Trends in Cognitive Sciences

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Review

Openness to Experience: from ecology to culture

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Individuals high in Openness to Experience are more likely to enjoy imaginary worlds, visit museums, be vaccinated, support redistribution, endorse animal rights, and volunteer, alongside a wide array of other characteristic behaviors. Although these behaviors appear disparate, we propose that they form a coherent constellation grounded in a tendency to explore the unknown and tolerate uncertainty. This clarifies why levels of Openness vary across individuals, groups, and historical periods: exploration is modulated by ecological conditions such as safety and resource availability. When environments make exploration worthwhile, Openness expands; when conditions are harsh or precarious, it contracts. Consequently, ecological differences should generate systematic differences in cultural forms. This framework explains how ecological conditions shape culture through their effects on personality.

Highlights

Openness to Experience predicts cultural, political, and lifestyle outcomes, but existing research has not explained why these diverse behaviors cluster within a single trait, or why Openness varies across individuals, groups, and historical periods.

We propose that two psychological mechanisms, curiosity and ambiguity tolerance, jointly constitute the core of Openness, explaining why aesthetic, epistemic, and social behaviors cohere within the same individuals.

Evolutionary models predict that curiosity should be calibrated to ecological conditions; we review comparative, developmental, and cross-cultural evidence showing that Openness is flexibly modulated by cues of safety and resource availability.

This framework yields testable predictions: population-level increases in Openness should produce corresponding shifts in symbolic culture, scientific investment, and moral inclusiveness—patterns we trace across regions and historical periods.

Toward a unified account of Openness

Openness to Experience (Openness; see Glossary) is a central dimension of human personality within frameworks such as the **Big Five** or the HEXACO (Honesty-Humility, Emotionality, eXtraversion, Agreeableness, Conscientiousness, Openness to Experience) [1] (Box 1). Prior accounts have successfully characterized what Openness correlates with, but a unified framework explaining why these diverse outcomes cluster within a single trait and why Openness systematically varies across individuals, groups, and historical contexts is still lacking (although see [6]). This review advances a framework that links ecological conditions, psychological orientations, and cultural outcomes. We propose that Openness reflects relatively stable differences in how individuals explore and engage with ambiguity, and that these differences are adaptively modulated by ecological cues such as resource availability. Under this view, Openness is not merely a list of disparate preferences or traits, but a coherent psychological orientation that promotes exploratory engagement with particular life domains when ecological conditions make such engagement beneficial.

In the following sections, we first outline the behavioral constellation of Openness, describing the diverse behaviors and preferences associated with the trait, and explain how these manifestations reflect a shared underlying orientation. We then examine how Openness is ecologically modulated, drawing on evidence from ecological, cross-cultural, developmental, and comparative perspectives to show how environmental conditions shape its expression. Next, we discuss the cultural expressions of Openness, illustrating how variation in this trait scales up to influence symbolic culture, moral norms, and patterns of innovation. We conclude by highlighting implications for understanding cultural change and future directions for research at the intersection of ecology, psychology, and culture.

The behavioral constellation of Openness

Openness predicts attraction to a range of behaviors and cultural expressions that foreground imagination, abstraction, innovation, and conceptual novelty [1,7–10] (Figure 1). In modern

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Box 1. The Big Five: A descriptive, hierarchical taxonomy with predictive power

The Big Five personality dimensions were not based on any *a priori* structural theory (though they still relied on theoretical assumptions about which questionnaire items were important to assess [2]). Instead, they emerged from patterns of covariation observed in large sets of descriptors, following the lexical hypothesis that significant personality differences are encoded in language: when thousands of individuals are asked to rate themselves or others on everyday personality items (e.g., 'is imaginative', 'keeps commitments', and 'is sociable'), some descriptors systematically co-occur across individuals. Statistical analyses (notably factor analyses) reveal stable clusters of items that group together, and, at a broader level, five robust higher-order dimensions repeatedly emerge: Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism.

Crucially, the Big Five traits are heritable. Twin and family studies show that genetic variation accounts for a substantial portion of differences between individuals on each dimension, including Openness [3]. Heritability does not imply genetic determinism, as even highly heritable characteristics, such as height, are subject to developmental and environmental factors (e.g., malnutrition).

Beyond their measurement origin, Big Five traits predict life outcomes of major societal relevance. Openness correlates with career pathways involving symbolic reasoning and creativity; Conscientiousness predicts educational and occupational achievement as well as a lower risk of substance misuse; Neuroticism predicts mental and physical health; and several traits together predict morbidity and mortality risk [4]. Thus, these dimensions are not mere statistical artifacts: they consistently forecast meaningful real-world behavior.

At the same time, Big Five traits show long-term rank-order stability. Individuals who score relatively high or low on a given trait tend to remain so across decades, even as their absolute levels may change [5]. Personality is therefore neither rigid nor volatile: people tend to maintain their relative standing compared with others over their lifespan. Together, these findings justify treating Big Five traits as empirically grounded, partially stable, biologically influenced, and developmentally malleable dimensions of human individuality, and provide the foundation for examining how Openness shapes behavior, varies across environments, and influences cultural dynamics.

societies, open individuals tend, on average, to be drawn not only toward abstract or experimental art [11–14], new and sophisticated music [15,43,44], highly fictive stories [16–18,45] but also toward nonfiction books [19] and novel food [20].

