Journal of Experimental Psychology: General
2016, Vol. 145, No. 3, 266–272

0096-3445/16/$12.00 http://dx.doi.org/10.1037/xge0000140

BRIEF REPORT

Curiosity and Reward: Valence Predicts Choice and Information Prediction Errors Enhance Learning

Caroline B. Marvin and Daphna Shohamy
Columbia University

Curiosity drives many of our daily pursuits and interactions; yet, we know surprisingly little about how it works. Here, we harness an idea implied in many conceptualizations of curiosity: that information has value in and of itself. Reframing curiosity as the motivation to obtain reward—where the reward is information—allows one to leverage major advances in theoretical and computational mechanisms of reward-motivated learning. We provide new evidence supporting 2 predictions that emerge from this framework. First, we find an asymmetric effect of positive versus negative information, with positive information enhancing both curiosity and long-term memory for information. Second, we find that it is not the absolute value of information that drives learning but, rather, the gap between the reward expected and reward received, an "information prediction error." These results support the idea that information functions as a reward, much like money or food, guiding choices and driving learning in systematic ways.

Keywords: curiosity, reward, valence, prediction error, learning

Curiosity is a powerful force. Yet for something that drives many of our daily pursuits, surprisingly little is known about it. Psychologists have long struggled to provide a formal account of curiosity. It has been defined as "an inconsistency or a gap" in knowledge (James, 1890, p. 430) and has been suggested to arise when an animal is discomfited by uncertainty or a lack of information (Berlyne, 1960). Building on these ideas, Loewenstein (1994) posited an information gap theory of curiosity, suggesting that curiosity is the result of a perceived gap between what one knows and what one wants to know. An innovation of this theory is that it aims to describe, in more concrete terms, the subjective value of that which curiosity seeks: information. Indeed, the idea that information has value in and of itself—that it is rewarding—is implied in many of our conceptualizations of curiosity. But so far there has been scarce experimental evidence supporting this notion.

Recent studies have demonstrated that monkeys value information about upcoming primary rewards (such as water; Bromberg-Martin & Hikosaka, 2009, 2011). They are even willing to forgo some portion of this reward to receive advance information about it, despite the information's having no influence on the likelihood of receiving the reward (Blanchard, Hayden, & Bromberg-Martin, 2015). Further, the same dopaminergic neurons that signal changes in the value of the reward also code changes in the value of information, suggesting that information and primary rewards share behavioral and neurobiological properties. Research in humans has further supported this idea, demonstrating that people are more willing to wait and pay for information about which they're more curious (Kang et al., 2009) and that high-curiosity information is associated with activation in brain areas known to respond to rewards, including the nucleus accumbens and the caudate (Gruber, Gelman, & Ranganath, 2014; Kang et al., 2009).

There is also a strong link between how valuable information is and the likelihood of remembering it. People are more likely to remember high-curiosity information; even incidental information presented during a high-curiosity state is better remembered later (Gruber et al., 2014; Kang et al., 2009; Mullaney, Carpenter, Grotenhuis, & Burianek, 2014). Such findings dovetail with well-known findings regarding the enhancing effect of reward on subsequent memory (e.g., Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006).

These studies support an information-as-reward hypothesis, demonstrating that curiosity conforms to basic characteristics of reward-motivated behavior. However, they leave open critical questions related to the extent to which this analogy holds true at

This article was published Online First January 18, 2016.

Caroline B. Marvin and Daphna Shohamy, Department of Psychology, Columbia University.

Daphna Shohamy and Caroline B. Marvin developed the study concept and design; Caroline B. Marvin conducted data collection and data analysis, under the supervision of Daphna Shohamy; and Caroline B. Marvin and Daphna Shohamy wrote the article.

Funding was provided by a National Science Foundation Career Development Award to Daphna Shohamy. We thank Katherine Duncan, Raphael Gerraty, Shuo Jiang, Melanie Pincus, and Travis Riddle for assistance in programming and statistical analysis; Kelly Braga and Celia Durkin for assistance in overseeing the participants; and Erin Kendall Braun, Rahia Mashoodh, Lucy Owen, Melanie Pincus, and Nina Rouhani for helpful comments on the article.

Correspondence concerning this article should be addressed to Caroline B. Marvin or Daphna Shohamy, Department of Psychology, Columbia University, 1190 Amsterdam Avenue MC 5501, New York, NY 10027. E-mail: cbm2118@columbia.edu or ds2619@columbia.edu

a deeper level. In particular, there are two central features of reward-driven behavior that have been extensively characterized but whose relevance to curiosity remains unknown. These are (a) valence (reward vs. punishment) and (b) predictions errors.

