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Nature, Dimensionality, and Determinants

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Abstract: Curiosity has been a popular subject of inquiry by psychological scientists for over a century. Nevertheless, its nature, dimensionality, and determinants all remain surprisingly poorly understood. While there is general agreement on a "broad strokes" understanding of curiosity as a desire for new knowledge, the precise character of that desire and the specific behaviors it may motivate continue to spark considerable disagreement and debate. In this chapter, I discuss both previous and contemporary theory and research on curiosity as a psychological construct. I describe curiosity in terms of two types: D-type and I-type. D-type curiosity is theorized to reflect an uncomfortable "need to know" that becomes increasingly bothersome until satisfied by obtaining the desired specific pieces of missing information. I-type curiosity is theorized to be a more relaxed "take it or leave it" attitude towards the discovery of new information, in which the aim is simply to have fun while learning. Qualitative differences between I-type and D-type curiosity experiences – being motivated either to induce situational interest or reduce situational uncertainty, respectively – are hypothesized to translate into significant quantifiable differences in the extent to which each type of curiosity energizes behavior. Specifically, D-type curiosity is hypothesized to be associated with both more intense levels of state-curiosity and greater persistence in subsequent information seeking behavior as compared to I-type curiosity. Finally, future directions for research are discussed.

Historically, the experience and expression of curiosity has been conceptualized in terms of one of two ostensibly opposite and mutually exclusive motives for seeking out new information. The first account, commonly known as *curiosity drive theory*, viewed curiosity as an uncomfortable state of uncertainty brought about from exposure to novel, complex, or ambiguous stimuli. By gathering new knowledge about such stimuli, uncertainty could be reduced or eliminated, which was theorized to sate curiosity and be rewarding (e.g., Berlyne, 1950, 1960; Litman & Jimerson, 2004). The second account, typically referred to as the *optimal level of arousal theory of curiosity*, was based on evidence that in the absence of novel, complex, or ambiguous stimuli, individuals frequently chose to seek them out. This alternate account of curiosity claimed that people were motivated to maintain an "optimal" degree of arousal, which was pleasurable, achieved by interactions with stimuli capable of inducing situational interest (e.g., Day, 1971; Kashdan, Rose, & Fincham, 2004). In keeping with this approach, being over-aroused by extremely unusual stimuli or under-aroused (i.e., bored) by overly-familiar stimuli was theorized to be unpleasant (Berlyne, 1967; Leuba, 1955).

However, the drive and optimal arousal models of curiosity both fell short in that neither could comprehensively account for information-seeking behavior. If uncertainty was always intolerably distressing, it would be easier to try and avoid it entirely (Frenkel Brunswick, 1949; Furnham & Marks, 2013). On the other hand, if uncertainty was initially pleasurable, but investigation would unavoidably lead to over-familiarity and boredom, then why bother to learn anything new? This debate remained essentially unresolved for decades, with arguments for both a drive account (e.g., Loewenstein, 1994) and an optimal arousal account (e.g., Spielberger & Starr, 1994) touted well into the latter part of the twentieth century, coupled with the insistence that one view necessarily excluded the other. By the end of the twentieth century, the most common definition of curiosity was little more than a sheepish admission that no agreement on a meaningful definition exists (Keller, Schneider, & Henderson, 1994). Unfortunately, disagreements on the nature of curiosity have persisted into the twenty-first century (Grossnickle, 2014).

Interest and Deprivation Curiosity

In response to the long-standing lack of agreement among curiosity theorists, Litman and Jimerson (2004) posited that the seemingly contrary ideas espoused by the drive and optimal arousal perspectives were, in fact, *not* incompatible at all. Indeed, there is considerable evidence that suggests most motivational systems involve *both* reduction- and induction-oriented behaviors. Hunger and subsequent eating behavior, for example, can be stimulated by the uncomfortable pangs associated with a specific nutritional deficit, but can also be activated by the pleasing sight or smell of food (e.g., Cornel, Rodin, & Weingarten, 1989; Herman, & Polivy, 2004; Lowe & Butryn, 2007). Likewise, strictly psychological or social motives, such as desires for academic or job-related achievement, can involve striving to reduce a deficiency due to a perceived discrepancy between a current situation and a preferred one (i.e., feed-back self-regulation), as well as working toward the attainment of a brand new goal without identifying any particular deficiency in one's condition (i.e., feed-forward self-regulation; Carver & Scheier, 1998; Locke & Latham, 2002; Mullaney, Carpenter, Grotenhuis, & Burianek, 2014).