Beyond cultural preferences, open individuals typically cultivate particular lifestyles [21–24]. In contemporary Western samples, Openness predicts attraction to diverse sexual practices [25,26], greater experimentation with psychoactive substances such as cannabis [27], and a higher likelihood of living in urban rather than agricultural environments [28]. Open individuals from modern societies are also more likely to get vaccinated [29], support environmental and animal protection [30–33], and participate in voluntary or community initiatives [34–37].

Finally, Openness is also associated with political orientations [38] and moral views [39]. For instance, open individuals are more likely to endorse liberal political values [26] and resist conservative ideologies [11,38,46]—although this trend has been shown to be modulated by context [47]. Large, preregistered studies in the USA also showed that Openness (but not Agreeableness) predicts having close friends from different racial backgrounds, even after accounting for regional diversity [40,48]. This suggests that exploratory tendencies, beyond affiliative tendencies, help make cross-group connectedness possible.

Of course, individuals with similar levels of Openness may nevertheless vary in their specific activities and preferences. This variation arises from several factors. First, it can be attributed to the different facets of Openness—for instance, one individual may score high in aesthetic sensitivity, while another is primarily high in intellectual **curiosity** [49]. Second, behavioral outcomes are often shaped by other personality traits and their interactions with Openness [50]. For instance, morbid curiosity and a preference for horror-themed entertainment are better predicted by an interaction between high Openness and high Neuroticism [51]. Finally, the expression of the

Glossary

Ambiguity tolerance: the dispositional tendency to remain engaged when information is incomplete, uncertain, or cognitively complex.
Behavioral syndromes: correlated suites of personality traits that persist across contexts within a species. In animals, boldness, exploration, and risk-taking often covary, forming stable clusters regulated by shared physiological mechanisms. These syndromes help explain why exploratory tendencies and risk management co-occur across individuals.
Big Five: a hierarchical taxonomy derived from statistical covariation among everyday descriptors of personality. The five broad dimensions—Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism—capture relatively stable patterns in thoughts, emotions, and behavior observed across cultures and instruments.
Cultural evolution: changes in collective beliefs, practices, and symbolic forms over time. Cultural evolution here refers not to genetic processes but to shifts in artistic, scientific, political, and moral forms.
Curiosity: a motivational system that drives organisms to seek and learn new information.
Ecological harshness: chronic adversity in an environment, such as sustained resource scarcity, high mortality risk, or prolonged deprivation.
Ecological modulation: the process through which psychological systems adjust their typical level of expression in response to cues about the current or expected ecological environment.
Ecological unpredictability: temporal instability in environmental conditions, such as fluctuating resource availability or inconsistent caregiving.
Exploration–exploitation: a fundamental decision problem faced by both humans and nonhuman animals—whether to seek new information (exploration) or pursue known, reliable rewards (exploitation).
Openness to Experience (Openness): a Big Five personality dimension reflecting individual differences in imagination, creativity, intellect, and aesthetic sensitivity. Individuals high in Openness are sensitive to novelty, enjoy abstract or complex ideas, and tolerate uncertainty.

trait is impacted by the affordances surrounding the individual; for instance, a predisposition to experiment with psychoactive substances is more likely to manifest in contexts where such substances are readily available. In this sense, Openness is best understood as a high-level summary of motivations and strategies whose specific behavioral correlations are not necessarily invariant across ecologies, even though they rest on a shared psychological foundation (see section 'The psychological basis of Openness').

Taken together, these findings show that Openness reliably predicts a constellation of cultural, political, informational, and lifestyle behaviors. This raises a central question: what underlying dispositions cause these diverse tendencies to cluster in the same individuals?

Openness predicts diverse cultural, political, and lifestyle behaviors.

Phenotypic plasticity: the capacity of a single genotype to produce different physiological, morphological, or behavioral phenotypes depending on environmental conditions.

Usage-based models: frameworks proposing that cultural patterns arise from the repeated, goal-directed use of symbolic forms. Frequent use by individuals stabilizes artistic, linguistic, and scientific forms and structures across time.

The psychological basis of Openness

Curiosity is increasingly identified as a motivational core of openness. Early descriptions already emphasized an exploratory impulse [52], and subsequent psychometric studies show that curiosity emerges as a central facet of Openness inventories [53]. Defined as the drive to seek and learn new information [54], curiosity underlies the tendency to engage with unfamiliar ideas, sensations, and social or moral perspectives—an idea developed in mechanistic terms by recent theorists who conceptualize Openness as sensitivity to the reward value of information [55,56].

In addition to curiosity, the Openness constellation also reflects **ambiguity tolerance**—the capacity to remain engaged when information is unfamiliar, complex, or uncertain. Early personality theorists noted that individuals vary in their comfort with incomplete or conflicting information [57], and recent psychometric work shows that ambiguity tolerance strongly covaries with Openness ($r \approx 0.60$ [58]), at a magnitude similar to interest-based curiosity [59].

These two processes (curiosity and ambiguity tolerance) clarify why Openness does not uniformly predict information-seeking behavior. Openness only predicts information seeking in tasks that require sustained engagement with unresolved or fragmentary information, such as trivia questions that provoke curiosity without immediate resolution [60,61]. By contrast, in tasks where information quickly reduces uncertainty, individuals who dislike ambiguity may seek information to eliminate discomfort; in such contexts, Neuroticism—but not Openness—predicts information seeking [62,63]. Curiosity motivates the search for novelty, while ambiguity tolerance sustains engagement when novelty becomes cognitively challenging.