It is known that rewards and punishments—and gains and losses—have differential effects on both behavior and brain (e.g., Frank, Seeberger, & O'Reilly, 2004; Kahneman & Tversky, 1979; Tom, Fox, Trepel, & Poldrack, 2007; Seymour, Daw, Dayan, Singer, & Dolan, 2007). Positive versus negative outcomes also have asymmetric effects on information seeking (Case, Andrews, Johnson, & Allard, 2005; Fischer, Jonas, Frey, & Kastenmüller, 2008; Sweeny, Melnyk, Miller & Shepperd, 2010) and intertemporal choice (Berns et al., 2006; Hardisty, Appelt, & Weber, 2013; Loewenstein, 2006). People differentially seek positive versus negative information, depending on affect (e.g., Brashers, 2001; Griffin, Dunwoody, & Neuwirth, 1999; Schwarz & Clore, 1983; Yang & Kahlor, 2013). And they generally remember more-valenced, as opposed to neutral, information (for a review, see LaBar & Cabeza, 2006). Moreover, positive valence enhances the effect of reward on memory (Wittmann, Schiltz, Boehler, & Düzel, 2008). Thus, valence affects how information is sought and how it is remembered, suggesting it may affect the value of information itself.

A separate literature has suggested that gaps in information—*information prediction errors*—may be important drivers of curiosity and memory. Neurobiologically, rewards exert their effect through dopaminergic reward prediction errors (Daw & Doya, 2006; Schultz, 2006; Schultz, Dayan, & Montague, 1997). A key finding from computational and neurobiological accounts of reward-guided learning is that dopamine neurons in the midbrain signal the difference between the expected value of the reward and the value of the reward actually received, suggesting that it is the discrepancy between received reward and expected reward that drives learning (Rescorla & Wagner, 1972; for a review, see Schultz, 2006). If information operates similarly, information prediction errors may play a key role in curiosity and learning. Indeed, a core feature of Loewenstein's (1994) information gap theory is that curiosity is partly driven by predictions about the ability of information to resolve uncertainty. This idea applies a "reference-point concept" to curiosity, suggesting that people are sensitive to both absolute and relative gaps in information and arguing that they are more likely to be curious about information if they estimate that the probability of that information satisfying their curiosity is high (Loewenstein, 1994, p. 87).

Here, we examined the information-as-reward hypothesis, testing two new predictions about the role of valence and information prediction errors in driving curiosity and memory. We used willingness to wait, a well-established measure of reward-motivated behavior (e.g., Frederick, Loewenstein, & O'Donoghue, 2002). Because it is known that time is valuable, waiting can be used as a measure of the motivational value of rewards (e.g., Hayden, Parikh, Deaner, & Platt, 2007). If curiosity reflects the value of information, one would expect participants to show greater willingness to wait for more-valuable information, that is, information that engendered greater curiosity.

We tested two hypotheses: (1) The valence of information affects curiosity and subsequent learning, specifically that positively and negatively valenced information engender greater curiosity and promote better learning than does neutral information and (2) information prediction errors affect learning. The notion of quantifying curiosity as the anticipation of the value of information and satisfaction as the judged value of received information is a new idea, directly motivated by theories and studies in systems neuroscience demonstrating that dopaminergic neurons show parallel responses to the anticipation and receipt of information. We tested the relevance of this framework to curiosity, proposing that the difference between the satisfaction experienced upon receipt of information and the curiosity experienced in anticipation of information functions as an information prediction error. We hypothesized that this information prediction error is an important factor in how curiosity drives learning, such that people better remember information associated with more-positive prediction errors.

Method

Participants

A total of 84 individuals participated in this 2-day study (mean age $= 20.9 \pm 4.9$ years; 56 female, 28 male). On the first day, 55 participants received research credit for their participation and 29 participants were paid \$12/hr. The participants who received research credit were then surprised with an offer to participate in a follow-up experiment in the lab for payment instead of credit; 43 returned (mean age $= 21.5 \pm 6.4$ years; 27 female, 16 male). The participants paid on the first day were told from the onset that this was a 2-day study, though they were not told the purpose of the second session; 26 of these participants returned for the second day (mean age $= 20.7 \pm 2.3$ years; 18 female, 8 male). On the second day, all participants were paid \$12/hr. Three participants were excluded from the analysis because they did not complete the curiosity and satisfaction-rating portion of the task on the first day, leaving 81 participants who participated fully in the first day of the study and 66 participants who participated fully in both days of the study.