Based on these ideas, Litman and Jimerson (2004) reasoned that different types of curiosity could be aroused when individuals discover opportunities to learn something new, based solely on the expectation that this new information would generate pleasurable experiences of situational *interest* (Litman &

Spielberger, 2003; Renninger & Hidi, 2011). Alternatively, curiosity can also be activated when individuals decide they are missing key pieces of information needed to better understand something, in which case curiosity reflects a feeling of *deprivation* attributed to the present lack of desired knowledge (Litman, 2008, 2010; Litman, Crowson, & Kolinski, 2010; Loewenstein, 1994).[1] According to Litman and Jimerson (2004), experiences of interest-type (I-type) curiosity are expressed in situations where individuals do not feel they are missing any important pieces of information, per se, but rather find an opportunity to learn something new that is anticipated to be aesthetically pleasing or entertaining (e.g., getting to hear a new anecdote expected to be amusing). Deprivation-type (D-type) curiosity, on the other hand, is activated when individuals become aware that they have an incomplete understanding of something they want to make sense of (c.f., Chater & Loewenstein, 2016). If the missing information is found, it can be incorporated into a relevant repertoire of knowledge, eliminate a specific knowledge gap, and result in improved comprehension (e.g., being able to figure or find out the solution to a stymying logical problem).

Accordingly, D-type curiosity is theorized to reflect an uncomfortable "need to know" that becomes increasingly bothersome until satisfied by obtaining the desired specific pieces of missing information (Litman, 2005, 2008). By contrast, I-type curiosity is theorized to be a more relaxed "take it or leave it" attitude toward the discovery of new information, more broadly speaking, in which the aim is simply to have fun while learning.[2] These qualitative

1 Intuitively, experiences of interest and curiosity overlap but imply meaningfully different phenomena, even though both lay and scientific definitions commonly conflate the two. Hidi & Anderson (1992) posited that curiosity and interest differed in at least two important ways. First, curiosity is always associated with seeking *new* information, whereas this is not prerequisite for interest. Second, both reduction and induction accounts are based on evidence that increased contact with a curiosity-arousing stimulus always reduces curiosity; however, there is no evidence to suggest that interest declines similarly, and in fact, may intensify with greater contact. Put more precisely, interest tends to involve direct interaction with information perceived as *available*, whereas curiosity always involves a desire for information perceived as (presently) *unavailable*. In this context, I-type curiosity could be construed as a special case of situational interest, where the emphasis is on gathering new information anticipated to generate situational interest as evidenced by increased positive affect and sustained engagement, akin to aesthetic appreciation (c.f., Renniger & Hidi, 2016). On the other hand, Silvia (2005) has compellingly argued that situational interest can involve being engaged or immersed in a particular subject without positive affect. Using the Silvia definition, one could also make the case that D-type curiosity is a special case of interest as sustained attention aimed at completing knowledge sets. In this case, subsequent states of positive affect would be attributed to the reward associated with successfully reducing knowledge discrepancies rather than aesthetic appreciation.

2 One reasonable question to ask is whether I-type curiosity and D-type curiosity might as well be labeled as "Diversive Curiosity" and "Specific Curiosity," (Day, 1971) or as "Breadth" and "Depth" (Ainley, 1987; Langevin, 1971); the former suggests seeking out a relatively wide range of new information (i.e., simply seeking novelty might satisfy one's curiosity), while the latter suggests seeking out a very narrow range of information. However, there are several reasons why this explanation is less satisfactory than one rooted in the I/D distinction. First, there is no definitive or consistent way to scale the degree to which any unknown is relatively

differences between I-type and D-type curiosity experiences – i.e., being motivated either to induce situational interest or reduce situational uncertainty, respectively – are hypothesized to translate into significant quantifiable differences in the extent to which each type of curiosity energizes behavior. Specifically, D-type curiosity is hypothesized to be associated with both more intense levels of state curiosity and with greater persistence in subsequent information-seeking behavior as compared to I-type curiosity (Litman, Hutchins, & Russon, 2005).[3]

Psychometric Assessment, Correlates, and Dimensionality of I-type and D-type Curiosity

Psychometric research has been particularly helpful in the study of curiosity for two major reasons. First, although many outward information-seeking behaviors can be directly observed, the specific thoughts, feelings, and experiential states that underlie and give rise to their expression are far more difficult to measure directly. Second, psychometric research on curiosity has been useful for empirically evaluating the construct validity of theoretical ideas about its nature and dimensionality (e.g., Ainley, 1987), as well as for facilitating identification of the most valid and reliable indicators of curiosity (c.f., Gerbing & Anderson, 1988). As theoretical views on the nature of curiosity have evolved to reflect consideration of distinct "feelings of interest" and "feelings of deprivation," researchers have developed several new psychometric instruments, specially designed to assess individual differences in the experience and expression of Interest (I) type curiosity and Deprivation (D) type curiosity (see Litman and Silvia, 2006 for a detailed review and discussion).

broad or narrow in scope, nor has there ever been one developed. These labels have always been a greater source of confusion than clarity – indeed, Berlyne (1966) did not even consider "diversive exploration" to be motivated by curiosity, but rather an expression of *sensation seeking*. Second, the Diversive/Breadth and Specific/Depth labels do not impart any information about the relevant emotional-motivational experiences that might be involved in their arousal or satiation, making them functionally equivalent. In short, the concepts of I-type curiosity and D-type curiosity, and their distinction in experience and expression, *encompass and extend* beyond the less clear differentiation between Diversive/Breadth and Specific/Depth.

