013). The role of practice in the acquisition of skills is also exemplified by return rates of ache hunters who become proficient years after reaching their peak strength (Walker et al., 2002). Moreover, experimental archeology studies have showed that learners' inability to produce stone tools is largely accounted for by a failure to properly execute intended actions rather than a failure to conceptualize appropriate goals (Pargeter et al., 2020). A consequence of this is that skills may take much longer to successfully transmit, while knowledge, although not instantaneous by any means, will often be faster to transmit.

The fact that skills require extensive practice creates specific demands for learners and might have led to the emergence of unique mechanisms to support their proper acquisition (Sterelny, 2014). One example is the production of miniature toys by adults that allow children to emulate adult activities. Many ethnographical studies have revealed that adults facilitate skill acquisition by providing children with toy or small hunting weapons at an early age. For instance, at the Par-Tee site in Oregon, children were provided with miniature atlatls for them to practice with (Losey & Hull, 2019). Other examples include miniature baskets, digging sticks, and spears which support the acquisition of subsistence skills such as harvesting and small-game hunting (Lew-Levy et al., 2017).

Transmission pathways

The fact that the transmission of skills is likely to incur larger costs to demonstrators compared to knowledge suggests that their respective transmission pathways might differ. In particular, the costs associated with the transmission of skills may disincentivize teaching toward non-kin and limit learning opportunities (Buckley, this volume). Reviews of the ethnographic literature confirms that skills are mostly transmitted vertically. For instance, Shennan and Steele (1999) have reported that craft and tool-making traditions are predominantly transmitted from father to son or mother to daughter. A recent meta-ethnographic review studying how children learn subsistence skills also suggests that same-sex vertical transmission is one of the major ways by which children learn various foraging skills (Lew-Levy et al., 2017). To some extent, this is true of knowledge transmission as well. Studies looking at the distribution of knowledge in hunter-gatherer population have also showed that not all knowledge is equally shared despite being cheaper than skills to transmit. For instance, field studies have showed that knowledge about medicinal plants were mostly shared between spouses and kin, while plants that serve other functions were shared more widely. This illustrates that transmission networks are content specific even in the case of simple pieces of knowledge that can be transmitted at low cost. Nonetheless, because the transmission of skills requires more effort on the part of the demonstrator, skilled individuals should be more inclined to teach kin because of inclusive fitness benefits (Buckley, this volume).

The fact that skills tend to be passed on vertically does not mean they are exclusively transmitted in this way. For instance, ethnographic studies have showed that hunting skills are sometimes taught by uncles, grandfathers and other elders (Puri, 2006; Wallace & Hoebel, 1986). In some cases, like among Ethiopian Chabu, adolescents even choose their teachers, preferring to go on hunts with knowledgeable individuals (Dira & Hewlett, 2016). Yet, for teaching toward non kin to occur it must be supported by informal or formal institutions that compensate teacher for their efforts. For instance, cultural evolution scholars have argued that learners use deference to buy access to skilled models (Henrich & Gil-White, 2001).

Economists have long stressed the role of institutions in providing an enforcement mechanism that incentivize cultural transmission of skills (de la Croix et al., 2017). Within families, no enforcement mechanism is required because parents and relatives are inclined to teach kin because of inclusive fitness benefits. However, outside the family, skills are often passed from knowledgeable individuals to learners in return for help with routine tasks and menial assignments. For complex tasks, transmissions mechanisms often take the form of an apprenticeship, which is a relation linking a skilled individual (typically an adult) to a learner (typically a child or adolescent). The duration of apprenticeships can vary, but it typically increases with the complexity of the skill involved (de la Croix et al., 2017). Research among stone-adze makers of Langda in Indonesian, for instance, has shown that toolmaking skills are traditionally transmitted through semi-formal apprenticeships that began around age 12 and last several years (Stout, 2005). In exchange for being trained, learners must often commit to defer to the teacher and follow the tradition precisely. Teachers also evaluate the commitment of potential learners and might evaluate their potential by asking them to perform activities relevant to the skill that they wish to acquire (Stout, 2005). Studies investigating the transmission of skills in preindustrial modern Europe have also found that parents often paid premiums, with the amount depending on the prestige of the teacher. Premiums could also vary depending on the physical strength of learners with strong individuals paying less than weak individuals (de la Croix et al., 2017).

