Cumulative Cultural Evolution from a Psychological Perspective: Theoretical Development and Integration of Explanatory Schools

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Abstract

Cumulative cultural evolution represents an important subset of cultural evolution, focusing on the gradual accumulation of culture and referring to adaptive changes in aspects such as complexity and efficiency that occur during cultural transmission and modification. Although cumulative cultural evolution constitutes an interdisciplinary concept, it possesses strong psychological undertones. Psychological factors, particularly cognitive factors, occupy a significant position in the development of its conceptual framework and explanatory approaches, and the emphasis on cognition has driven theoretical development and the integration of explanatory schools within cumulative cultural evolution. Future research may further clarify the measurement criteria for cumulative cultural evolution from a theoretical development perspective, investigate the processes and details of cumulative cultural evolution from an explanatory integration perspective, and more deeply examine the influence of psychological factors on cumulative cultural evolution from a psychological perspective.

Full Text

Preamble

Cumulative Cultural Evolution from a Psychological Perspective: Theoretical Development and Integration of Schools

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Abstract

Cumulative cultural evolution represents a significant subset of cultural evolution, focusing specifically on the gradual accumulation of culture. It refers to adaptive changes in complexity, efficiency, and other dimensions that occur as culture is transmitted and modified over time. Although cumulative cultural evolution is an interdisciplinary concept, it possesses a strong psychological foundation. Psychological factors—particularly cognitive factors—have occupied a central position in the development of its conceptual framework and explanatory schools, and this emphasis on cognition has driven theoretical advances and integration within the field. Future research could further clarify the measurement criteria for cumulative cultural evolution from a theoretical development perspective, investigate its processes and details through the integration of explanatory schools, and more deeply examine the influence of psychological factors on cumulative cultural evolution.

Keywords: cumulative cultural evolution, cultural evolution, explanatory schools, ratcheting effect, mountaineering effect
Classification: B849: C91

The renowned German physicist Max Planck once observed that "science is inherently a whole; its division into separate departments is not due to the nature of things, but to the limitations of human cognitive capacity. In reality, there exists a continuous chain from physics to chemistry, through biology and anthropology to the social sciences" (Planck, 1975). Interdisciplinary and cross-scientific research has attracted considerable scholarly attention (Lu, 2005; Suo & Xiao, 2023). From an interdisciplinary perspective, cultural evolution research—inspired by biological evolution theory—occupies the intersection of natural and social sciences, holding significance for natural sciences, humanities, social sciences, and psychology as an intermediary science. It extends the applicability of evolutionary theory from biological evolution to the sociocultural domain, enhancing the extrapolative power of a theory originally confined to natural sciences. Simultaneously, the introduction of evolutionary theory enables the internal mechanisms of cultural change to be explored through empirical methods, thereby increasing the verifiability of humanities and social science research. Moreover, cultural evolution research reveals how human behavior and decision-making patterns are shaped by psychological factors, as well as the mechanisms underlying psychological change. As Baumard et al. (2024) note: "Cultural artifacts from the past, like cognitive fossils, preserve the psychological imprints of those long gone, allowing us to trace the deep and shallow psychological changes throughout history." This cross-disciplinary integration not only enriches the content of each discipline but also promotes a deeper understanding of cultural complexity and diversity.

In the field of cultural evolution, culture is defined as all information that can influence individual behavior, including beliefs, knowledge, tools, technologies, attitudes, norms, and language—information that can be acquired from other

group members through various forms of social transmission (Chen & Xie, 2020; Mesoudi, 2017). This mode of information acquisition is termed social learning: learning by individuals influenced by other group members, whether through observing others' behavior or through interaction with them (Heyes, 1994). In this context, the "individuals" acquiring information are not limited to humans but include animals as well. Furthermore, in cultural evolution research, culture is divided into material culture and social culture (Fay et al., 2018). The former focuses on technical cultural information with clear internal physical causal logic, such as tool-making; the latter emphasizes non-technical cultural information based on social customs and interpersonal agreements, such as customs and aesthetics.

Cumulative Cultural Evolution (CCE) constitutes an important subset of cultural evolution, focusing specifically on gradual cultural accumulation. It refers to adaptive changes in complexity, efficiency, and other aspects that occur as culture is transmitted and modified over time (Yang et al., 2023; Buskell, 2022; Mesoudi & Thornton, 2018). The result of cultural accumulation represents the sum of biased selections and modifications made by groups in adapting to their environment (including both social and natural environments). Unlike the broader concept of cultural evolution, cumulative cultural evolution was initially proposed to explain the uniqueness of human culture (Boesch & Tomasello, 1998; Tomasello, 1990). However, as research has expanded and deepened, some scholars have incorporated certain non-human cultural accumulation phenomena into the scope of cumulative cultural evolution, demonstrating new theoretical developments in this area (Mesoudi & Thornton, 2018). Meanwhile, theoretical advances are also evident in the shift from characterizing cumulative cultural evolution as a single-directional, continuous improvement to recognizing it as an overall trend improvement encompassing multiple directions (Lombard, 2016). Additionally, current explanatory schools in cumulative cultural evolution are primarily divided into two factions: one derived from natural selection theory, proposing a cultural selection perspective; the other grounded in cognitive science, emphasizing the shaping role of cognitive factors, particularly individual cognitive factors. Each school maintains its own position while overlapping to some extent. In recent years, researchers have attempted to integrate these two schools from both theoretical and empirical perspectives (Heyes et al., 2022a; Mesoudi, 2021; Osiurak et al., 2022). The development of theoretical concepts and explanatory schools has endowed this field with vibrant intellectual vitality. Specifically, this paper adopts a psychological perspective, first 梳理 ing the developmental trajectory of cumulative cultural evolution theory, then elaborating on the two explanatory schools in this field, exploring in depth the approaches to integrating different schools, and finally considering potential directions for future empirical research. We hope that future psychological research will continue to delve deeper into this field, providing more empirical evidence to support theoretical development.