This dual mechanism helps explain why Openness correlates with a broad range of cognitive constructs [64]. Curiosity promotes engagement with novel ideas and problems, supporting tendencies such as the need for cognition [65] and creative ideation [66], while ambiguity tolerance allows individuals to persist when tasks lack clear structure or immediate resolution, contributing to fantasy proneness [66] and a preference for novelty [67].

Crucially, this dual model of Openness also helps explain its broad behavioral constellation. For instance, it clarifies why imaginative or unconventional cultural content (e.g., abstract art, fictional worlds, and complex music) is, on average, more appealing to open individuals: for these individuals, epistemic exploration and perceptual ambiguity are rewarding rather than threatening.

Finally, the same model of Openness explains social and political outcomes. Engaging with unfamiliar people, ideas, or moral claims requires a willingness to tolerate uncertainty about one's assumptions, social categories, or values. Curiosity fosters interest in unfamiliar groups and norms, while ambiguity tolerance reduces the discomfort associated with revising beliefs or

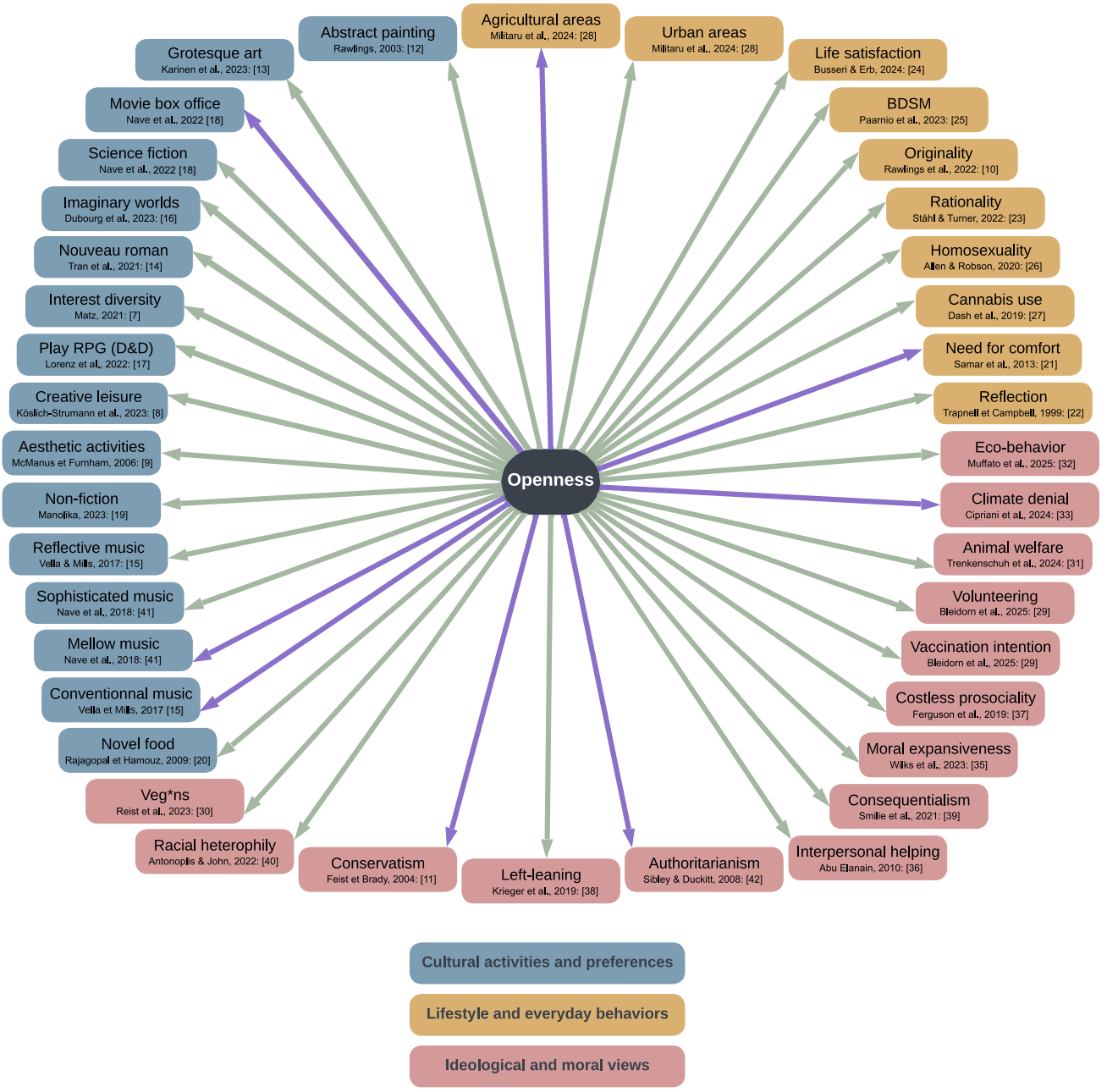

Figure 1. Behavioral correlates of Openness to Experience across domains. This figure summarizes a nonsystematic review of published studies examining the correlates of Openness across diverse domains [7–42]. The links represent positive (green) or negative (purple) associations with Openness. Openness to Experience is typically assessed through standard personality inventories, most commonly the NEO-PI-R, BFI (Big Five Inventory), TIPI, or IPIP-based scales. The outcome variables vary widely in the measurement method. Some are based on self-report surveys (e.g., artistic engagement, moral attitudes, and environmental behaviors), others on behavioral tasks (e.g., music preference sorting), or on digital behavioral traces, such as Facebook likes. (NB: 'Veg*ns' means vegetarian or vegan; 'Nouveau Roman' refers to an experimental French literary movement that rejected traditional plot and character). IPIP: International Personality Item Pool; NEO-PI-R: Neo Personality Inventory; TIPI: Ten-Item Personality Inventory. (See [12,28,13,16,14,7,17,8,9,19,15,41,20,30,40,11,38,42,36,39,35,37,29,31,33,32,22,21,27,26,23,10,25,24].)

expanding moral boundaries. In this view, attitudes toward multiculturalism, environmentalism, or animal welfare are not driven by altruism alone but also by exploratory engagement [68].

More generally, this account of Openness further clarifies why this trait encompasses a broad and seemingly disparate constellation of behaviors and preferences: it may reflect how this trait adapts to varying local affordances (see the Niche Diversity hypothesis [69]). For an Open individual, the mere proximity of a museum or a theater can shift their behavioral output toward aesthetic exploration (without that proximity necessarily increasing the individual's underlying trait level). By adopting the 'Niche-Diversity' hypothesis, we propose that the visibility of Openness in modern societies is a byproduct of rich societies providing a vast array of affordances for this trait. This logic may help clarify why the structure and correlates of Openness observed in Western cultures fail to generalize to other cultural groups and contexts [6].

The ecological modulation of Openness

By clarifying why so many cultural, moral, political, and lifestyle behaviors cluster around a single personality dimension, we now have a powerful tool for explaining social phenomena. If Openness shapes these behaviors, then populations that differ in Openness should differ systematically in the types of art they produce, the scientific practices they value, the political attitudes they endorse, and the moral boundaries they draw. In other words, variation in personality distributions should generate correlated variation in cultural forms.

Previous research has documented genetic, developmental, and demographic influences on Openness (Box 2), but these influences cannot account for large, patterned differences between regions, socioeconomic strata, and historical periods. We argue that ecological conditions are the more fundamental driver.