Thus, compared to knowledge, the high costs associated with skill transmission are likely to require specific mechanisms that mitigate or eliminate the moral hazard problem in the teacher-learner relationship. It is likely that informal and formal institutions that compensate teachers for their effort are key determinants of the dissemination of skills.

Resulting evolutionary dynamics

The difference between skills and knowledge suggest that the cultural evolutionary dynamics of skill might differ from that of knowledge in significant ways. First, limited learning opportunities will make skills more prone to cultural loss than knowledge. Moreover, difficulty of transmitting skills relative to knowledge may render their persistence across generations increasing fragile. Evidence of this can be seen in the Polar Inuit that, following an epidemic in the 1820's that killed many elder group members, rapidly lost the ability to make and use kayaks, leisters and bows and arrows (Boyd et al., 2011). These technologies were regained through contact with migrating Inuit from Baffin Island, but in the meantime the Polar Inuit were unable to make and use these tools even though many of them would have grown up surrounded by their use and undoubtedly understood the general principles behind their creation and use. Nonetheless, given the historical nature of this account it is unclear the extent to which the Polar Inuit suffered from a loss of knowledge or skill.

Second, skills may evolve more slowly than knowledge. There are two reasons to suppose this might be the case: (1) as already discussed there are reasons to suppose that skills transmission is a slower process than knowledge transmission, if true, and assuming that both transmit with similar fidelity, then skill evolution will also be slower than knowledge evolution, and (2) the evidence reviewed above suggests that complex skills (due to the cost of their transmission) are disproportionately transmitted vertically. Such a process will slow the spread of innovations within and between populations, and cause cultural evolution to approximate genetic evolution which is slower than cultural change (Perreault, 2012). Boudot and Buckley (2017), for instance, reported that loom designs and weaving techniques (that are mostly transmitted from mother to daughter through a lengthy apprenticeship) exhibit low rates of innovation. An additional reason why skills might evolve slowly is that teachers are often concerned with detecting and correcting errors in learners' techniques. These corrections, however, not only concern actual errors but also deviation from the traditional way of performing the technique (Buckley & Boudot, 2017). This is likely to increase the fidelity of transmission between generations but will ultimately reduce opportunities for innovation.

Due to the conservative way in which skills are transmitted, mechanisms are likely to be required to promote the diffusion of innovations between families. One such mechanism is marriage. Weavers, for instance, often move from the parental household to their spouse's household (Buckley & Boudot, 2017). Yet, because innovation rates are low, skills are often uniform within communities with no variation between household. Another mechanism that has been put forward by anthropologists is ritual relationship, which has been shown to promote interactions between communities (Hill et al., 2014). For instance, quantitative analyses of interaction rates have revealed that ritual relationship is a more important predictor than kinship for different types of interaction, including opportunities for cultural transmission (such as observing tool-making skills). However, it is not entirely clear whether occasional episodes of observation are sufficient to enable the transmission of complex skills.

Apprenticeships may also help diffuse skills beyond single families. Economists, for instance, have argued that because semi-formal and formal apprenticeship are independent from family ties, they allow learners to acquire skills from larger populations (de la Croix et al., 2017). For instance, they have argued that, compared to China where training was provided by family members, preindustrial Western Europe had a formal system of apprenticeship organized by guilds that were better at disseminate techniques and innovations. One interesting feature of guilds is that they introduced journeymanship (Lis et al., 1994). Journeymen were considered competent craftsmen and were authorized to work in the field they have been trained at but could not yet work as self-employed master craftsmen. Rather they had travel to another city to acquire additional skills, which exposed them to a broader range of skills and fostered the spread of new techniques. (De la Croix et al., 2017 have compared their status to postdoctoral researchers in scientific fields). It is likely that regions that relied on institutions such as extended families and clans may have experienced lower rates of innovations than regions where learners could sample from larger pools of skilled teachers.