Determination of Sample Size

In a previous pilot study ($N = 38$), we ran a simplified logistic regression model using the average curiosity rating associated with each question as the predictor and found the following result: $e\text{\^{}}\beta_0 = 0.07$ ($p < .001$); $e\text{\^{}}\beta_{\text{curiosity}} = 2.03$ ($p < .001$). Then, using the powerMediation package in R (Qiu, 2015), which calculates sample sizes on the basis of the methods outlined in Hsieh, Bloch, and Larsen (1998), we calculated that a sample size of 63 would yield of power of 0.8 at alpha level 0.05. This study differs somewhat from the current study in that the curiosity ratings were generated by a separate group of participants; we, therefore, aimed for a slightly larger sample size to ensure adequate power.

Materials

The task was presented on Apple Macintosh computers, using Matlab (2010) and the Psychophysics Toolbox (Brainard, 1997) to present stimuli and collect responses. Study stimuli included general interest trivia questions culled from Internet sources, including www.corsinet.com and www.triviaplaying.com. Examples included "Which poisonous snake smells like fresh cut cucumbers?" "What comet was first sighted by the Chinese in 240 B.C.?" and

"What does 'SPF' mean on sunscreen containers?" Participants saw 69 trivia questions in the initial trivia task. The same 69 questions were also used in both the curiosity-rating and subsequent memory components of the task explained in the Procedure section.

Preexperiment Valence Ratings

Across three separate trivia studies, we asked participants to rate the valence of trivia questions. These participants ($N = 102$, mean age $= 22.69 \pm 5.96$ years; 72 female, 30 male) were shown each trivia question and asked to rate how positive or negative they thought each question was on a 7-point scale ranging from 1 (*Very negative*) to 7 (*Very positive;* see Figure 1c). We pooled the results of these valence ratings to create average valence ratings for each question. We then ordered these questions on the basis of their valence ratings and conducted a split of 1/3, 1/3, 1/3, corresponding to valence categories of negative ($M = 3.36 \pm 0.32$), neutral ($M = 4.10 \pm 0.15$), and positive ($M = 4.78 \pm 0.33$). The mean valence ratings for each category differed significantly from each other, $F(2) = 147.10$, $p < .001$ (pairwise, Bonferroni-corrected t tests; all $ps < .001$).

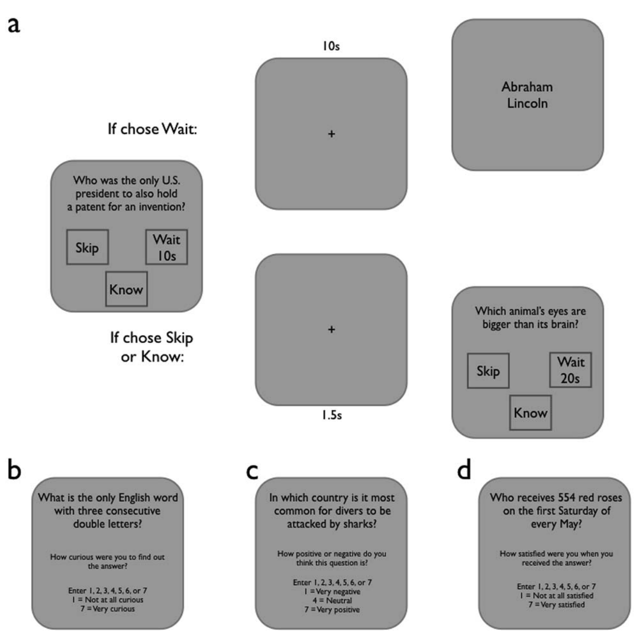

Figure 1. Experimental paradigm for testing the relationship between curiosity and willingness to wait for information. Panel a: In the primary task, participants were shown a trivia question and three possible response choices. If participants chose *Skip* or *Know,* they automatically advanced to the next question. If they chose *Wait,* they had to wait the designated amount of time, and then the answer was displayed. After completing the primary trivia task, participants were asked to generate curiosity ratings (Panel b), rating each question on a scale from 1 (*Not at all curious*) to 7 (*Very curious*) and satisfaction ratings (Panel d), rating each answer on a scale from 1 (*Not at all satisfied*) to 7 (*Very satisfied*). Participants in separate studies were shown these same questions and asked to generate valence ratings (Panel c), again on a scale from 1 (*Very negative*) to 7 (*Very positive*).

Procedure

First, participants read a brief set of instructions and completed a practice round of the trivia task. In the trivia task (see Figure 1a), participants were presented with each trivia question, along with three possible response choices: *Skip, Wait,* or *Know*. Participants had 8 s to read the question and choose their response. They were instructed that if they already knew the answer, they should press the *Know* key. They were instructed to press *Skip* if they did not know the answer but weren't interested in finding out the answer or weren't willing to wait the amount of time designated by the *Wait* option. After a brief fixation, both the *Skip* and *Know* responses were followed directly by the next question. Participants were instructed to press the *Wait* response if they did not know the answer and were interested in finding out the answer and willing to wait the amount of time designated. The time delays associated with the *Wait* option varied, in 5-s increments, from 10 to 30 s. Upon choosing this option, participants saw a fixation cross for the duration of the wait time, and then the answer appeared. Once they chose to wait, they could not change their choice. Once the answer was displayed, participants advanced to the next question by key press. Participants were instructed at the outset that the entire experiment would last 1 hr, regardless of their responses.

