Trends in
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How do natural environments shape adaptive cognition across the lifespan?

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How does human cognition adapt to idiosyncratic features of our real-world experiences across our lifetimes? The dynamic interaction between individuals and their natural environments is rarely the focus of study within cognitive science, but I argue that a more ecological approach will be critical for advancing developmental science and revealing the adaptive nature of cognition.

It has long been argued that cognition is adaptive – that the mental processes and representations that inform an organism's behavior are fundamentally shaped, over the course of its lifetime, by the information processing demands of its environment [1]. Yet, over the past 25 years, the study of cognition has largely proceeded within laboratory settings in which researchers deliberately forego the complexity of real-world environments to achieve tight experimental control over information processing. Inherent in this reductive approach are several simplifying assumptions: experimental tasks capture aspects of cognition that are evoked in real-world settings; experimental manipulations producing effects on local timescales are sufficient to reveal central properties of learning systems, which accumulate knowledge over months and years; and individual differences in the responses to an experimental manipulation can be treated as statistical noise.

In recent years, cognitive scientists have grown increasingly critical of these simplifying assumptions, and have argued that they fundamentally limit our ability to understand real-world cognition. Laboratory tasks and stimuli lack the complexity of natural environments and may fail to capture the important statistical regularities that influence cognition – observations that have motivated calls for greater naturalism within cognitive science [2]. While such demands for greater ecological validity have led to increased use of naturalistic and virtual reality-based stimuli in laboratory research, this is only a half measure. The study of how natural experience shapes cognition cannot be accomplished by simply bringing more realistic stimuli into the laboratory, but instead requires bringing the laboratory into the real world.

Observational empirical studies have identified relations between idiosyncratic real-world experiences and general cognitive abilities that must arise from adaptive dynamics that unfold over much longer timescales than those indexed in typical laboratory experiments. For example, individuals who have spent extensive amounts of time playing video games have been shown to exhibit better selective attention than nonplayers [3]. These findings suggest that regular exposure to contexts that reward rapid and accurate detection of visual features of the environment yields improvements in attention that generalize to novel contexts and situations. While this example reveals that cognition is shaped by specific activities people choose to pursue, other work demonstrates that cognition is also influenced by more global features of their environments. Individuals who grew up in cities with more complex street layouts were found to be more capable of navigating complex spatial environments as adults [4]. This work reveals that spatial navigation abilities adapt to the degree of navigational challenge presented by early-life spatial environments.

Such empirical findings provide compelling arguments against viewing individual differences in cognition as mere unexplained noise, demonstrating that they can reflect systematic variation in information processing. A more complete cognitive science should seek to understand the adaptive mechanisms through which individual differences emerge, as cognitive abilities become aligned with the demands that individuals confront in the real world.

The importance of such an ecological approach, which treats individuals and their natural environments as the object of study, has been articulated convincingly by many influential scholars in past decades [5]. James Gibson famously argued for the importance of asking 'not what's inside your head, but what your head's inside of' [6]. However, it is only in recent years that we have acquired the technological advances to facilitate quantification of both natural environments and individuals' behaviors within them to feasibly and effectively implement an ecological cognitive science.

Embracing the ecological study of cognition would require several key shifts in scientific practice. Our theories must specify hypotheses about the nature of the adaptive process through which environmental information shapes cognition. Ideally, these proposed mechanisms of adaptive change would be expressed within formal models that facilitate quantitative testing of these hypotheses [7]. Aspects of the individual environment that are proposed to mechanistically alter cognition must be measured. Such measurements could take the form of dynamic, continuously recorded data (e.g., geolocation data and records of social contacts), or compiled statistics that summarize important features of the environment (e.g., location-specific sociodemographic data). For example, geolocation data have been used to test the hypothesis that day-to-day variation in novelty exposure modulates affective states [8], and information about infants' sociodemographic environments has been used to examine the relation between the diversity of linguistic input and learning from diverse social interaction partners [9]. While these studies are a good starting point, they could be expanded to track behavior across extended timescales to reveal processes of dynamic change over the lifespan. Understanding dynamic changes in cognition will also require tasks (or ideally, measures of natural behavior), which are sensitive to the cognitive process of interest and are sufficiently reliable to index cognitive change. Research samples will need to have adequate diversity along relevant dimensions of environmental variation to be sufficiently powered to identify the effects of such variability. In cultivating these methodological practices, cognitive science might look toward the fields of behavioral ecology and ethology, which have developed innovative approaches for quantifying the complex behaviors of organisms in natural environments.

The observational methods central to such an ecological approach would complement, not supplant, the controlled experimental methods of laboratory research. Hypotheses derived from theories that are based on laboratory data can be validated in the real world. A better understanding of the cognitive challenges individuals face in real-world contexts can direct laboratory research agendas toward ecologically valid questions. Laboratory studies will undoubtedly be necessary to identify neurobiological mechanisms of adaptive change.

An ecological approach to the study of cognition will be particularly critical for advancing developmental science. Cognitive development is a dynamic process that involves experience-dependent adaptation and specialization over multiple timescales. Developmental science should provide mechanistic accounts of how this process of change is driven by bidirectional interactions between individuals and their environments [10]. Cross-sectional studies identifying differences in cognitive abilities can be helpful guideposts, pointing to which aspects of cognition do (or do not) tend to differ between individuals of different ages. Studies that identify variation in developmental outcomes as a function of variation in past experience (e.g., studies of early-life adversity) can point to the dimensions of experience that may influence the development of a cognitive ability. But understanding how and why such differences arise requires the direct study of the dynamic interactions between the individual and specific, statistical properties of their environments over time [11], coupled with mechanistic models that explain how such interactions unfold.

More broadly, the ecological study of cognition stands to yield mechanistic insights that extend to many domains beyond cognitive development. Understanding how the statistics of organisms' environment shape their cognitive abilities can shed light on the origins of cross-species differences in cognition [12] or how human cultural practices drive cognitive differentiation [13]. Features of social and geographic environments have been shown to influence mental health [14] suggesting that a mechanistic understanding of the emergence of psychopathology may depend on quantifying the adaptive – or maladaptive – influence of the experienced environment on cognition.

A central goal of the study of cognition is to understand the mental computations that underlie behavior. Over the next quarter century, cognitive science will make greater advances toward this goal if it embraces the complexity of the real-world environments in which behaviors and their underlying cognitive computations dynamically unfold.

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