Conclusion

Human adaptation relies on the cultural accumulation of both skills and knowledge. Theoretical and empirical work indicate that our ability to transmit cultural information results from a combination of factors that operate at the individual and population levels. In this chapter, we briefly reviewed these factors and have argued that most cultural evolutionary work has studied the transmission of knowledge. Yet, humans extract resources and exploit technologies that require high level of skill. As we have argued, skills and knowledge differ along many dimensions, and we should be be cautious not to assume that findings about the transmission of knowledge necessarily generalize to skills. Compared to knowledge, the transmission of skills might occur via different learning mechanisms, over longer periods of time and might involve different transmission pathways. Understanding how cultural transmission differ between skills and knowledge is critical for debates about the relationship between of humans' unique social structure and the transmission and accumulation of cultural innovations. Indeed, it has been argued that humans live in large networks of unrelated individuals that might be conducive to the spread and accumulation of cultural information (Hill et al., 2014). Yet, actual measurements of cultural transmission in natural populations remain scarce and little is still known about how skills, in particular complex ones, spread in natural populations. Due to the features of skills, it seems unreasonable to assume that large social networks will automatically result in large skill transmission networks. Additional mechanisms such as semi-formal and formal institutions have probably been key to promote the dissemination and accumulation of skills. A more detailed understanding of the cultural transmission of skills, alongside and in interaction with knowledge, will provide a more general basis for understanding cultural evolution and human adaptation.

References

Balikci, A. (1970). *The Netsilik Eskimo*. Waveland Press.

Boyd, R., Richerson, P. J., & Henrich, J. (2011). The cultural niche: why social learning is essential for human adaptation. *Proceedings of the National Academy of Sciences*, *108*(Supplement_2), 10918–10925. https://doi.org/10.1073/pnas.1100290108

Buchanan, B., O'Brien, M., & Collard, M. (2015). Drivers of technological richness in prehistoric Texas: an archaeological test of the population size and environmental risk hypotheses. *Archaeological and Anthropological Sciences*, 1-10. doi:10.1007/s12520-015-0245-4

Buckley, C. D., & Boudot, E. (2017). The evolution of an ancient technology. *Royal Society Open Science, 4*(5), 170208. https://doi.org/10.1098/rsos.170208

Caldwell, C. A., & Millen, A. E. (2008). Experimental models for testing hypotheses about cumulative cultural evolution [Article]. *Evolution and Human Behavior, 29*(3), 165-171. <Go to ISI>://WOS:000255224600002

Caldwell, C. A., & Millen, A. E. (2010). Human cumulative culture in the laboratory: Effects of (micro) population size. *Learning & Behavior, 38*(3), 310-318. Retrieved from <Go to ISI>://WOS:000282066200011

Cataldo, D. M., Migliano, A. B., & Vinicius, L. (2018). Speech, stone tool-making and the evolution of language. *Plos One, 13*(1), e0191071. https://doi.org/10.1371/journal.pone.0191071

Collard, M., Kemery, M., & Banks, S. (2005). Causes of Toolkit Variation Among Hunter-Gatherers: A Test of Four Competing Hypotheses. *Canadian Journal of Archaeology, 29*(1), 1-19. Retrieved from www.jstor.org/stable/41103514

Collard, M., Ruttle, A., Buchanan, B., & O'Brien, M. J. (2013a). Population Size and Cultural Evolution in Nonindustrial Food-Producing Societies. *Plos One, 8*(9), e72628. doi:10.1371/journal.pone.0072628

Collard, M., Buchanan, B., O'Brien, M. J., & Scholnick, J. (2013b). Risk, mobility or population size? Drivers of technological richness among contact-period western North American hunter-gatherers. *Philosophical Transactions of the Royal Society B: Biological Sciences, 368*(1630). doi:10.1098/rstb.2012.0412

Collard, M., Buchanan, B., & O'Brien, M. J. (2013c). Population Size as an Explanation for Patterns in the Paleolithic Archaeological Record: More Caution Is Needed. *Current Anthropology, 54*(S8), S388-S396. Retrieved from http://www.jstor.org/stable/10.1086/673881

Creanza, N., Kolodny, O., & Feldman, M. W. (2017). Greater than the sum of its parts? Modelling population contact and interaction of cultural repertoires. *Journal of The Royal Society Interface, 14*(130). https://doi.org/10.1098/rsif.2017.0171

Crown, P. L. (2001). Learning to Make Pottery in the Prehispanic American Southwest. *Journal of Anthropological Research, 57*(4), 451-469. http://www.jstor.org/stable/3631355

de la Croix, D., Doepke, M., & Mokyr, J. (2017). Clans, Guilds, and Markets: Apprenticeship Institutions and Growth in the Preindustrial Economy. *The Quarterly Journal of Economics, 133*(1), 1-70. https://doi.org/10.1093/qje/qjx026