The evolutionary rationale behind this **ecological modulation** is straightforward: in ancestral environments, exploration entailed risks (time, energy, and exposure to harm) but also yielded information essential for long-term fitness [84,85]. Natural selection, therefore, favored flexible

Box 2. Individual factors of variation in Openness

Genetic heritability is a major determinant of variation in Openness. A recent meta-analysis of behavioral-genetic studies shows that genetics explained about 40% of individual differences in Openness, with even higher estimates in twin studies [3]. Genome-wide association studies (GWASs) have examined this relationship as well and reported that genetic variation accounted for roughly 15% of the variance in Openness after correcting for measurement error [70]. The gap between GWAS and twin-study estimates is known as the 'missing heritability' problem and likely results from the fact that GWAS cover only part of the genome and often miss alleles with very small effects due to limited sample power [71]. Researchers are still investigating both the evolutionary origins of Openness and the causal pathways from genes to behavior [72].

The link between Openness and gender is more mixed. An analysis of five large datasets spanning more than 230 countries found that women scored higher on Openness than men on four of the five personality inventories, despite substantial cross-country variability [73]. Other large studies, however, have reported opposite trends [74], mixed results [75], or no gender differences [76,77]. At the aspect level, the consensus is clearer: men tend to score higher on the intellect aspect, whereas women score higher on the Openness aspect, including Openness to emotions and aesthetics [73].

Openness also varies with age, but the pattern depends on the life stage. A meta-analysis of 16 longitudinal samples shows an overall decline across the adult lifespan [78], although this average trend conceals age-specific shifts. During childhood and adolescence, evidence is mixed: some studies report decreases in Openness, others document increases, and meta-analyses find no consistent linear trend [79]. Instead, Openness appears to rise in early adolescence and then decline [80]. Across adulthood, several meta-analyses and large-scale studies reveal an inverted U-shaped relationship: Openness increases in early adulthood, or even until middle adulthood, and then declines in later life [81]. Facet-level analyses support this pattern but also highlight nuances [82]. For example, in an analysis of 1667 participants from the Seattle Longitudinal Study, overall Openness began to decline after age 40, whereas the Openness to actions facet continued to increase [83].

regulation: curiosity and ambiguity tolerance should increase when safety and surplus make exploration worthwhile and decrease when immediate exploitation offers higher payoffs [86]. This adaptive modulation reflects an optimal allocation of effort, consistent with models showing that quantitative differences in available resources produce qualitative differences in behavioral priorities [87]. This psychological modulation is a particular case of **phenotypic plasticity**: environments that afford exploration increase Openness, whereas harsher or more precarious conditions suppress it. Importantly, this logic does not only apply to humans; many nonhuman species show analogous modulation of exploratory dispositions when their ecological conditions change.

Ecological modulation of exploration in nonhuman animals

Animals display stable individual differences in behavioral traits [88]. Among these traits, exploration, neophilia, and play correspond most closely to the human constellation of Openness. These traits are typically assessed with standardized behavioral tests, such as novel object or novel environment exploration, latency to emerge or resume activity after a simulated predator, and willingness to sample unfamiliar food. These personality expressions are sufficiently stable to allow the study of **behavioral syndromes** [89].