2. The Proposal and Development of Cumulative Cultural Evolution Theory

2.1 Initial Theoretical Establishment and Empirical Testing

As early as the 1980s, Boyd and Richerson (1985) proposed the "dual-inheritance theory" through mathematical modeling based on Darwin' s theory of biological evolution. This model suggested that culture, like genes, is inheritable in specific social environments and generates new possibilities during transmission. Under the influence of dual-inheritance theory, this "gradual improvement" in cultural evolution gradually formed the conceptual consensus of "cumulative cultural evolution" (Fracchia & Lewontin, 1999; Tomasello, 2000). Initially, Tomasello (1990) used the directionally irreversible ratchet as a metaphor for cumulative cultural evolution, coining the term "ratcheting effect." This concept describes the fundamental nature of cumulative cultural evolution: through social learning, cultural information can be transmitted from one generation to the next, gradually accumulating to produce collective-level adaptations such as more effective technologies or more complex structures. Due to the necessity of information transmission in this process, social learning mechanisms (such as imitation and teaching) received significant attention during this stage (Boyd & Richerson, 1996; Castro & Toro, 2004; Tomasello et al., 1993).

In terms of empirical research, scholars have categorized experimental methods for studying cumulative cultural evolution into three types (Xin & Liu, 2012; Yang et al., 2023; Mesoudi & Whiten, 2008). The first is the single-subject experimental method, which analyzes changes in data from a single subject performing the same task multiple times. The second is the "micro-society" experimental method, also known as the "transmission chain" design, which simulates intergenerational cultural transmission in laboratory conditions using different subjects (for example, starting with the first subject and proceeding sequentially to the last, with each subject' s experimental results being passed to the next adjacent subject). The third involves using computer modeling to simulate cultural development trends. Early experimental studies demonstrated that with the transmission of cultural information, the flight distance of paper airplanes and the height of handmade towers showed cumulative improvement (Caldwell & Millen, 2008).

Subsequently, an increasing number of researchers have verified cumulative cultural evolution in laboratory settings (Caldwell & Millen, 2010; Dean et al., 2012; Derex et al., 2013; Tan & Fay, 2011) and further explored social learning mechanisms related to imitation, simulation, and teaching (Chen & Xie, 2020; Morgan et al., 2015; Reindl et al., 2017; Wasielewski, 2014).

2.2 Development of Criteria for Cumulative Cultural Evolution

Cumulative cultural evolution was initially proposed to explain the uniqueness of human culture (Boesch & Tomasello, 1998; Tomasello, 2000). Early researchers attributed laboratory learning failures in chimpanzees to behavioral

conservatism—that is, their difficulty in abandoning learned behaviors to accept new ones—and suggested that such conservatism might potentially inhibit cumulative cultural evolution in this species (Marshall-Pescini & Whiten, 2008). Subsequent studies also found that young children demonstrated superior cumulative cultural learning effects compared to chimpanzees and capuchin monkeys in completing complex laboratory tasks (Dean et al., 2012). Consequently, some scholars viewed cumulative cultural evolution as capable of explaining developmental differences between human culture and that of other species (Henrich, 2015). However, as exploration of this field deepened, researchers discovered that some non-human cultures also exhibited cumulative improvement trends. For instance, Alem et al. (2016) found in laboratory settings that bees could acquire new food-obtaining skills through observation, and that these skills could spread throughout bee populations. Sasaki and Biro (2017) examined homing route selection in pigeons, with results showing cumulative improvement in route selection efficiency (later generations chose shorter routes compared to earlier ones). These findings challenged earlier explanations of the scope of cumulative cultural evolution, prompting some researchers to consider how to further refine the concept.

2.2.1 Core Criteria for Cumulative Cultural Evolution Mesoudi and Thornton (2018) comprehensively examined 35 definitions of cumulative cultural evolution from previous theoretical and empirical work and, based on existing empirical evidence and the "ratcheting effect" description, proposed a set of core criteria applicable to both humans and non-humans. These criteria are: (1) modification of existing behaviors or cultural products, or emergence of new behaviors or products; (2) transmission of these behaviors or products through social learning; (3) improvement of cultural behaviors and products during transmission, manifested as enhanced cultural adaptability (such as behaviors better suited to the environment, optimized product performance, or increased aesthetic value); and (4) repetition of the first three steps over time, resulting in continuous cultural improvement. In summary, behaviors or cultural products are transmitted across generations through social learning and undergo sustained improvement over time.

These core criteria function as a baseline standard and have since been widely applied in empirical research as 判定 criteria. That is, if all four core criteria are simultaneously satisfied, cumulative cultural evolution can be said to exist. For example, in a paper airplane construction task, subsequent participants can view paper airplanes made by previous participants (criterion 2), newly made airplanes show improvement based on predecessors' work (criterion 1) with increased flight distance (criterion 3), and studies have found that paper airplane flight distance increases along the transmission chain (criterion 4) (Fay et al., 2019). Notably, due to the universality of these core criteria, many subsequent researchers studying non-human subjects have also used them as reference standards (Gruber et al., 2021; Whiten et al., 2022). For instance, sparrows learn songs from conspecifics (criterion 2), after social learning different

notes are combined to form new songs (criterion 1), over time notes evolve into syllables and then into complete songs (criterion 3), and song complexity and clarity gradually increase (criterion 4) (Williams & Lachlan, 2021). Similarly, after quantitative processing and evaluation of humpback whale population song records, research has found that new song material emerges in humpback whale groups (criterion 1), songs gradually spread within populations (criterion 2) and become increasingly complex (criterion 3), and over nine years of records show that repetition of these three processes increases song attractiveness (criterion 4) (Garland et al., 2022). Additionally, recent field research documented that in wild chimpanzee communities, a social custom of "handshake grooming" exists, with younger chimpanzees using more new types of handshakes than older individuals (criterion 1), mothers teaching this custom to their offspring (criterion 2), this custom gradually converging within the chimpanzee group over 12 years (criterion 4), and exhibiting group survival adaptability (criterion 3) (van Leeuwen & Hoppitt, 2023).