Derex, M., Beugin, M.-P., Godelle, B., & Raymond, M. (2013). Experimental evidence for the influence of group size on cultural complexity. *Nature, 503*, 389-391. https://doi.org/https://doi.org/10.1038/nature12774

Derex, M., & Boyd, R. (2015). The foundations of the human cultural niche. *Nat Commun, 6*, 8398. doi:https://doi.org/10.1038/ncomms9398

Derex, M., & Boyd, R. (2016). Partial connectivity increases cultural accumulation within groups. *Proceedings of the National Academy of Sciences, 113*(11), 2982-2987. https://doi.org/https://doi.org/10.1073/pnas.1518798113

Derex, M., Perreault, C. & Boyd, R. (2018). Divide and conquer: intermediate levels of population fragmentation maximize cultural accumulation. *Philosophical Transactions of the Royal Society B: Biological Sciences* **373**, 20170062, doi:10.1098/rstb.2017.0062.

Derex, M. & Mesoudi, A. (2020) Cumulative Cultural Evolution within Evolving Population Structures. *Trends Cogn. Sci.* **24**, 654-667, doi:10.1016/j.tics.2020.04.005.

Derex, M. (2022) Human cumulative culture and the exploitation of natural phenomena. *Philosophical Transactions of the Royal Society B: Biological Sciences* **377**, 20200311, doi:https://doi.org/10.1098/rstb.2020.0311.

Dira, S. J., & Hewlett, B. S. (2016). Learning to Spear Hunt Among Ethiopian Chabu Adolescent Hunter-Gatherers. In H. Terashima & B. S. Hewlett (Eds.), *Social Learning and Innovation in Contemporary Hunter-Gatherers: Evolutionary and Ethnographic Perspectives* (pp. 71-81). Springer Japan. https://doi.org/10.1007/978-4-431-55997-9_6

Fay, N., De Kleine, N., Walker, B., & Caldwell, C. A. (2019). Increasing population size can inhibit cumulative cultural evolution. *Proceedings of the National Academy of Sciences*, 201811413. doi:10.1073/pnas.1811413116

Flynn, E., & Whiten, A. (2010, Aug). Studying children's social learning experimentally "in the wild" [Article]. *Learning & Behavior, 38*(3), 284-296. <Go to ISI>://WOS:000282066200009

Fogarty, L., Strimling, P., & Laland, K. N. (2011). The evolution of teaching. *Evolution*, *65*(10), 2760–2770.

Henrich, J. (2004). Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses - The Tasmanian case [Article]. *American Antiquity, 69*(2), 197-214. <Go to ISI>://WOS:000221068800001

Henrich, J., & Gil-White, F. J. (2001). The evolution of prestige - Freely conferred deference as a mechanism for enhancing the benefits of cultural transmission [Review]. *Evolution and Human Behavior, 22*(3), 165-196. <Go to ISI>://WOS:000169145200002

Henrich, J. (2015) *The secret of our success: how culture is driving human evolution, domesticating our species, and making us smarter*. Princeton University Press.

Hill, K. R., Wood, B. M., Baggio, J., Hurtado, A. M., & Boyd, R. T. (2014). Hunter-Gatherer Inter-Band Interaction Rates: Implications for Cumulative Culture. *Plos One, 9*(7), e102806. https://doi.org/10.1371/journal.pone.0102806

Kaplan, H. S., & Robson, A. J. (2002, July 23, 2002). The emergence of humans: The coevolution of intelligence and longevity with intergenerational transfers.

Proceedings of the National Academy of Sciences, 99(15), 10221-10226. https://doi.org/10.1073/pnas.152502899

Kawabe, T. (1983). Development of hunting and fishing skill among boys of the Gidra in lowland Papua New Guinea. *Journal of human ergology, 12*(1), 65-74.