Comparative work now documents consistent individual variation in exploration, neophobia, and play that is systematically modulated by ecological conditions. Such ecological modulations of Openness-like traits have been shown across diverse species, including gelada baboons (*Theropithecus gelada* [90]), meerkats (*Suricata suricatta* [91]), parrots [92], killifish (*Fundulus diaphanus* [93]), lizards (*Eulamprus quoyii* [94]), honeybees (*Apis mellifera* [95]), and wild Asian elephants (*Elephas maximus* [96]). For instance, in free-ranging meerkats, experimental food provisioning increased juvenile play rates, demonstrating that energetic surplus promotes exploratory activities [91]. Similarly, in honeybees, experimental manipulation of energetic state shifted foraging strategies along an **exploration–exploitation** continuum: bees with high energetic reserves explored more broadly [95]. Finally, in killifish, populations from predator-free lakes initiated exploration sooner and more vigorously than those from predator-rich lakes [93].

Together, experimental provisioning, energetic manipulations, and landscape comparisons converge on the same inference: when resources are plentiful, energetic state is high, or predator risk is low, animals shift toward information gathering, play, and exploratory sampling; when resources are scarce or predation risk is high, tendencies contract toward exploitation and caution.

Of course, exploration in nonhuman animals and Openness in humans are not instantiated in the same way. In humans, the same exploratory orientation is scaffolded by symbolic cognition, language, and cumulative culture, allowing curiosity and ambiguity tolerance to be expressed in abstract, social, and normative domains, including science, art, morality, and ideology. Yet, these differences likely reflect the representational systems through which exploration is expressed, rather than a fundamentally different underlying trait. It is, therefore, unsurprising that this same ecological modulation applies to humans.

Evidence for ecological modulation of Openness in humans

Human populations exhibit the same ecological modulation of exploratory tendencies observed in nonhuman animals. Across countries, regions, and socioeconomic strata, Openness systematically covaries with ecological favorability. Large-scale personality surveys reveal higher average Openness in wealthier nations and in regions with greater stability and social safety nets [97] (although see [98]). At finer geographical scales, rapid shifts in local ecological resource levels also recalibrate exploratory tendencies; rising housing costs—which serve as a proxy for

increasing local amenities—predict subsequent increases in city-level Openness, driven jointly by selective migration and social acculturation [99,100].

At the individual level, individuals raised in more prosperous or secure households consistently score higher in Openness than those in less favorable environments. For instance, some studies have shown that familial socioeconomic levels or other factors of environmental quality are associated with higher levels of curiosity in kindergarten [101,102], greater creativity in elementary school children [103], and heightened levels of Openness in adolescence [104,105]. Meta-analytic evidence indicates that parental socioeconomic status reliably predicts higher Openness [98].

Beyond socioeconomic variation, this ecological framework could also partially account for age-related shifts in Openness. Children and adolescents exhibit higher levels of exploratory behavior compared with adults [106], plausibly because early development is characterized by unusually favorable ecological conditions created by sustained parental investment. In human societies, parents routinely buffer offspring from material risk by providing food, protection, and social support well beyond infancy, even in forager societies [107], reducing the costs of exploration and learning [108]. From this perspective, extended human development may function as an adaptive solution to the exploration–exploitation trade-off: by externalizing risk onto caregivers, children and adolescents can afford high levels of Openness during periods when exploration is most valuable [109].

These findings converge across diverse methodologies—cross-sectional comparisons, intranational gradients, within-individual change—suggesting that ecological conditions modulate exploratory dispositions.

Importantly, this ecological modulation of Openness may help explain why the structure and correlates of this trait do not show high cross-cultural generalizability [6]. As noted above, one source of variation lies in local affordances: even when exploratory motivation is present, the domains through which it is expressed depend on available niches. However, there is a complementary explanation: in environments characterized by chronic insecurity or scarcity, exploration is not merely expressed differently but is adaptively downregulated; when exploratory engagement is rare, its behavioral manifestations become sparse and unstable, reducing between-individual variance and weakening the anchoring of standardized indicators [129].

From this perspective, ecological conditions operate at two separate levels: resource security determines how adaptive exploratory engagement is, shaping levels of Openness, whereas cultural affordances determine how exploration can be expressed and, thus, how it is optimally measured.

Which ecological cues modulate Openness?

If Openness is modulated by ecological conditions, then cultural variation becomes predictable only insofar as we can identify which ecological cues the mind uses to regulate exploratory motivation. Environments contain multiple potential cues, and not all are treated equally by the evolved mechanisms that regulate curiosity and ambiguity tolerance. Identifying the cues that matter is, therefore, central to building a predictive framework linking ecology, personality, and culture.

Harshness versus unpredictability. Behavioral ecology distinguishes two dimensions that shift trade-offs between immediate and delayed benefits: **ecological harshness** and **ecological unpredictability** [110]. Harshness refers to chronic adversity or resource scarcity; unpredictability reflects unstable or volatile conditions over time. Evidence that harshness reduces Openness is

strong and consistent. Lower parental income, education, and occupation predict lower Openness in adulthood [98], while exposure to adversity, such as parental death or unstable caregiving, produces similar effects [86]. Pathogen threat, which increases the costs of foreign stimuli and social contact, also predicts lower Openness in many, though not all, studies [111]. By contrast, evidence that unpredictability shapes Openness remains scarce, despite robust effects on other psychological traits [112]. This asymmetry suggests that chronic adversity may be a more stable and evolutionarily reliable signal than fluctuations in short-term instability when calibrating exploratory dispositions.