After the primary trivia task, participants were shown the same 69 questions and were asked to rate their curiosity upon first seeing each question, on a scale from 1 (*Not at all curious*) to 7 (*Very curious*). They were also asked to rate how satisfied they were with the answer, on a scale from 1 (*Not at all satisfied*) to 7 (*Very satisfied;* see Figure 1d).

Participants returned approximately one week ($M = 7.2 \pm 1.8$ days) after their initial sessions. During this follow-up session, participants saw the list of questions they'd seen the first day and typed in the answer to each question.

Analyses

All analyses were performed in R (R Core Team, 2013), and mixed effects logistic regression analyses were conducted using the lme4 package (Bates, Maechler, & Bolker, 2013). All *Know* trials were excluded from the analyses. Each trial for each participant was entered in as a separate data point, and mixed effects logistic regression models were run on the entire data set, with intercepts varying by participant; with trivia question as a random effect; and with other variables, including curiosity and delay time, included as both fixed and random effects. The exponential beta coefficients are reported for each model to allow for easier interpretation of each variable's effect.

Valence. First, we evaluated whether participants' choices to wait were informed by their curiosity and the valence of the question by running a mixed effects logistic regression analysis with the intercept varying randomly by participant, the trivia item as a random effect, and the valence category and individual curiosity ratings associated with each question as both fixed and random effects.

To analyze effects of memory, we excluded all *Skip* and *Know* trials, so that we examined only participants' memory for answers they chose to wait for. This eliminated one participant who did not wait for any answers, leaving 65 participants. We tested whether the valence of the information affected the likelihood of remembering it, running a mixed effects logistic regression analysis with the intercept varying randomly by participant, the trivia item as a random effect, and the individual curiosity ratings and prior valence category associated with each question as both fixed and random effects.

Information prediction error. For each question, we had the participants' ratings of curiosity about the question and satisfaction with the answer. Using these values, we calculated an information prediction error, that is, the difference between the actual value of the information received (satisfaction) and the anticipated value of the information (curiosity). For example, if a participant rated a question as a 4 in curiosity but a 6 in satisfaction, we considered that an information prediction error of +2; if the participant rated a question as a 4 in curiosity but the answer as a 2 in satisfaction, we considered that an information prediction error of −2. We then ran a mixed effects logistic regression model, with intercept varying by participant, trivia question as a random effect, and curiosity and information prediction error as both fixed and random effects.

Results

Valence

Participants' choices to wait were informed by their curiosity, as well as the positive valence of the question and the wait time associated with that trial ($e\text{^}\beta_0 = 0.04$, $p < .001$; $e\text{^}\beta_{\text{curiosity}} = 4.93$, $p < .001$; $e\text{^}\beta_{\text{wait time}} = 0.88$, $p < .001$; $e\text{^}\beta_{\text{negative}} = 1.02$, $p = .88$; $e\text{^}\beta_{\text{positive}} = 1.31$, $p < .01$; see Figure 2), such that participants were more likely to wait for information they were more curious about; less likely to wait for information associated with a longer delay; and more likely to wait for positive, compared to neutral, information.

Participants on average remembered 74.9% of answers correctly (range: 36.4%–97.4%). Participants' likelihood of remembering the answers correctly was predicted by their initial curiosity about the question and the positive valence rating associated with the question ($e\text{^}\beta_0 = 0.09$, $p < .001$; $e\text{^}\beta_{\text{curiosity}} = 1.79$, $p < .001$; $e\text{^}\beta_{\text{negative}} = 1.10$, $p = .35$; $e\text{^}\beta_{\text{positive}} = 1.36$, $p < .01$; see Figure 3), such that people were more likely to remember more-positive information and information about which they were more curious.

Information Prediction Error

We found that participants' likelihood of remembering an answer correctly was predicted by their curiosity about the question and the information prediction error (IPE) associated with that trial ($e\text{^}\beta_0 = 1.03$, $p > .05$; $e\text{^}\beta_{\text{curiosity}} = 1.26$, $p < .001$; $e\text{^}\beta_{\text{IPE}} = 1.19$, $p < .001$; see Figure 4), such that people were more likely to remember information for which there was a more-positive prediction error, that is, information for which satisfaction was greater than curiosity.