Although the core criteria have become important 判定 standards in empirical research, understanding cumulative cultural evolution within the "ratcheting effect" framework remains limited. The "ratcheting effect" overemphasizes the role of social learning, yet individual cognition also plays a significant role in the process of cumulative cultural evolution (Osiurak & Reynaud, 2020). For example, cognitive flexibility and technical reasoning skills can identify novel, adaptive solutions amid changing task demands (Bluet et al., 2022; Davis et al., 2022). These elements are not reflected in the "ratcheting effect" framework. In Vale et al.' s (2022) view, social learning can only ensure the transmission of cultural information, but this information processing is rudimentary; only higher-level cognitive abilities (such as understanding physical principles) can bring about breakthroughs and innovations in cultural products, facilitating cumulative cultural evolution. Consequently, researchers have gradually recognized that in addition to social learning, individual cognitive factors also play an important role in cumulative cultural evolution (Osiurak et al., 2023; Vale et al., 2022), leading to extensions of the core criteria for cumulative cultural evolution.

2.2.2 Extensions of Core Criteria for Cumulative Cultural Evolution
With the rise of cognitive science, researchers have increasingly emphasized the role of individual cognitive factors. Lombard (2016), using examples from hunting-era weapon types (e.g., spears, bows and arrows) and functions (e.g., offense, defense), highlighted the important role of cognitive flexibility in cumulative cultural evolution. In his view, the "ratcheting effect"describes cumulative cultural evolution as having a fixed and singular direction, unable to explain the diversity of cultural change directions resulting from cognitive flexibility. Using the "mountaineering effect" provides a better metaphor for cumulative cultural evolution (Lombard, 2016). Specifically, culture may experience stagnation, redirection, or regression during development. In certain situations, abandoning or modifying predecessors' cultural behaviors to achieve goals can be viewed

as flexible adaptation to the environment. Just as when climbing toward a mountain peak, the route does not proceed straight forward due to various environmental or human factors but involves turns, backtracking, or detours.

Based on the "mountaineering effect," Haidle and Schlaudt (2020) extended the core criteria for cumulative cultural evolution: (1) development and change in individual (cultural) behavior; (2) changes in natural or social learning environments, with transmission of new (cultural) behaviors in the altered environment; (3) learned behaviors leading to performance changes that provide both possibilities and constraints for future development; and (4) repetition of the above steps over time to produce cumulative development.

This extended framework incorporates two new perspectives. First, in stating the third criterion, the core criteria describe learned new behaviors as causing "improvement" in performance (Mesoudi & Thornton, 2018), whereas Haidle and Schlaudt (2020) argue that learned new behaviors cause "alteration" in performance, as new behavioral transmission may either facilitate current cultural goal achievement or create obstacles, much like taking a detour while mountain climbing. Of course, from the perspective of evolutionary outcomes, the overall trend remains upward development. Notably, in the specific process of development, researchers propose constraints on future development to illustrate that cultural products do not necessarily become increasingly complex or efficient over time. This also lays the groundwork for later researchers to propose different cultural accumulation trends, which will be elaborated in subsequent evaluations.

Second, Haidle and Schlaudt (2020) fully incorporate an interactive perspective between transmission subjects and their environment into the concept of cumulative cultural evolution, suggesting that subjects can appropriately adjust their processing of cultural information according to environmental changes, thereby fully demonstrating the importance of individual cognitive factors in cumulative cultural evolution (Fay et al., 2021; Reindl et al., 2020). For example, Wilks et al. (2021) used a multi-round search game to explore how working memory affects children' s cumulative performance under different environmental cues. Researchers divided environmental cues into long-term cues (where cue prompts remained present throughout each round) and short-term cues (where cue prompts appeared once and then disappeared in each round), while measuring children' s working memory capacity. Experimental results showed that under long-term cue conditions, all children displayed cumulative cultural trends in their performance. Under short-term cue conditions, only children with stronger working memory capacity showed better performance.

2.3 Significance and Evaluation of Theoretical Development in Cumulative Cultural Evolution

From the initial "ratcheting effect" to the later "mountaineering effect," the refined theory better aligns with cultural evolution processes from a macro per-

spective (a comparison of the two conceptual frameworks appears in Table 1), helping people understand cumulative cultural evolution more comprehensively and systematically, and enhancing the explanatory power of cumulative cultural evolution theory—cultural accumulation does not proceed entirely through continuous addition, and cumulative cultural evolution can explain both continuous and discontinuous cultural development (Kolodny et al., 2015; Vidiella et al., 2022). This can be understood from two aspects.

First, cultural accumulation trends are diverse. Buskell (2022) argues that early descriptions of cumulative development were overly general, and he specifically categorizes cumulative development trends into four types: adaptiveness, complexity, efficiency, and disparity. Adaptiveness concerns how technologies, customs, etc., generated during cultural evolution help individuals better adapt to natural or social environments over time. Complexity involves cultural products becoming more refined and diversified over time. Efficiency refers to the economy and effectiveness of cultural products in performing specific functions. Disparity emphasizes the diversity and uniqueness among cultural products. Notably, cultural accumulation trends do not necessarily manifest simultaneously in all these dimensions. For example, adaptiveness does not necessarily entail complexity. Varnum et al. (2021) evaluated 14,661 American popular songs from 1958 to 2016 and found that as music genre variety increased in the market, popular song lyrics became simpler, because when new song choices multiplied, songs with simpler lyrics that reduced cognitive load were more easily transmitted. Meanwhile, there are also examples where cultural accumulation trends simultaneously reflect both adaptiveness and complexity, such as research showing that with economic development, people could break free from family relationship constraints to pursue free love, and in adapting to this new environment, romantic elements in literary novels gradually increased, making love stories increasingly complex (Baumard et al., 2022).

Second, cultural improvement processes are not necessarily continuous. Certain cultures may stagnate due to historical or natural factors (such as social turmoil or epidemic spread), but later these cultural features may be reutilized, and improvements based on new experiences make the cultural products themselves more vibrant, which also signifies the existence of cumulative cultural evolution (Haidle & Schlaudt, 2021). A typical example is the Renaissance that occurred from the 14th to 16th centuries. After Western classical culture flourished in antiquity, it suffered significant damage during the medieval "Dark Ages" due to church control and epidemic devastation. However, through athletic competitions, theatrical performances, public speeches, and other means, large amounts of Western classical culture were transmitted among the Italian populace (Xie, 2016). The Renaissance, originating in Italy, greatly promoted global cultural development, with some works remaining cornerstones of the art world to this day.