Kempe, M., & Mesoudi, A. (2014). An experimental demonstration of the effect of group size on cultural accumulation. *Evolution and Human Behavior, 35*(4), 285-290. http://linkinghub.elsevier.com/retrieve/pii/S1090513814000294?showall=true

Kline, M. A., & Boyd, R. (2010). Population size predicts technological complexity in Oceania. *Proceedings of the Royal Society B-Biological Sciences, 277*(1693), 2559-2564. Retrieved from <Go to ISI>://WOS:000279784000018

Laland, K. N. (2017). *Darwin's Unfinished Symphony: How Culture Made the Human Mind*. Princeton University Press.

Lew-Levy, S., Reckin, R., Lavi, N., Cristóbal-Azkarate, J., & Ellis-Davies, K. (2017, 2017/12/01). How Do Hunter-Gatherer Children Learn Subsistence Skills? *Human Nature, 28*(4), 367-394. https://doi.org/10.1007/s12110-017-9302-2

Lis, C., Soly, H., & Mitzman, L. (1994). “An Irresistible Phalanx”: Journeymen Associations in Western Europe, 1300–1800. *International Review of Social History, 39*(S2), 11-52. https://doi.org/10.1017/S0020859000112921

Losey, R. J., & Hull, E. (2019). Learning to use atlatls: equipment scaling and enskilment on the Oregon Coast. *Antiquity*, *93*(372), 1569–1585. https://doi.org/10.15184/aqy.2019.172

Lucas, A. J. *et al.* (2020). The value of teaching increases with tool complexity in cumulative cultural evolution. *Proceedings of the Royal Society B: Biological Sciences* **287**, 20201885, doi:doi:10.1098/rspb.2020.1885.

Marquet, P. A., Santoro, C. M., Latorre, C., Standen, V. G., Abades, S. n. R., Rivadeneira, M. M., Hochberg, M. E. (2012). Emergence of social complexity among coastal hunter-gatherers in the Atacama Desert of northern Chile. *Proceedings of the National Academy of Sciences, 109*(37), 14754-14760. doi:10.1073/pnas.1116724109

Mesoudi, A. (2011, Sep). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused [Article]. *Evolution and Human Behavior, 32*(5), 334-342. <Go to ISI>://WOS:000294105300005

Migliano, A. B., Page, A. E., Gómez-Gardeñes, J., Salali, G. D., Viguier, S., Dyble, M., Thompson, J., Chaudhary, N., Smith, D., Strods, J., Mace, R., Thomas, M. G., Latora, V., & Vinicius, L. (2017, 2017/02/08). Characterization of hunter-gatherer networks and implications for cumulative culture. *Nature Human Behaviour, 1*(2), 0043. https://doi.org/10.1038/s41562-016-0043

Miton, H. & Charbonneau, M. (2018). Cumulative culture in the laboratory: methodological and theoretical challenges. *Proceedings of the Royal Society B: Biological Sciences* **285**, 20180677, doi:10.1098/rspb.2018.0677 (2018).

Morgan, T. J. H., Rendell, L. E., Ehn, M., Hoppitt, W., & Laland, K. N. (2012). The evolutionary basis of human social learning. *Proceedings of the Royal Society B-Biological Sciences, 279*(1729), 653-662. <Go to ISI>://WOS:000299114100005

Morgan, T. J. H., Uomini, N. T., Rendell, L. E., Chouinard-Thuly, L., Street, S. E., Lewis, H. M., Cross, C. P., Evans, C., Kearney, R., Torre, I. De, Whiten, A., & Laland, K. N. (2015). Experimental evidence for the co-evolution of hominin tool-making teaching and language. *Nature Communications*, *6*, 1–8. https://doi.org/10.1038/ncomms7029

Muthukrishna, M., Shulman, B. W., Vasilescu, V., & Henrich, J. (2014, January 7, 2014). Sociality influences cultural complexity. *Proceedings of the Royal Society B: Biological Sciences, 281*(1774), 20132511. https://doi.org/10.1098/rspb.2013.2511

Nonaka, T., Bril, B., & Rein, R. (2010). How do stone knappers predict and control the outcome of flaking? Implications for understanding early stone tool technology. *Journal of Human Evolution*, *59*(2), 155–167. https://doi.org/DOI 10.1016/j.jhevol.2010.04.006

Pargeter, J., Khreisheh, N., Shea, J. J., & Stout, D. (2020). Knowledge vs. know-how? Dissecting the foundations of stone knapping skill. *Journal of Human Evolution, 145*, 102807. https://doi.org/https://doi.org/10.1016/j.jhevol.2020.102807

Pargeter, J., Liu, C., Kilgore, M. B., Majoe, A., & Stout, D. (2022). Testing the Effect of Learning Conditions and Individual Motor/Cognitive Differences on Knapping Skill Acquisition. *Journal of Archaeological Method and Theory*. https://doi.org/10.1007/s10816-022-09592-4

Pelegrin, J. (1993). Framework for analyzing prehistoric stone tool manufacture and a tentative application to some early stone industries. In A. Berthelet & J. Chavaillon (Eds.), *The Use of tools by human and non-human primates* (pp. 302–314). Clarendon.