Discussion

We found that information—even trivial information—can function as a reward, guiding choices and learning in predictable ways. First, we found that the valence of information affects its reward value, with people more willing to wait for more-positive, compared to neutral, information. Moreover, this valence effect extended to memory, with a greater likelihood of remembering more-positive information. Second, we found that memory was better when there was a positive prediction error, that is, when the reward value upon receipt was greater than the anticipated reward value.

The importance of valence in these studies is particularly interesting given that it is critical to learning. Recent studies have offered some important insights into the mechanisms underlying biases toward positive information and different tendencies to learn from positive versus negative information (Frank et al., 2004; Sharot, Guitart-Masip, Korn, Chowdhury, & Dolan, 2012). The effects of valence on curiosity also raise questions about the possible role of emotion. Indeed, emotion may even serve as another form of information (Clore & Huntsinger, 2007; Schwarz, 2011). Although we did not directly measure emotion in this experiment, existing data provide a possible framework. In particular, taking a dimensional approach to emotion (Feldman Barrett

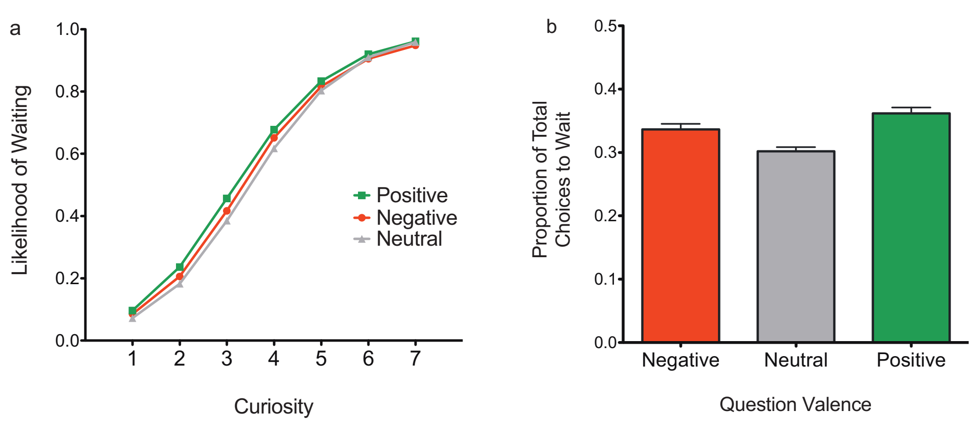

Figure 2. Participants were more likely to wait for more positive information. Panel a: To display the effects of curiosity and valence on waiting behavior, for graphing purposes, a pared-down model was run separately for questions in each valence category (negative, neutral, positive). Panel b: The raw proportion of waiting was calculated (the number of trials for which an individual chose to wait in each valence category divided by the total number of trials for which they chose to wait). The graph displays the mean proportions of waiting; error bars represent the standard errors of the mean. See the online article for the color version of this figure.

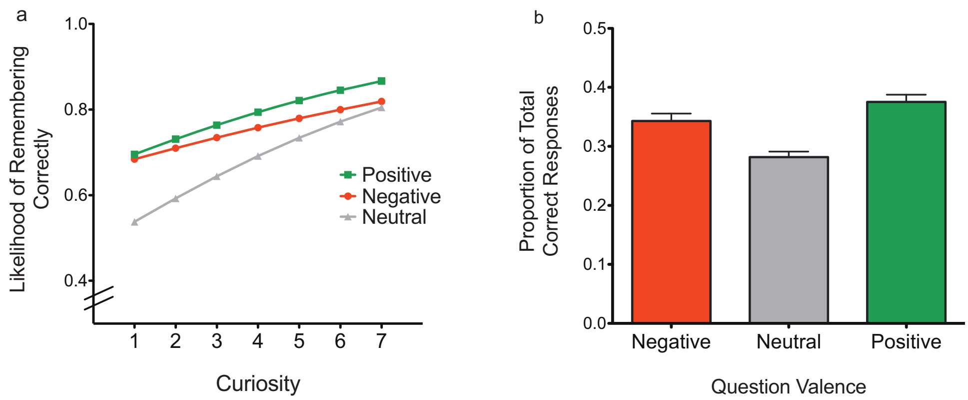

Figure 3. Participants were more likely to remember more-positive information. Panel a: To display the effects of curiosity and valence on subsequent memory, for graphing purposes, a pared-down model was run separately for questions in each valence category (negative, neutral, positive). Panel b: The raw proportion of correct responses was calculated (the number of trials for which an individual correctly remembered the answer in each valence category divided by the total number of answers they correctly remembered). The graph displays the mean proportions of correct answers; error bars represent the standard errors of the mean. See the online article for the color version of this figure.