Table 1 Comparison of the "Ratcheting Effect" and "Mountaineering Effect" Conceptual Frameworks

Dimension	Ratcheting Effect	Mountaineering Effect
Perspective	Describes cumulative cultural evolution as a unidirectional, continuous improvement process.	Describes cumulative cultural evolution as a diverse, holistic improvement process.
Theoretical Foundation	Based on natural selection theory, emphasizing the importance of fidelity in cultural information transmission and the role of social learning mechanisms.	Incorporates cognitive science perspectives on top of the ratcheting effect, emphasizing individual cognitive processing of information in addition to social learning.
Core Criteria (Mesoudi & Thornton, 2018)	(1) Modification of existing behaviors/products or emergence of new ones; (2) Transmission through social learning; (3) Improvement during transmission, shown as enhanced adaptability; (4) Continuous improvement through repetition.	–
Extended Core Criteria (Haidle & Schlaudt, 2020)	–	(1) Development and change in individual behavior; (2) Environmental changes with transmission in altered contexts; (3) Performance alterations providing possibilities and constraints; (4) Cumulative development through repetition.
Significance	Establishes foundational framework; focuses on high-fidelity transmission.	Provides broader perspective; acknowledges complexity and diversity; emphasizes cognitive factors.

Source: Compiled by the authors

3. Two Explanatory Schools of Cumulative Cultural Evolution: The "California School" and the "Paris School"

Beyond the development of 判定 criteria for cumulative cultural evolution, explaining the process itself represents a deeper question—one that involves how individuals select, transmit, and modify specific information from existing cultural resources. From the "ratcheting effect" to the "mountaineering effect," the role of cognitive factors in cumulative cultural evolution has gained increasing attention. Under the ratcheting effect framework, social learning mechanisms (such as observational learning, imitation, and teaching) reliably ensure faithful cultural information transmission (Yang et al., 2023; Tomasello et al., 1993). Under the mountaineering effect framework, individual cognitive abilities of transmission subjects (such as cognitive flexibility and technical reasoning) have gradually gained prominence (Bluet et al., 2022; Davis et al., 2022). How these psychologically relevant factors combine to explain cumulative cultural evolution has currently formed two major theoretical schools—the "California School" (emphasizing cultural selection and preservation) and the "Paris School" (emphasizing cultural modification and transformation). Both schools agree that cultural achievements humans have attained in various ecological niches depend on the accumulation of cultural learning over time (Sterelny, 2017), but they differ in their emphasis when explaining the essential processes and directional stability of cumulative cultural evolution. Like the conceptual framework' s developmental trajectory, the evolution of explanatory schools has gradually broken free from the constraints of natural selection theory, placing greater emphasis on the shaping role of cognitive factors, particularly individual cognitive factors.

3.1 The "California School" Perspective and Related Research

3.1.1 The "California School" Perspective The "California School" perspective, also known as the "traditional" view, is influenced by natural selection theory and treats cultural evolution as a preservation mechanism—much like genetic inheritance, cultural transmission represents the inheritance of culture from one generation to the next (Boyd & Richerson, 1985). Specifically, through selection of predecessors' cultural information, the selected culture is transmitted relatively intact across multiple generations, ultimately forming gradual cultural development. This process is called cultural selection (Mesoudi, 2021). For example, in agricultural culture, people through generations of selection of various crops not only cultivated varieties suited to local climate and soil but also increased crop yields. The California School emphasizes that during evolution, transmitted cultural information should be as complete and undamaged as possible—that is, transmitted with high fidelity (Boyd & Richerson, 1985).

From a realistic perspective, however, not all culture is preserved and transmitted. Therefore, a key question in the cultural selection process is: what kind of cultural information is more likely to be transmitted? Scholars in this school argue that cultural selection is influenced by people' s subjective psychologi-

cal tendencies (Singh, 2022), which cause some cultural information to appear more frequently in populations than other information. Some cultural information content possesses natural transmission advantages, known as content bias in the cultural selection process. Beyond content bias, the cultural selection process also exhibits context bias, where cultural transmission is influenced by circumstances beyond the cultural content itself (Chen & Xie, 2020; Henrich & McElreath, 2007). For example, information endorsed by the majority (regardless of actual content) has greater transmission advantage.

In summary, from the California School' s perspective, because people are influenced by psychological tendencies that make specific cultural information more easily transmitted, and social learning ensures the fidelity of this selected information, the combination of these factors produces adaptive changes in learned cultural behaviors or products during transmission, manifesting as cumulative cultural evolution (Henrich & McElreath, 2007).

3.1.2 Related Research A considerable number of cumulative cultural evolution studies have explored social learning mechanisms and their boundary conditions (Yang et al., 2023). Existing research shows that in tasks involving manual construction of transportation tools, if the production process is simple, imitation, simulation, and teaching all equally promote cumulative cultural evolution; if the production process is difficult, teaching demonstrates stronger promotional effects (Lucas et al., 2020).

Regarding content bias, Eriksson and Coultas (2014) studied the transmission of stories evoking different levels of disgust, finding that stories containing highly disgusting elements received more selection and retention. Subsequent transmission chain studies showed that stories containing negative information (such as someone being ill) had higher preservation rates during transmission than stories containing positive or neutral information (Bebbington et al., 2017). Similarly, people prefer to transmit information containing threatening elements (such as products causing allergic reactions) over positive or neutral elements (Blaine & Boyer, 2018). This may be because such information elicits stronger emotional responses in recipients (Horner et al., 2021), which from an evolutionary perspective is adaptive in helping avoid risks.