Individual versus aggregate ecology. Ecological conditions can be measured at multiple scales: household, neighborhood, regional economy, or national wealth. Openness covaries with socioeconomic indicators at both individual and aggregate levels, but individual-level measures are generally more predictive [113]. This pattern implies that we are more sensitive to the constraints and opportunities we experience directly, rather than to the broader ecological conditions in which those experiences occur. Aggregate indicators remain useful for tracking temporal trends, yet they are better considered as population-scale consequences of shared ecological cues, not the cues themselves.

Objective versus subjective indicators. Objective measures (e.g., income and years of education) and subjective indicators (e.g., perceived socioeconomic status and feelings of insecurity) often correlate, but subjective indicators frequently exhibit stronger associations with psychological traits [114]. This is consistent with the idea that modulation depends on perceived opportunities and risks rather than objective conditions. People can live in material comfort while perceiving their environment as unstable, threatening, or competitive; under those subjective cues, Openness should decline despite objective affluence.

Developmental timing. Modulation may occur through early-life conditions, current conditions, or cumulative exposure. Although both early and current environments relate to Openness [100], early-life cues tend to be more predictive [114]. However, Openness also changes in response to ecological shifts later in life [100,115], suggesting that modulation remains at least partially flexible. A plausible conclusion is that variations in Openness reflect both early modulation and ongoing updates, with early cues setting broad thresholds and later cues adjusting exploratory motivation within them.

Taken together, ecological modulation of Openness depends on the perceived costs and benefits of exploration, inferred from cues of chronic harshness, local resources, subjective safety, and developmental exposure. If these cues shape the population distribution of Openness, then cultural variation should follow ecological variation rather than emerging randomly or solely from historical contingencies. This sets the stage for the following section, which examines how ecological differences translate into systematic differences in culture.

The cultural expressions of Openness

Because Openness shapes the way individuals explore aesthetic content, evaluate information, reason about moral boundaries, and adopt unconventional lifestyles (Figure 1), variation in its distribution should scale up to produce collective variation in cultural products, scientific preferences, political attitudes, and social norms (Figure 2).

Under this view, cultural patterns are not arbitrary expressions of tradition or ideology but are aggregated behavioral manifestations of population-level psychological dispositions (Box 3).

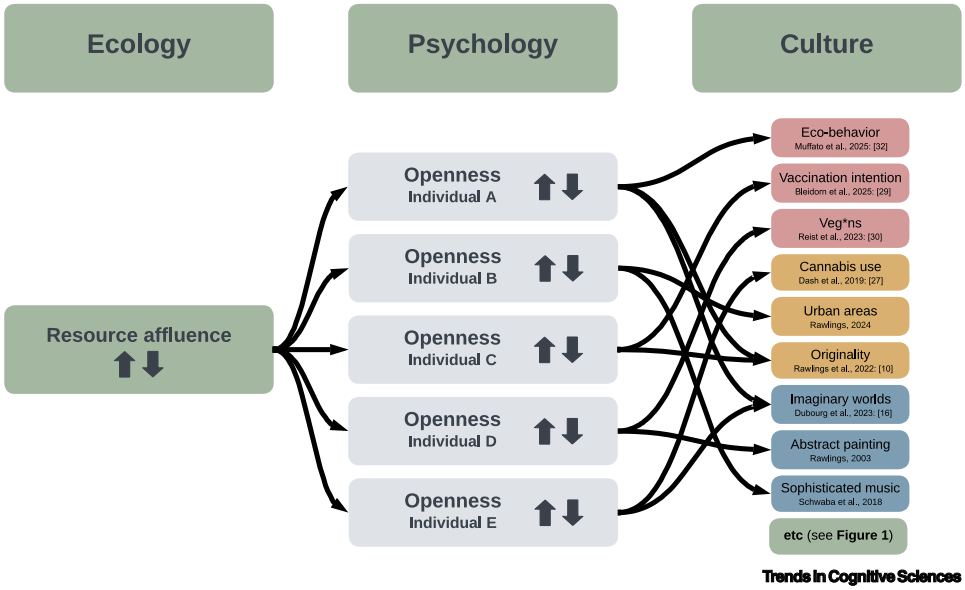

Figure 2. Ecological modulation of Openness across levels of analysis. Ecological and psychological modulations across levels of analysis. At the individual level, secure and predictable environments increase exploratory motivation and Openness. When aggregated across populations, these shifts in motivational orientation raise the mean level of Openness, fostering collective trends in creativity, cultural innovation, and symbolic engagement. If, on average, a population becomes higher in Openness, we should expect corresponding shifts in the cultural ecology (e.g., the emergence of more science fiction novels, experimental music, and jazz venues, the proliferation of vegan restaurants and animal rights campaigns, increasing social acceptance of unconventional sexual practices, and a declining appeal of authoritarian leaders or exclusionary ideologies; see Figure 1). In some cases, these cultural innovations may in turn feed back on ecological conditions (e.g., through scientific advances in medicine or the expansion of formal education), further increasing safety and resource availability, though not all cultural change necessarily produces such effects. (See [32,29,30,27,10,16,12].)