& Russell, 1998; Posner, Russell, & Peterson, 2005; Russell, 1980), one might think of an individual's curiosity as reflecting an arousal state. Prior evidence has suggested that pupil dilation, a common measure of emotional arousal (Bradley, Miccoli, Escrig, & Lang, 2008), is greater in states of higher curiosity (Kang et al., 2009). Of course, compared to the types of stimuli typically used in experiments examining the effect of emotion on information seeking and memory, this information was relatively weak in arousal and valence. Still, our results regarding valence suggest useful tools for future work to more directly investigate the role of emotion in curiosity.

Curiosity can be difficult to define and is often conflated with other similar concepts, including interest (Grossnickle, 2014). We operationalized curiosity as the anticipation of reward, where the reward is information. Similarly, information can come in many forms and have a variety of uses, many of which might contribute to its reward value and valence. Here, we focused on trivia, because it offers a rich, multidimensional stimulus set, which has been used previously to examine curiosity (e.g., Gruber et al., 2014; Kang et al., 2009; Mullaney et al., 2014). One interesting feature of trivia is that it is information that, by definition, has no real utility and thus provides a conservative test of the information-as-reward hypothesis. Future work should determine to what extent our findings and those by others (e.g., Kang et al., 2009) generalize to other forms of information.

Prior literature has focused primarily on the anticipation associated with curiosity; here we additionally examined the impor-

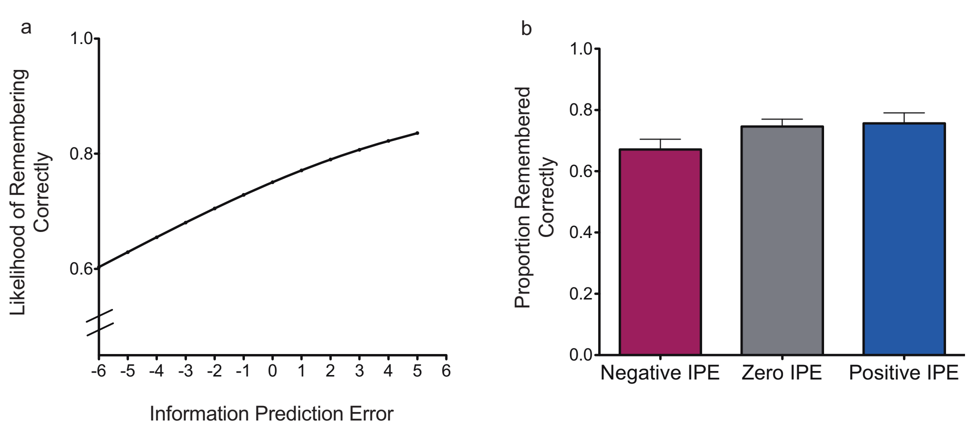

Figure 4. More-positive information prediction errors (IPE) predicted greater likelihood of remembering the answer correctly. Panel a: For graphing purposes, a pared-down model was run to depict the mean likelihood of remembering the answer, as a factor of information prediction error. Panel b: To further illustrate the differences on the basis of IPEs, IPEs were grouped into three categories (negative IPE, 0 IPE, and positive IPE), and the proportion of correctly remembered information was calculated in each IPE category for each individual. The graph displays the mean proportions across all individuals, with the error bars representing the standard errors of the mean. See the online article for the color version of this figure.

tance of satisfaction. Given that Loewenstein (1994) postulated that a core feature of curiosity is its tendency to leave the curious person unsatisfied, it is important to examine what happens when curiosity is satisfied and how satisfaction predicts subsequent learning. We found that curiosity is often satisfied and that the disparity between the anticipated versus received reward predicts later memory. This finding is consistent with recent animal studies of dopamine neurons (Bromberg-Martin & Hikosaka, 2011), suggesting that it may be important to consider both the value of information and the value of reward itself in reinforcement learning models (Oudeyer, Kaplan, & Hafner, 2007; Yamamoto & Ishikawa, 2010).

Understanding curiosity could have important implications for educational interventions and learning strategies for children in the classroom. It could also have implications for psychiatric and neurological disorders, particularly those that implicate dopaminergic systems, such as schizophrenia and Parkinson's disease. These disorders often list deficiencies in reward processing among their symptoms. It would, thus, be instructive to learn whether such deficits extend to information and, therefore, whether diminished curiosity might accompany some of these disorders.

References

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron, 50,* 507–517. http://dx.doi.org/10.1016/j.neuron.2006.03.036

Bates, D., Maechler, M., & Bolker, B. (2013). *lme4: linear mixed-effects models using 'Eigen' and S4*. Retrieved from http://CRAN.R-project.org/package=lme4

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. http://dx.doi.org/10.1037/11164-000

Berns, G. S., Chappelow, J., Cekic, M., Zink, C. F., Pagnoni, G., & Martin-Skurski, M. E. (2006, May 5). Neurobiological substrates of dread. *Science, 312,* 754–758.