Regarding context bias, researchers have conducted empirical studies on success and prestige biases, conformity bias, and naturalness bias. Osiurak, Cretel et al. (2020) used the fixed-group method (a type of micro-society experimental design for cumulative cultural evolution where multiple group members make multiple attempts to solve the same task) to examine the effects of technical reasoning ability, theory-of-mind skills, and agreeableness on task performance. Results showed that people tend to learn from individuals with high technical reasoning ability (because they complete tasks more successfully). Similarly, using the fixed-group method, a study employing a group quiz game demonstrated that when direct success cues are absent, participants tend to use prestige bias for social learning (Brand et al., 2020). Moreover, this prestige-based social

learning also exists in non-human species (Lee & Yamamoto, 2023). Other researchers compiled music sampling data from 1987 to 2018 (where musicians process portions of existing songs for use in new compositions), involving 14,387 artists who used 38,500 samples from 1,463 sample sources. Analysis results showed that artists were more likely to choose more popular samples, indicating conformity bias in music sampling (Youngblood, 2019). Notably, people' s preference for naturalness—such as preferring natural over synthetic drugs (Li & Cao, 2020), being more willing to purchase natural foods (d' Astous & Labrecque, 2021), and valuing gifted individuals more highly (Ma et al., 2023) —is considered naturalness bias (Zhang & Yu, 2023).

3.2 The "Paris School" Perspective and Related Research

3.2.1 The "Paris School"Perspective If the California School views cultural accumulation over time as a preservation mechanism formed through cultural selection, then the other explanatory school of cultural evolution, the "Paris School," treats this as a transformative process. Originating from cognitive science and psychology, the Paris School emphasizes the role of cognitive factors in shaping cultural differences and regularities, arguing that cognitive factors reconstruct cultural information in meaningful ways, thereby influencing the process of cumulative cultural evolution (Sperber, 1996). The Paris School challenges cultural selection guided by natural selection theory, arguing that natural selection used to explain gene replication cannot be transferred to explain cultural evolution (Acerbi & Mesoudi, 2015). According to the Paris School, the main cause of cumulative cultural development is individuals' agency in modifying learned cultural information in a particular direction, causing cultural traits to converge on specific types or trends. This process is called biased transformation (Mesoudi, 2021).

Regarding the direction of cultural trait transformation, some Paris School scholars committed to finding causal explanations for cultural phenomena have proposed Cultural Attraction Theory (CAT), which posits that cultural attractors create individuals' internal tendencies to modify culture (Sperber, 1996). Cultural attractors include psychological factors (such as cognitive mechanisms and psychological susceptibilities) and ecological factors (such as pathogens and climate) (Scott-Phillips et al., 2018). Psychological factors are also described as cognitive attractors in some studies (Baumard & Dubourg, 2022; Morin, 2013).

In essence, the core of the Paris School lies in viewing cumulative cultural evolution as a process of biased cultural transformation guided by cultural attractors—an important distinction from the California School, which emphasizes only cultural preservation. In this process, cultural changes and even reconstructions are influenced by universal cognitive mechanisms or ecological environments, causing cultural traits to gradually converge and ultimately facilitating cumulative cultural evolution.

3.2.2 Related Research Regarding psychological factors, Morin (2013) analyzed European portrait oil paintings from the Renaissance period, finding that during this era, subjects' gazes gradually evolved to direct staring, and that portraits with direct gaze were more likely to be considered "best" because this aesthetic preference for direct gaze was considered to have cognitive attraction. Subsequently, Miton et al. (2015) used anthropological data and transmission chain studies to find that different bloodletting treatment modes could be found in various cultures worldwide, and that compared to other treatment methods, the concept of bloodletting could be stably transmitted even in cultures that did not advocate it. In other words, regarding bloodletting, there exists a universal cognitive mechanism (i.e., psychological factor) that leads people to adopt bloodletting as a treatment method, such as the desire to have "bad things" leave the body (Miton et al., 2015).

Furthermore, cognitive factors' shaping, modification, and even reconstruction of cultural information are evident in various cumulative cultural evolution studies. In the domain of social culture, modeling analysis of divination ethnography shows that divination can be considered a cognitive practice activity. As divination proceeds, diviners update their beliefs by combining prior experience with actual outcomes—that is, they undergo cognitive reconstruction, making certain divination result interpretations more explanatory (Hong & Henrich, 2021). The developmental trend of filial piety concepts in a global context also shows characteristics of cognitive reconstruction, with people' s understanding frameworks shifting from sociocultural norms and values to internal psychological mechanisms of parent-child interaction (such as authoritarianism and reciprocity) (Bedford & Yeh, 2021). In the domain of material culture, researchers emphasize the facilitating role of cognitive factors (Harris et al., 2021; Osiurak et al., 2023). Laboratory studies have found that 3- to 5-year-old children can rely on their own cognitive reasoning abilities, independent of social learning mechanisms (such as teaching and imitation), to gradually and independently solve cumulative cultural puzzle-box tasks (Reindl et al., 2020). Osiurak et al. used transmission chain experiments to repeatedly verify that individuals' technical reasoning cognitive abilities not only help improve product performance but also positively promote understanding of the physical principles behind products (Osiurak, De Oliveira et al., 2020; Osiurak et al., 2021).

Regarding ecological factors, current empirical research has focused on how different environmental factors (such as pathogens, climate, and geological conditions) influence the evolution of cultural values. Pathogens importantly influence the formation of cultural values; for example, the higher the infectious disease prevalence in a region, the more likely people living there are to coordinate and gradually evolve collectivist values (Chen & Xie, 2023). Ecological data from 155 countries show that extreme climate is closely related to cultural creativity because under excessively hot and cold conditions, indigenous peoples across generations need innovative solutions to survival problems, such as obtaining and preserving food to cope with extreme weather (Van de Vliert & Murray, 2018). Similarly, climate affects narrative preferences; after cod-

ing personal oral histories from 106 U.S. cities, researchers found that personal oral histories from cities with harsher climates and greater temperature fluctuations contained more redemption themes (Jones & Kerr, 2023). Finally, geological conditions also affect cumulative cultural evolution. Buildings in the Himalayan seismic zone often use wooden frame structures and brick-stone walls, with durable and recyclable construction materials, symmetrical overall design, and weight-minimizing considerations. These features developed from locals' long-term experience in earthquake-resistant activities, reflecting centuries of earthquake awareness in local culture (Bothara et al., 2022).