Box 3. A usage-based view of culture

Usage-based models of language explain grammar not as an autonomous system that spreads by transmission but as an emergent byproduct of repeated usage. Patterns solidify because speakers rely on them to achieve communicative goals; frequency and function, not replication, create structure [116]. In this view, the question is not why a linguistic item spreads but why speakers keep using it.

This logic applies to culture more broadly [117]. Instead of assuming that cultural forms persist because they replicate successfully (as in Dual Inheritance Theory [118] or the epidemiology of representations [119]), a usage-based approach treats cultural products as practices maintained by motivated individuals within specific ecological conditions: (i) creators use forms to attract attention, earn income, or express status or identity; (ii) audiences consume them because they satisfy preferences or solve informational problems; (iii) institutions (schools, platforms, museums, and publishers) sustain forms when they support organizational or political goals; and (iv) material and technological environments condition what is cheap, visible, and profitable to produce or consume [117].

As in usage-based linguistics, where linguistic structure emerges from speakers actively employing forms to achieve communicative goals, cultural structure emerges from individuals strategically using cultural forms to pursue their goals. Cultural items persist not because they replicate well but because people repeatedly *use them*—by consuming them or by producing them.

This framework clarifies why Openness affects **cultural evolution**: populations high in Openness differ in the kinds of practices they repeatedly choose—novel genres, experimental art, exploratory scientific norms, and unconventional lifestyles. Over time, these preferences shape what authors produce, what institutions support, and what technologies are developed to serve exploratory audiences. Just as frequent linguistic patterns become grammar, frequently selected explorative practices become cultural structure.

Societies in which individuals tend to be more curious and more tolerant of ambiguity should be more likely to generate artistic experimentation, scientific exploration, expansive moral concern, and openness to unconventional practices. Conversely, societies in which local ecologies calibrate Openness downward should exhibit the opposite tendency: a greater preference for familiar cultural forms, stronger adherence to prescriptive norms, and lower engagement with symbolic or moral novelty.

This section examines how ecological variation in Openness translates into observable cultural differences across three major domains: symbolic culture (art, fiction, and aesthetic complexity), public knowledge systems (science, information seeking, and institutional learning), and collective values (morality, political ideology, and social norms).

Symbolic culture and artistic abstraction

When the baseline of Openness shifts in the population, audiences become more receptive to unconventional cultural forms, creators have greater incentive to produce them, and cultural markets gradually reorganize around exploratory consumption. Consistent with the strong association between Openness and attraction to imaginary worlds and symbolic novelty, computational analyses show that the proportion of cultural works featuring invented settings—fantasy realms, speculative futures, alternative histories—has increased steadily in Europe, North America, China, and Japan, closely tracking long-term rises in economic prosperity and institutional stability [120,121].

Beyond the growth of imaginary worlds, cultural forms also become more fictive. Fictiveness refers to the degree to which a narrative diverges from everyday reality in its events, agents, causal structure, or informational content. Highly fictive features demand both curiosity (to acquire new narrative knowledge) and tolerance for ambiguity (to engage with unfamiliar or counterintuitive content), making highly fictive works more attractive in societies where Openness increases. Large-scale longitudinal analyses confirm this pattern: measures of fictiveness grow over time across regions, with the steepest increases appearing in societies experiencing sustained gains in education, income, and security [45].

Together, these results show how changes in Openness can produce systematic changes in cultural forms. This rise in exploratory demand is unlikely to be limited to literature: similar shifts characterize popular music (e.g., genre hybridization in contemporary pop and multisection formats in K-pop), mainstream cinema (e.g., expansive fictional worlds and multiverse narratives), and global visual culture (e.g., manga and digital art forms). These broad transformations suggest that increases in Openness contribute to the historical move away from mimetic realism toward widely accessible cultural products that reward symbolic exploration.

Science, superstition, and epistemic institutions

Scientific practice is another domain where exploration becomes possible only under secure ecological conditions. Engaging with uncertain hypotheses, interpreting noisy data, and investing time in noninstrumental inquiry are costly behaviors unless basic needs are satisfied and failure is tolerable. Consistent with this perspective, large-scale historical estimates show that the Scientific Revolution emerged first in regions with unusually high living standards—most notably the Netherlands and England—where individuals were richer, healthier, and better nourished than in any earlier societies [113]. A similar pattern had appeared centuries earlier: during the medieval period, the most scientifically productive region was the Islamic world, where high levels of economic development were associated with great advances in mathematics, optics, and astronomy.

The same ecological mechanism helps explain the Industrial Revolution. Technical innovation requires exploratory cognition: experimenting with unfamiliar mechanisms, investing time in

trial-and-error engineering, and tolerating failure before success becomes possible. This technological boom was preceded by unusually high wages, low mortality, and historically unprecedented levels of nutrition and energy availability [122]. In England and the Netherlands, average workers consumed more calories than elites in most previous civilizations, were paid for skilled labor rather than subsistence, and faced fewer constraints on time and risk. Under these conditions, artisans, merchants, and engineers could afford long-term exploratory projects, leading to the proliferation of mechanical inventions in textiles, metallurgy, navigation, and energy production.