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,* 602–614. http://dx.doi.org/10.1016/j.neuron.2014.12.050

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology, 45,* 602–607. http://dx.doi.org/10.1111/j.1469-8986.2008.00654.x

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10,* 433–436. http://dx.doi.org/10.1163/156856897X00357

Brashers, D. E. (2001). Communication and uncertainty management. *Journal of Communication, 51,* 477–497. http://dx.doi.org/10.1111/j.1460-2466.2001.tb02892.x

Bromberg-Martin, E. S., & Hikosaka, O. (2009). Midbrain dopamine neurons signal preference for advance information about upcoming rewards. *Neuron, 63,* 119–126. http://dx.doi.org/10.1016/j.neuron.2009.06.009

Bromberg-Martin, E. S., & Hikosaka, O. (2011). Lateral habenula neurons signal errors in the prediction of reward information. *Nature Neuroscience, 14,* 1209–1216. http://dx.doi.org/10.1038/nn.2902

Case, D. O., Andrews, J. E., Johnson, J. D., & Allard, S. L. (2005). Avoiding versus seeking: The relationship of information seeking to avoidance, blunting, coping, dissonance, and related concepts. *Journal of the Medical Library Association, 93,* 353–362.

Clore, G. L., & Huntsinger, J. R. (2007). How emotions inform judgment and regulate thought. *Trends in Cognitive Sciences, 11,* 393–399. http://dx.doi.org/10.1016/j.tics.2007.08.005

Daw, N. D., & Doya, K. (2006). The computational neurobiology of learning and reward. *Current Opinion in Neurobiology, 16,* 199–204. http://dx.doi.org/10.1016/j.conb.2006.03.006

Feldman Barrett, L., & Russell, J. A. (1998). Independence and bipolarity in the structure of current affect. *Journal of Personality and Social Psychology, 74,* 967–984. http://dx.doi.org/10.1037/0022-3514.74.4.967

Fischer, P., Jonas, E., Frey, D., & Kastenmüller, A. (2008). Selective exposure and decision framing: The impact of gain and loss framing on confirmatory information search after decisions. *Journal of Experimental Social Psychology, 44,* 312–320. http://dx.doi.org/10.1016/j.jesp.2007.06.001

Frank, M. J., Seeberger, L. C., & O'Reilly, R. C. (2004, December 10). By carrot or by stick: Cognitive reinforcement learning in parkinsonism. *Science, 306,* 1940–1943. http://dx.doi.org/10.1126/science.1102941

Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of Economic Literature, 40,* 351–401. http://dx.doi.org/10.1257/jel.40.2.351

Griffin, R. J., Dunwoody, S., & Neuwirth, K. (1999). Proposed model of the relationship of risk information seeking and processing to the development of preventive behaviors. *Environmental Research, 80*(2), S230–S245. http://dx.doi.org/10.1006/enrs.1998.3940

Grossnickle, E. M. (2014). Disentangling curiosity: Dimensionality, definitions, and distinctions from interest in educational contexts. *Educational Psychology Review, 26,* 1–38.

Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. *Neuron, 84,* 486–496. http://dx.doi.org/10.1016/j.neuron.2014.08.060

Hardisty, D. J., Appelt, K. C., & Weber, E. U. (2013). Good or bad, we want it now: Fixed-cost present bias for gains and losses explains magnitude asymmetries in intertemporal choice. *Journal of Behavioral Decision Making, 26,* 348–361. http://dx.doi.org/10.1002/bdm.1771

Hayden, B. Y., Parikh, P. C., Deaner, R. O., & Platt, M. L. (2007). Economic principles motivating social attention in humans. *Proceedings of the Royal Society B: Biological Sciences, 274* (1619), 1751–1756. http://dx.doi.org/10.1098/rspb.2007.0368

Hsieh, F. Y., Bloch, D. A., & Larsen, M. D. (1998). A simple method of sample size calculation for linear and logistic regression. *Statistics in Medicine, 17,* 1623–1634. http://dx.doi.org/10.1002/(SICI)1097-0258(19980730)17:14<1623::AID-SIM871>3.0.CO;2-S

James, W. (1890). *Principles of psychology*. http://dx.doi.org/10.1037/11059-000

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47,* 263–291. http://dx.doi.org/10.2307/1914185

Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science, 20,* 963–973. http://dx.doi.org/10.1111/j.1467-9280.2009.02402.x

LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience, 7,* 54–64. http://dx.doi.org/10.1038/nrn1825

Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116,* 75–98. http://dx.doi.org/10.1037/0033-2909.116.1.75

Loewenstein, G. (2006, May 6). The pleasures and pains of information. *Science, 312,* 704–706. http://dx.doi.org/10.1126/science.1128388

Matlab [Computer software]. Natick, MA: The MathWorks, Inc.

