Dialogue

Celeste Kidd

Assistant Professor of
Psychology,
University of California,
Berkeley

celestekidd@gmail.com

Curiosity as Driver of Extreme Specialization in Humans

The features that make us uniquely and distinctly human have been of interest to many people, from psychologists to philosophers to religious scholars, for centuries. Typical candidate traits include things like speech (Lieberman, 1991), upright posture (Clarke & Tobias, 1995), protracted childhoods (Jolly, 1972), helpless infants (Piantadosi & Kidd, 2016), sophisticated social cooperation (Melis & Semmann, 2010), and creativity (Carruthers, 2002).

There is, however, an essential human trait that has received far less recognition: the capacity for extreme specialization. Many humans spend a lifetime perfecting a single niche skill, such as a musical instrument, art medium, or style of dance. Others specialize in trades with economic roles (e.g., butchers, bakers, and candlestick makers). And while some other species exhibit certain forms of specialization—ants, for example, exhibit increased task specialization as the colony size increases (Amador-Vargas et al., 2015)—none approach the breadth and depth of specialization found in humans. In particular, specialization in species usually seems to hinge on abilities that are directly relevant to survival. Human specialization, in contrast, knows no limits or bounds and seems applicable to virtually any domain of existence. Here we will argue that this extreme specialization is enabled in large part due to key mechanisms within the human attentional system—specifically those mechanisms that bias learners towards material for which they already possess some background knowledge. More broadly, this extreme specialization is enabled by the driving pressures that underlie human curiosity.

Curiosity can be thought of as the force behind the acquisition of new knowledge (James, 1913; Pavlov, 1927; Skinner, 1938; Oudeyer & Kaplan, 2007; Gottlieb et al., 2013). It is a strong determinant of how we spend our days, and influences not just our intellectual interests, but also a myriad of recreational decisions, from who we speak to and what we discuss, to what we listen to and watch, to what we fixate on in a scene and what we learn about the world. It is a key driving force behind the grandest human innovations, yet less sophisticated, purpose-specific forms of curiosity can be observed in more primitive intelligences (e.g., C. elegans). Curiosity, or intrinsic motivation, is likely a necessary feature of intelligent systems generally. Even robotic and artificial intelligence systems must possess a mechanism to seek out and learn material that is relevant to their present and future goals (Oudeyer & Kaplan, 2007).

Human curiosity is known to relate to our existing knowledge. For example, work from the infant attention literature suggests that infants prefer novel stimuli, defined as distinct from what the infant already knows (Sokolov, 1963) or partially encoded representations over either entirely known or entirely novel ones (Dember & Earl, 1957; Kinney & Kagan, 1976; Berlyne, 1978; Kidd et al., 2013). More contemporary theories observe that curiosity is triggered when a gap is detected between what a learner currently knows, and what they could know (Loewenstein, 1994). This suggests the involvement of metacognition, since a learner must first identify that there is a gap to be filled before curiosity should be piqued. Yet little work to date has explored the relationship between metacognitive processes and curiosity. Are people who possess more metacognitive abilities pertaining to their own knowledge more curious? Can you make someone more curious by calling attention to what they do not know?

While we know that there exists some relationship between existing knowledge about a stimulus and the learner's degree of interest in that stimulus, we still do not fully understand precisely how those two factors relate to each other, nor do we understand the cognitive or neural mechanisms underlying how and why the learner's curiosity is piqued (for a review of what we don't know, see Hayden & Kidd, 2015). For example, we do not understand how neural reward systems treat information and weigh it in decision-making, though it is clear that humans and monkeys are willing to sacrifice some reward to gain even useless information (Blanchard, Hayden, & Bromberg-Martin, 2015). Is there a common currency for reward and information, and how is the value of information determined, represented, and integrated neurally?

We have limited evidence to suggest that being in a curious state could facilitate learning (Gruber et al., 2014; Stahl & Feigenson, 2015); however, we also have evidence that learners are more curious when they possess information that is partially encoded, and thus on the verge of being learned (Kang et al., 2009). Thus, we must be sensitive to the fact that some of the apparent boosts to learning attributed to curiosity in the literature may have the direction of causality wrong—being on the verge-of-learning may induce greater curiosity, rather than curiosity inducing better learning. How do we understand curiosity and the biological mechanisms underlying it in a way that reasonably accounts for these two apparently opposing causal mechanisms?

What is the purpose of this curiosity system, and why does it yield the sort of specialization that we see in humans but not other species? How does it function, and what purposes does it serve? Why are there humans that become compelled to acquire information about fictitious worlds (e.g., Harry Potter, Star Wars)? What might be the connection between curiosity, creativity, and specialization?