Perreault, C. (2012). The Pace of Cultural Evolution. *PLOS ONE*, *7*(9). https://doi.org/10.1371/journal.pone.0045150

Powell, A., Shennan, S., & Thomas, M. G. (2009). Late Pleistocene Demography and the Appearance of Modern Human Behavior [Article]. *Science, 324*(5932), 1298-1301. <Go to ISI>://WOS:000266635100037

Puri, R. K. (2006). *Deadly Dances in the Bornean Rainforest: Hunting Knowledge of the Penan Benalui*. Brill. https://doi.org/https://doi.org/10.1163/9789004454200

Putt, S. S., Woods, A. D., & Franciscus, R. G. (2014). The Role of Verbal Interaction During Experimental Bifacial Stone Tool Manufacture. *Lithic Technology*, *39*(2), 96–112. https://doi.org/10.1179/0197726114Z.00000000036

Salali, Gul D., Chaudhary, N., Thompson, J., Grace, Olwen M., van der Burgt, Xander M., Dyble, M., Page, Abigail E., Smith, D., Lewis, J., Mace, R., Vinicius, L., & Migliano, Andrea B. (2016). Knowledge-Sharing Networks in Hunter-Gatherers and the Evolution of Cumulative Culture. *Current Biology, 26*(18), 2516-2521. https://doi.org/10.1016/j.cub.2016.07.015

Shennan, S. J., & Steele, J. (1999). Cultural learning in hominids: a behavioural ecological approach. *Mammalian Social Learning: Comparative and Ecological Perspectives.*, 367-388.

Snyder, W. D., Reeves, J. S. & Tennie, C. (2022). Early knapping techniques do not necessitate cultural transmission. *Science Advances* **8**, eabo2894, doi:doi:10.1126/sciadv.abo2894.

Stanley, J., & Krakauer, J. (2013). Motor skill depends on knowledge of facts [Hypothesis and Theory]. *Frontiers in Human Neuroscience, 7*(503). https://doi.org/10.3389/fnhum.2013.00503

Sterelny, K. (2014). *The Evolved Apprentice: How Evolution Made Humans Unique*. MIT Press. https://books.google.com/books?id=ejjJoAEACAAJ

Stout, D. (2005). The social and cultural context of stone-knapping skill acquisition. *Stone knapping: the necessary conditions for a uniquely hominin behaviour*, 331-340.

Tamariz, M. (2019). Replication and emergence in cultural transmission. *Physics of Life Reviews*, *30*, 47–71. https://doi.org/10.1016/j.plrev.2019.04.004

Walker, R., Hill, K., Kaplan, H., & McMillan, G. (2002). Age-dependency in hunting ability among the Ache of Eastern Paraguay. *Journal of Human Evolution, 42*(6), 639-657. https://doi.org/https://doi.org/10.1006/jhev.2001.0541

Wallace, E., & Hoebel, E. A. (1986). *The Comanches: Lords of the South Plains*. University of Oklahoma Press. https://books.google.fr/books?id=u21D6CakZHIC

Whiten, A. (2015). Experimental studies illuminate the cultural transmission of percussive technologies in Homo and Pan. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*. https://doi.org/10.1098/rstb.2014.0359

Whittaker, J. C. (2013). Comparing Atlatls and Bows: Accuracy and Learning Curve. *Ethnoarchaeology*, *5*(2), 100–111.

https://doi.org/10.1179/1944289013z.0000000009

Wisdom, T. N., Song, X., & Goldstone, R. L. (2013). Social Learning Strategies in Networked Groups. *Cognitive Science, 37*(8), 1383-1425. Retrieved from http://dx.doi.org/10.1111/cogs.12052