3.3 Summary

Overall, the California School focuses more on the preservation process of culture, emphasizing high-fidelity transmission of cultural products and the social learning mechanisms that promote such transmission. Through cultural selection, selected cultural information obtains high-fidelity transmission during intergenerational social learning. The Paris School, conversely, focuses more on the transformation process of culture, emphasizing biased transformation of cultural products during transmission, with particular attention to psychological and ecological factors involved. Through biased transformation, cultural information is continuously modified and reconstructed during transmission, ultimately converging in a consistent direction.

4. Integration of Explanatory Schools

4.1 Necessity and Possibility of School Integration

According to the conceptual descriptions of cumulative cultural evolution in both the "ratcheting effect" and "mountaineering effect," cultural transmission in cumulative cultural evolution involves both selective inheritance from previous generations and adaptive modification during transmission (Haidle & Schlaudt, 2020; Mesoudi & Thornton, 2018). Therefore, adopting a more systematic perspective to integrate the California School, which emphasizes cultural preservation, and the Paris School, which emphasizes cultural transformation, will not only help generate more valuable and complete explanatory theories and promote conceptual development but also provide ideas and directions for relevant empirical research.

Recently, researchers proposed the Bifocal Stance Theory to encompass both the preservation and transformation mechanisms emphasized by the two schools (Heyes et al., 2022a). This theory suggests that preservation and modification cultural behaviors depend on individuals' flexible use and transformation between instrumental and ritual stances during transmission. The instrumental stance focuses on goal-directedness and utility of behavior, emphasizing understanding and improvement to achieve specific goals, tending toward high innovation, adaptive modification, and low copying fidelity. The ritual stance focuses on the ritualistic and normative aspects of behavior, emphasizing social integra-

tion and relationship building, tending toward high copying fidelity, stability maintenance, and low modification innovation. Bifocal Stance Theory posits that these two stances are not mutually exclusive but complementary. Innovations and modifications under the instrumental stance require stabilization and accumulation through high-fidelity transmission in the ritual stance. Similarly, culture preserved in the ritual stance can become the foundation for innovation and improvement. Therefore, cumulative cultural evolution can be viewed as the dynamic interaction result of these two stances and their roles in innovative modification and faithful transmission. Moreover, these two stances are environmentally adaptive, manifested as flexible selection and transformation between stances in different contexts under the influence of cognitive factors, which can be either deliberate or subconscious (Heyes et al., 2022a). Bifocal Stance Theory is not only an integration and refinement of the original views of the two schools but also proposes a more inclusive conceptual framework.

Overall, the two explanatory schools do not have sharp conflicts of either/or, and to some extent even intersect. First, certain views of the two schools are closely related. As mentioned earlier, the foundation of social learning emphasized by the California School is cognitive factors (Rendell et al., 2011), while the biased transformation emphasized by the Paris School also includes cognitive factors among psychological factors. Second, some views of the two schools reflect that they are actually addressing the same question from different angles. For example, in describing human-environment interaction, the California School' s context bias perspective focuses on how context influences human selection, while the Paris School' s cognitive perspective focuses on how humans make flexible decisions based on context. Essentially, both describe the same phenomenon, merely changing the subject of focus due to different concerns.

Most crucially, regarding explanations for the stable development results of cultural characteristics, the two schools ultimately reach similar understandings of faithful transmission. The California School represents a bottom-up explanatory approach. In this view, faithful transmission is the goal, reflected in each cultural transmission process. However, in the process of faithful transmission, which information is more easily faithfully transmitted through social learning mechanisms? This is influenced by individual psychological tendencies, manifesting as content and context biases in cultural transmission. The Paris School represents a top-down explanatory approach. Although this school does not use the term "fidelity," insisting that culture converges through biased transformation during intergenerational transmission (Buskell, 2017), from a realistic perspective, the result of cultural information being modified and reconstructed to converge in a particular direction is actually a manifestation of "fidelity." Therefore, whether the California School or the Paris School, under both schools' explanations, cultural cumulative evolution ultimately produces similar results.

Based on the above analysis, a model diagram of the two schools' perspectives can be constructed (see Figure 1 [Figure 1: see original paper]).

Figure 1 Explanatory pathways and corresponding cases for the California

School and Paris School

The left side of the figure shows explanatory pathways, the right side shows cases. Case 1 corresponds to the California School perspective. As shown, in the initial stage of cultural creation, there are five cultural traits. Over time, the initial circular cultural trait with dense dots is selected and copied by more people, increasing in frequency among all cultural information, ultimately showing a stable cultural development trend. Case 2 corresponds to the Paris School perspective. As shown, in the initial stage of cultural creation, there are also five cultural traits. Unlike Case 1, the circular trait with dense dots does not exist initially. These cultural traits are transmitted across generations over time. Although initially different, due to the guidance of cultural attractors, cultural traits are gradually modified (each column represents the modification process of one cultural trait). This biased transformation causes culture to gradually converge toward the circular trait with dense dots, ultimately showing the same stable cultural development trend as Case 1.

Source: Compiled by the authors

4.2 Research on School Integration

The integration of the two explanatory schools represents a frontier direction in this field, and researchers have made efforts in empirical studies, achieving some results. Mesoudi (2021) used computational models to explore the effects of cultural selection (implemented through payoff-biased social learning, i.e., setting model individuals to preferentially select individuals with the highest payoff values in the previous time series) and biased transformation (setting an attractor factor X in the model, unrelated to payoff but causing discrete feature values to aggregate toward X) on cultural evolution within groups (Model 1) and between groups (Model 2). Model 1 results showed that directional changes in cultural evolution could be produced through cultural selection alone, biased transformation alone, or their combined effects. Model 2 results showed that under cultural selection conditions, cultural traits converged within respective groups, producing cross-cultural differences. Under biased transformation conditions, each group converged on a particular cultural trait, producing cross-cultural stability. Therefore, Mesoudi (2021) argued that their combined effects explain cumulative cultural evolution, and that the same psychological mechanisms may underlie both directional changes. These mechanisms cause biased transformation in culture, gradually stabilizing cultural evolution in one direction.