Amador-Vargas, S., Gronenberg, W., Wcislo, W. T., & Mueller, U. (2015). Specialization and Group Size: Brain and behavioural correlates of colony size in ants lacking morphological castes. Proceedings of the Royal Society B, 282(1801), 20142502.
Berlyne, D. E. (1978). Curiosity and learning. Motivation and Emotion, 2(2), 97-175.
Blanchard, T. C., Hayden, B. Y., & Bromberg-Martin, E. S. (2015). Orbitofrontal cortex uses distinct codes for different choice attributes in decisions motivated by curiosity. Neuron, 85(3), 602-614.
Carruthers, P. (2002). The cognitive functions of language. Behavioral and Brain Sciences, 25(6), 657-674.
Clarke, R. J., & Tobias, P. V. (1995). Sterkfontein Member 2 foot bones of the oldest South African hominid. Science, 269(5223), 521.
Dember, W. N., & Earl, R. W. (1957). Analysis of exploratory, manipulatory, and curiosity behaviors. Psychological Review, 64(2), 91.
Gottlieb, J., Oudeyer, P. Y., Lopes, M., & Baranes, A. (2013). Information-seeking, Curiosity, and Attention: Computational and Neural Mechanisms. Trends in Cognitive Sciences, 17(11), 585-593.
Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. Neuron, 84(2), 486-496.
James, W. (1913). The Principles of Psychology, Volume II. New York, NY, United States: Henry Holt and Company.
Jolly, A. (1972). The Evolution of Primate Behavior. New York, NY, United States: MacMillan.
Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T. Y., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. Psychological Science, 20(8), 963-973.
Kidd, C., & Hayden, B. Y. (2015). The psychology and neuroscience of curiosity. Neuron, 88(3), 449-460.
Kidd, C., Piantadosi, S.T., & Aslin, R.N. (2012.) The Goldilocks Effect: Human infants allocate attention to visual sequences that are neither too simple nor too complex. PLOS ONE, 7(5), e36399.
Kinney, D. K., & Kagan, J. (1976). Infant attention to auditory discrepancy. Child Development, 155-164.
Lieberman, P. (1991). Uniquely Human: The evolution of speech, thought, and selfless behavior. Cambridge, MA, United States: Harvard University Press.
Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. Psychological Bulletin, 116(1), 75.
Melis, A. P., & Semmann, D. (2010). How is human cooperation different?. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 365(1553), 2663-2674.
Oudeyer, P. Y., & Kaplan, F. (2007). What is intrinsic motivation? A typology of computational approaches. Frontiers in Neurorobotics, 1, 6.
Pavlov, I.P. (1927). Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex. Oxford, England: Oxford University Press.
Piantadosi, S. T., & Kidd, C. (2016). Extraordinary intelligence and the care of infants. Proceedings of the National Academy of Sciences, 113(25), 6874-6879.
Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. Science, 348(6230), 91-94.
Skinner, B. F. (1938). The Behavior of Organisms: An Experimental Analysis. Oxford, England: Appleton–Century.
Sokolov, E. (1963). Perception and the Conditioned Reflex. Oxford, England: Pergamon Press.

Towards Computational Models of Curiosity in Cognitive Development

Elizabeth Bonawitz

Computational Cognitive
Development Lab,
Rutgers University,
Newark, USA

elizabeth.bonawitz@rutgers.edu

Kidd raises an interesting chicken and egg problem pertaining to curiosity and the specialization of knowledge. One the one hand, epistemic curiosity likely depends on some prior knowledge being in place; it is piqued given the realization of a gap between known and unknown information (Lowenstein, 1994). On the other hand, curiosity drives knowledge enrichment. For example, binding association and intervention is a key component of causal knowledge in early development (Bonawitz et al., 2010). Curiosity may help drive this link between observed associative relationships and the outcomes of our interventions by motivating action. One way to gain insight into these self-reinforcing roles of curiosity and developing knowledge is to examine them in early childhood.

Computational modeling further helps to make precise the role of prior knowledge and opportunities for information gain. By bridging these approaches we can come to better understand the contributions of curiosity to our uniquely human traits. There is a long tradition of modeling curiosity (e.g. see Oudeyer 2018 for a review) and also of modeling the role of prior knowledge in human learning (e.g. see Tenenbaum, Griffiths, & Kemp, 2006). Taking the theory-based probabilistic perspective as a starting point, we might conceptualize of curiosity as an artifact that falls out from "running" certain inferential processes. Indeed, we can think of the mind as carrying out simulations (Battaglia, Hamrick, & Tenenbaum, 2013), search (Ullman, Goodman, & Tenenbaum, 2012), and sampling (Bonawitz et al., 2014; Griffiths, Vul, & Sanborn, 2012) over intuitive theories. Curiosity may exist as a state during this inferential process and be greatest when information is likely to be gained, when information will likely resolve conflict or uncertainty, when the reward of knowledge is high and that cost of carrying out the information seeking action is low, and so forth.

Curiosity is also often encoded simply as a drive or utility in a learning system, but modeling can also help specify the causes of curiosity and quantify their contribution towards this drive in early development. For example, models can specify the role of prior knowledge and various utilities, providing a framework to build a utility calculus of curiosity. Recent research suggests that even very young children are already capable of carrying out this intuitive calculus, and that curiosity and prior knowledge are deeply intertwined. For example, young children are more motivated to explore when events violate the predictions of intuitive theories (Bonawitz et al., 2012; Stahl & Feigenson, 2015), suggesting that even the young mind is driven to reduce uncertainty and learn more following a conflict of beliefs and evidence. Preschoolers are also sensitive to information gain, exploring over exploiting rewards when the knowledge gained will serve later use (Bonawitz, Bass, & Lapidow, 2018). Curiosity may be piqued when it is brought to the attention of a learner that knowledge is incomplete. For example, research with preschoolers has found that pedagogical questions simultaneously point to the importance of particular features, while also encouraging further exploration and discovery (Yu, Landrum, Bonawitz, & Shafto, 2018).

Computational approaches provide an important starting point for understanding the intertwined roles of curiosity and knowledge acquisition, but current frameworks do not yet have a meaningful way to incorporate affect. Discovery can feel good and thus rewards curiosity (e.g. "Explanation as Orgasm, Gopnik, 2000), but affect also cyclically drives exploration (e.g. as