Finally, the ecological transition also helps explain the historical decline of magical thinking and superstition. As living standards rose in early modern Europe, individuals became less dependent on supernatural agents to cope with uncertainty and more optimistic about the prospect of improving the world through their own actions. Significantly, this decline occurred before science had demonstrated any material benefits, suggesting that prosperity first modified psychological attitudes toward uncertainty [123]. Science itself is cognitively counterintuitive and requires trust in abstract mechanisms and invisible causal structures [124], so its adoption became appealing only when individuals were sufficiently secure to tolerate conceptual uncertainty and invest in exploratory reasoning.

Cooperation, tolerance, and the expansion of moral boundaries

Moral change is another outcome of variation in Openness. Extending concern beyond kin, local groups, or familiar identities requires both the motivation to engage with unfamiliar perspectives and the capacity to tolerate uncertainty about who counts as a legitimate beneficiary of moral concern. Inclusive political attitudes (e.g., support for redistribution, environmental protection, animal welfare, and multicultural policies) demand that individuals entertain values that challenge inherited boundaries of solidarity. When Openness is low, unfamiliar groups are more readily perceived as potential threats, and norms restricting cooperation to known categories remain stable.

As prosperity increases and Openness rises, individuals become more willing to reconsider inherited norms, broaden moral boundaries, and experiment with legal protections for outsiders and nonhuman entities. Historical evidence supports this ecological pattern. Moments of rising prosperity in Europe saw the diffusion of demands for religious freedom, legal equality, abolition of privileges, and universal civil rights. This is evident in cultural productions, which reflect the dominant values, motivations, and preferences of a given historical period [125]: quantitative analyses of theatrical productions in Paris and London across several centuries show that economically prosperous periods feature plots emphasizing negotiation, alliance, and mutually beneficial exchange, whereas poorer or unstable contexts emphasize predation, opportunistic gain, and distrust ([126] see also [121] for a parallel pattern in Chinese history). Likewise, European portraiture reveals a long-term rise in facial cues associated with perceived trustworthiness, suggesting that as cooperation becomes more profitable, signaling willingness to cooperate becomes advantageous [127].

This dynamic persists in modern societies. Large-scale comparative surveys show that citizens in richer and better-educated countries are more tolerant, more trusting of unfamiliar others, and more supportive of democratic norms [128]. While trust is typically represented as a facet of Agreeableness, in this context, it likely reflects an Openness-driven willingness to engage with unknown social partners and a higher tolerance for the risks inherent in social novelty. Across the past century, each cohort has expressed less authoritarian, more individualistic, egalitarian, and expressive values than the previous one, mirroring rises in material security. Crucially, such changes need not originate in ideological persuasion or elite activism; rather, political movements

succeed when they align with the underlying psychological dispositions fostered by favorable ecological conditions.

Concluding remarks

Across artistic, scientific, and moral domains, the diverse behaviors associated with Openness are not accidental: they form a coherent constellation rooted in exploratory motivation and tolerance for ambiguity. Individuals high in Openness are drawn to imaginary worlds, abstract ideas, experimentation, and inclusive moral norms because each of these practices requires approaching unfamiliar information and sustaining engagement when outcomes are ambiguous. By showing that Openness itself is modulated by ecological conditions—rising with prosperity, safety, and predictability—we offer a principled explanation for individual variations and long-term cultural change. As environments make exploration psychologically affordable, societies produce richer symbolic worlds, invest in scientific inquiry, and expand cooperation and moral concern beyond traditional boundaries. Cultural evolution can therefore be understood as the aggregate expression of a population's exploratory psychology, regulated by the ecological conditions in which it develops [117]. Longitudinal, cross-cultural, and historical analyses linking ecological indicators to changes in cultural outputs provide a promising avenue for further testing the predictions this framework generates (e.g., in Chinese history, see [121]). Several key questions remain open, especially concerning how exploratory dispositions respond to ecological cues across development and how individual modulations scale up to shape emergent, collective cultural patterns (see Outstanding questions).

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Declaration of interests

The authors declare no competing interests.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT in order to assist with language editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Outstanding questions

How do curiosity and ambiguity tolerance jointly respond to ecological signals? Do they modulate independently or via a shared mechanism that integrates expectations about the value of future information? Do modulations in curiosity and ambiguity tolerance produce separable changes in individual preferences?

Which ecological cues most reliably trigger exploratory behavior across species, and how consistent are these cues across taxa such as insects, fish, reptiles, birds, primates, and large mammals?

How early in development do humans begin to extract ecological cues that regulate exploratory motivation?

To what extent is Openness modulated by immediate conditions versus cumulative life-history exposure, and how quickly do exploratory dispositions respond to ecological improvement or deterioration? How resilient is Openness to ecological shocks such as pandemics, conflict, or economic crises, and how quickly do exploratory dispositions return once stability is restored?

By what mechanisms do population-level distributions of Openness give rise to emergent norms, institutions, and cultural practices? How are these collective patterns negotiated, stabilized, and transformed through individual interactions? To what extent and in what ways do such emergent cultural phenomena reshape the cues that modulate Openness?

Can we empirically trace retroactive feedback loops in which rising Openness increases investment in science, innovation, and institutional learning, thereby boosting prosperity, which, in turn, further increases Openness?

To what extent are age-related changes in Openness driven by development *per se* versus by predictable age-linked ecological conditions, such as parental protection and resource buffering? If age effects largely reflect ecological security, we should observe that the rise and decline of Openness across the lifespan should attenuate

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