Additional research shows that cognitive abilities such as technical reasoning, like copying, are deeply involved in cumulative cultural evolution processes. Researchers created a wheel-powered device and used a transmission chain design to allow several generations of operators to improve wheel system speed by configuring wheel parameters. Each participant had five attempts, with data from the last two configurations passed to the next participant. After completing all five attempts, participants took a test on their understanding of the

wheel system principles. Results showed that participants' product performance improvements were accompanied by increased understanding of underlying principles (Osiurak et al., 2021). To further empirically explore the California and Paris School perspectives, Osiurak et al. (2022) continued using the wheel power experimental paradigm. In their new experiment, they wanted to know whether, without high-fidelity transmission (i.e., copying), cognitive mechanisms could achieve solution convergence in the same task context. Therefore, they explored the effects of cognitive skills on technological cumulative cultural evolution under non-copying conditions. The experimental apparatus and tasks remained the same. Participants were divided into two groups, each with five attempts. One group could see only the previous participants' last two speed outcomes (speed information only condition), while the other could see both the last two speeds and wheel parameter configurations that had been randomly modified within a certain range (noisy parameter configuration plus speed information condition). After five experimental trials, participants again received a principle understanding test. As can be seen, under these two conditions, subsequent participants received either partial information or information with degraded reference value. If copying were important for technological cumulative cultural evolution, wheel speed improvements should not be observed under either condition. Experimental results showed that wheel speed in both groups improved after several generations of transmission, and participants' understanding of the system principles also increased. Importantly, as the transmission chain progressed, solutions across groups gradually became more similar. This means that high-fidelity transmission may not be fully explained by faithful copying; in similar environmental or goal contexts, biased transformation of culture under the influence of cognitive mechanisms can also gradually approach high-fidelity transmission (Osiurak et al., 2023).

5. Future Research Directions

Cumulative cultural evolution research involves anthropology, psychology, sociology, and even archaeology and ecology. Although this theory has gained general recognition and verification since its proposal, with increasingly clear explanatory scope and gradually strengthening explanatory power, many aspects can still be improved when such a macro concept enters micro-level empirical research. From a theoretical development perspective, conceptual measurement criteria need further clarification and conceptual enrichment. From a school integration perspective, the processes and details of cumulative cultural evolution can be explored from multiple aspects. From a psychological perspective, psychological factors play a non-negligible important role in cumulative cultural evolution, offering psychology researchers multiple avenues for further exploration.

5.1 Clarifying Measurement Criteria for Cumulative Cultural Evolution from a Theoretical Development Perspective

Although the core criteria have become measurement standards for many empirical studies since their proposal, there is still room for improvement in measurement criteria within empirical research when considering the actual circumstances of cumulative cultural evolution. Some researchers argue that cumulative cultural evolution results must be unattainable through individual effort (Boyd & Richerson, 1996; Rawlings et al., 2021), while others do not emphasize this aspect (Haidle & Schlaudt, 2020; Mesoudi & Thornton, 2018). Theoretically, cumulative cultural evolution should develop at the collective level (Haidle, 2019), but in actual research, limited by experimental conditions and tasks themselves, researchers can often only conduct short-term, highly operational tasks. Currently, only a very small number of empirical studies have explicitly included the "unattainable by individuals" criterion (Reindl et al., 2017). The vast majority of studies have not set up individual control groups or have used relatively simple tasks (such as paper airplane folding, clay tower building) (Caldwell & Eve, 2014; Caldwell & Millen, 2008; Lucas et al., 2020), making it impossible to demonstrate that individual performance under sufficient time conditions cannot match group performance. Additionally, the issue of cross-species comparisons in cumulative cultural evolution involves selecting the strictness level of criteria. Based on Mesoudi and Thornton' s (2018) core criteria plus the "unattainable by individuals" criterion, Rawlings et al. (2021) reviewed previous cumulative cultural evolution studies in non-humans, overturning some findings in non-human research.

In summary, to promote further development of cumulative cultural evolution theory, clarifying measurement criteria is essential (Buskell, 2022; Mesoudi & Thornton, 2018). Therefore, the "unattainable by individuals" criterion should be emphasized and considered as part of conceptual connotation in future research. For empirical studies, first, individual control groups should be considered during the research design phase. Second, the total experimental time for individual control group participants should be consistent with that for transmission chain experimental groups, because in existing studies, total time for individual control groups approximately equals task completion time, while total time for transmission chain groups includes both task completion and social learning time (Miton & Charbonneau, 2018). Finally, in reality, most cultural innovations originate from experts or skilled individuals in the field, at least not from complete novices (Haidle, 2019), yet most experimental participants are inexperienced novices (Lucas et al., 2020; Osiurak et al., 2022). Therefore, during participant selection, researchers could consider existing background knowledge or provide training to novices. As participants' baseline levels improve, task complexity can also be increased, which better verifies the "unattainable by individuals" criterion and more closely approximates actual cumulative cultural evolution.

5.2 Exploring Processes and Details of Cumulative Cultural Evolution from a School Integration Perspective

Theoretically, researchers believe that cumulative cultural evolution is a process incorporating both California School and Paris School perspectives (Heyes et al., 2022a; Mesoudi, 2021), but targeted empirical evidence exploring school integration remains insufficient. The newly proposed Bifocal Stance Theory urgently needs verification in future research (Heyes et al., 2022b). To address this issue, future research can strengthen empirical support from two aspects.

First, compared to the material culture domain, the social culture domain has fewer empirical studies, particularly regarding school integration, where almost no relevant research can be found, even though the ritual stance in Bifocal Stance Theory strongly emphasizes the social culture domain (Heyes et al., 2022a). Therefore, to effectively promote school integration, more empirical evidence from the social culture domain is needed. The primary challenge in this research area is quantitatively measuring "changes" that occur in the evolution of social cultural products. Two approaches can address this problem. One is to extract features from the research objects themselves for quantitative analysis. For example, function word analysis can be used in literary cultural evolution research. Domestic researchers analyzing function words in *Dream of the Red Chamber* found differences in writing style between the first 80 chapters and the last 40 chapters, suggesting possible different authors (Liu & Xiao, 2014). Similarly, foreign researchers have used function words as analysis units to explore how famous authors' writing styles changed throughout their lives (Ross, 2020). The other approach is quantitative analysis of background information related to research objects. Taking film art as an example, besides directly using genre or theme-oriented content analysis on the products themselves (Acerbi et al., 2017; Garland et al., 2022), researchers can also examine creative backgrounds for new quantifiable standards. For instance, researchers innovatively used changes in film crew configurations to examine cumulative development in Hollywood films' artistry and content complexity from 1910 to 2010 (Tinits & Sobchuk, 2020). This measurement method can be transferred to other social culture domains in future research, such as traditional rituals.