Mullaney, K. M., Carpenter, S. K., Grotenhuis, C., & Burianek, S. (2014). Waiting for feedback helps if you want to know the answer: The role of curiosity in the delay-of-feedback benefit. *Memory & Cognition, 42,* 1273–1284. http://dx.doi.org/10.3758/s13421-014-0441-y

Oudeyer, P. Y., Kaplan, F., & Hafner, V. V. (2007). Intrinsic motivation systems for autonomous mental development. *IEEE Transactions on Evolutionary Computation, 11,* 265–286.

Posner, J., Russell, J. A., & Peterson, B. S. (2005). The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and Psychopathology, 17,* 715–734. http://dx.doi.org/10.1017/S0954579405050340

Qiu, W. (2015). *powerMediation: Power/sample size calculation for mediation analysis* [Computer software manual]. Retrieved from https://cran.r-project.org/web/packages/powerMediation/powerMediation.pdf (R package version 0.1.3)

R Core Team. (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black, & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64–99). New York, NY: Appleton-Century-Crofts.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39,* 1161–1178. http://dx.doi.org/10.1037/h0077714

Schultz, W. (2006). Behavioral theories and the neurophysiology of reward. *Annual Review of Psychology, 57,* 87–115. http://dx.doi.org/10.1146/annurev.psych.56.091103.070229

Schultz, W., Dayan, P., & Montague, P. R. (1997, March 14). A neural substrate of prediction and reward. *Science, 275,* 1593–1599. http://dx.doi.org/10.1126/science.275.5306.1593

Schwarz, N. (2011). Feelings-as-information theory. In P. Van Lange, A. Kruglanski, & E. T. Higgins (Eds.), *Handbook of theories of social psychology* (pp. 289–308). Thousand Oaks, CA: Sage.

Schwarz, N., & Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *Journal of Personality and Social Psychology, 45,* 513–523. http://dx.doi.org/10.1037/0022-3514.45.3.513

Seymour, B., Daw, N., Dayan, P., Singer, T., & Dolan, R. (2007). Differential encoding of losses and gains in the human striatum. *Journal of Neuroscience, 27,* 4826–4831. http://dx.doi.org/10.1523/JNEUROSCI.0400-07.2007

Sharot, T., Guitart-Masip, M., Korn, C. W., Chowdhury, R., & Dolan, R. J. (2012). How dopamine enhances an optimism bias in humans. *Current Biology, 22,* 1477–1481. http://dx.doi.org/10.1016/j.cub.2012.05.053

Sweeny, K., Melnyk, D., Miller, W., & Shepperd, J. A. (2010). Information avoidance: Who, what, when, and why. *Review of General Psychology, 14,* 340–353. http://dx.doi.org/10.1037/a0021288

Tom, S. M., Fox, C. R., Trepel, C., & Poldrack, R. A. (2007, January 26). The neural basis of loss aversion in decision-making under risk. *Science, 315,* 515–518. http://dx.doi.org/10.1126/science.1134239

Wittmann, B. C., Schiltz, K., Boehler, C. N., & Düzel, E. (2008). Mesolimbic interaction of emotional valence and reward improves memory formation. *Neuropsychologia, 46,* 1000–1008. http://dx.doi.org/10.1016/j.neuropsychologia.2007.11.020

Yamamoto, N., & Ishikawa, M. (2010). Curiosity and boredom based on prediction error as novel internal rewards. In A. Hanazawa, T. Miki, & K. Horio (Eds.), *Brain-Inspired Information Technology* (pp. 51–55). http://dx.doi.org/10.1007/978-3-642-04025-2_8

Yang, Z. J., & Kahlor, L. (2013). What, me worry? The role of affect in information seeking and avoidance. *Science Communication, 35,* 189–212.

Received April 21, 2015
Revision received November 3, 2015
Accepted November 30, 2015 ■

Retraction of Förster (2011)

The following article from the August 2011 issue is being retracted: Förster, J. (2011). Local and global cross-modal influences between vision and hearing, tasting, smelling, or touching. *Journal of Experimental Psychology: General, 140*(3), 364–389. doi:10.1037/a0023175

The retraction is at the request of the author and the University of Amsterdam. This retraction follows the results of an investigation by the University of Amsterdam into the work of Jens Förster. The University requested the retraction of this article based on its qualitative judgement of "strong statistical evidence for low veracity". The author joined in the request for the retraction.

http://dx.doi.org/10.1037/a0040144