Second, as previously mentioned, both the California School emphasizing cultural selection and the Paris School emphasizing biased transformation play respective roles in explaining cumulative cultural evolution. To integrate the two schools' perspectives and comprehensively understand the specific occurrence process of cumulative cultural evolution, it is crucial to examine this lengthy process. However, laboratory studies using biological individuals are difficult to complete such vast and complex exploration tasks. With the rise of Artificial Intelligence (AI), besides traditional laboratory experiments, researchers have begun studying the relationship between robot social learning and cumulative cultural evolution (Kuckling, 2023; Whiten et al., 2022). Bredeche and Fontbonne (2021) deployed social learning algorithms in robot swarms, allowing them to capture randomly appearing items in simulated environments. Results

showed that interactive behaviors among robots developed from random and accidental to more directed patterns, indicating that robot swarm social learning can effectively simulate biological social learning. Additionally, a decade-long AI study made breakthrough attempts to explore the internal processes of cumulative cultural evolution. Initial experiments showed that through noisy imitation (not completely faithful), robot swarms produced social learning, leading to new adaptive behaviors. With technological advances, subsequent researchers programmed AI into robots to explore story transmission among robots. In the study, Robot A "told" its story to Robot B, such as "if I turn left I will hit the wall." When Robot B "heard" the story, it would generate corresponding instruction programs internally, simulate and evaluate them. Researchers noted that if stories are transmitted by more robots, robots will have sufficient cognitive mechanisms to generate a "narrative self," and through continuous co-narration, people will learn more details about cumulative cultural evolution (Winfield & Blackmore, 2021). In view of this, future research can rely on the vigorous development of various machine learning algorithms within computational cognitive science to more deeply explore and clarify the internal mechanisms of cumulative cultural evolution across multiple generations, thereby providing solid supporting evidence for school integration.

5.3 Deepening Exploration of Psychological Factors' Influence on Cumulative Cultural Evolution from a Psychological Perspective

Whether involving individual psychological tendencies in the California School perspective or psychological factors in the Paris School perspective, both play important roles in explaining cumulative cultural evolution processes. This means that cumulative cultural evolution research from a psychological perspective has even broader exploration space.

First, beyond the specific examples of content and context biases mentioned above, future research can explore more psychological tendencies affecting cumulative cultural evolution and their boundary conditions. Over the past two centuries, the proportion of novels involving fictional worlds in literature and film has increased regularly (Dubourg et al., 2023). With the rise of virtual games, fictional worlds have become increasingly attractive to young people, possibly related to people' s exploratory preferences (Baumard & Dubourg, 2022). In prosociality research, facial algorithm models have found that trustworthiness in European monarch portraits has increased over six centuries (Guillou et al., 2023). Therefore, future research can use transmission chain methods to examine whether psychological factors such as exploratory preferences and prosocial information preferences influence cumulative cultural evolution. Additionally, the influence of different psychological tendencies may vary across cultural domains. For example, in song evolution history, content bias (the transmission advantage of negative information) better predicts song influence than prestige bias (famous artists' creations) or success bias (hit songs' influence) (Brand et al., 2019), and studies on story transmission have also found transmission ad-

vantages for counterintuitive content (Berl et al., 2021). However, in the fine arts domain, content bias may not have such high influence. Laypeople appreciate artworks based on the artworks' own aesthetic value, whereas experts judge more based on prestige (works from famous museums) (Verpooten & Dewitte, 2017). How these two biases combine to jointly drive the cumulative evolution of human aesthetic mechanisms remains unknown. Therefore, future research can explore the advantages of content and context biases in different cultural domains and the synergistic mechanisms of different bias types in cumulative cultural evolution.

Second, with AI development, machines have gradually infiltrated people' s lives, even beginning to replace humans in some decision-making and work tasks. Some researchers created a human-machine hybrid transmission chain where the second participant in the chain was replaced by a robot that would provide a more effective but costly solution algorithm. Results showed that although this algorithm improved the performance of the immediately following participant, it quickly disappeared as the transmission chain progressed (Brinkmann et al., 2022). This suggests that humans may have a psychological tendency to seek maximum reward with minimum cost, which may offset AI' s influence. However, research on the evolution of professional Go players' decision-making over nearly seven decades shows that the emergence of AI (such as AlphaGo) prompts players to make novel decisions, enabling new developments in the Go domain (Shin et al., 2023). Nowadays, human-machine symbiosis has become an undeniable theme in social development (Wu, 2020). While AI brings convenience, it may also distort people' s concepts through false information (Kidd & Birhane, 2023). Future research can explore both positive and negative influences of human-machine symbiosis on cumulative cultural evolution from a cognitive factors perspective.

In conclusion, cumulative cultural evolution is a long dynamic process spanning tens of thousands of years. Condensing such a macro issue into micro-level empirical scientific research inevitably involves continuous revision and improvement. With the addition of new perspectives, conceptual connotations gradually enrich and definitional criteria become increasingly clear—this itself can be seen as a cumulative cultural evolution process. Under the macro research perspective of sociocultural transformation, researchers will verify broader cross-spatiotemporal hypotheses and clarify the adaptive development 脉络 and phylogenetic differences of cultural evolution (Turchin & Gavrilets, 2021). Under the micro research perspective of laboratory environments, researchers focus more on specific changes in cumulative trends during cultural transmission, concentrating on transmission details and boundary conditions of cumulative cultural evolution (Caldwell, 2020). Therefore, when conducting theoretical development and school integration in cumulative cultural evolution, it is necessary to combine both macro and micro perspectives, grasping macro trends theoretically while collecting more rigorous empirical evidence to explore underlying processes and psychological mechanisms.

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Note: Figure translations are in progress. See original paper for figures.