3 My use of the term "type" is occasionally a source of some feather-ruffling. My curiosity "types" are not meant to refer to people who are theorized to display *only* I-type *or* D-type curiosity. Rather, the term is meant to describe two relatively distinct subsets of emotional-motivational experiences and behavioral expressions that are found to diverge into meaningfully different, but not orthogonal, categories. The underlying determinants of this categorical distinction among indicators of curiosity are shorthand labels for two correlated dimensions of personality, in keeping with contemporary trait theory (c.f., Cloninger, 2009). More precisely, the terms "I-type" and "D-type" are overly simple descriptors for two broad dimensions of our sociocultural understanding of curiosity, and the complex interaction between those ideas and the activity of two specific brain systems that are implicated in appetite and pleasure (i.e., "wanting" and "liking," respectively; addressed in a later section of the chapter), including the relative magnitude of their activity and the distinct subjective experiences that follow.

Additionally, in keeping with the state-trait theory of curiosity (Spielberger & Starr, 1994), this line of research has also helped clarify the strength of the relationships between estimates of individual differences in I-type and D-type curiosity as dispositional traits and the degree to which such tendencies are predictive of the arousal of corresponding emotional-motivational curiosity states in real-time (Litman, Hutchins, & Russon, 2005).

Research on the interrelations among psychometric instruments designed to assess I-type and D-type curiosity have yielded three major sets of findings critical to evaluating their psychological meaningfulness. First, research has demonstrated that measures of I-type and D-type curiosity are moderately to strongly positively correlated with one another, as would be expected, given their shared association with desiring and seeking out new information (Litman & Silvia, 2006). Indeed, if they were only very weakly related, it would suggest that they mapped onto completely different constructs rather than psychologically distinct experiences and expressions of a common domain. Second, and consistent with the above finding, both I-type curiosity and D-type curiosity have been found to be either very weakly related or essentially uncorrelated with measures of conceptually unrelated constructs, such as extrinsic motives for material compensation and facets of Big Five Agreeableness, such as Compliance and Modesty (Litman, Crowson, & Kolinski, 2010; Litman & Mussel, 2013). The third major finding in psychometric research is that both types of curiosity are found to be associated with differences in individuals' orientations toward new knowledge, their use of relevant self-regulatory strategies, and their choices in setting self-directed learning goals. I-type curiosity and D-type curiosity are also found to differ in relation to the experience and expression of positive and negative affectivity, the magnitude of association with measures of conceptually relevant personality constructs (e.g., Big Five Openness), the intensity of experienced curiosity states, and the degree to which subsequent information-seeking behaviors are expressed.

Highly consistent with the theorized differences between I-type curiosity and D-type curiosity reviewed in the previous section, I-type curiosity is positively associated with orientations toward knowledge that manifest in novelty seeking and being more tolerant of ambiguity; self-regulatory strategies that involve optimistic appraisals about the unknown and a greater willingness to take risks in so doing; and setting learning-goals aimed primarily at learning new knowledge just for the fun of it. I-type curiosity is associated with positive affectivity and Big Five Openness. However, relative to its D-type counterpart, I-type curiosity is also associated with the arousal of generally lower intensity curiosity-states and the expenditure of less effort when given opportunities to actually seek out new information capable of satisfying it. In sum, I-type curiosity appears to correspond to exploring new things for the carefree pursuit of pleasure, but also corresponds to a relatively weak motive and less knowledge-seeking behavior, as compared to D-type curiosity. Quite different from I-type curiosity, D-type curiosity is found positively associated with using caution, deliberation, and judiciousness in the self-regulation of thinking and reasoning, and with setting learning-goals that define successful achievement on the basis of gaining knowledge that is objectively accurate and useful. D-type curiosity shows small positive associations to negative affectivity (consistent with an unsatisfied need-like condition) and is uncorrelated with positive affect. Although, like I-type curiosity, D-type is also positively related to Big Five Openness, it shows equally strong or stronger overlap with Conscientiousness (i.e., persistence). Also quite different from I-type curiosity, on the average, D-type curiosity is associated with the arousal of very intense curiosity-states and the exertion of greater effort when given opportunities to seek out new information expected to satiate its arousal (Lauriola et al., 2015; Litman, 2008, 2010; Litman, Hutchins, & Russon, 2005; Litman, Crowson, & Kolinski, 2010; Koo & Choi, 2010; Richards, Liman, & Roberts, 2013). Overall, these findings are highly consistent with the theorized distinction between I-type curiosity and D-type curiosity.

Psychometric studies of curiosity have also been especially helpful in elucidating its higher-order and lower-order dimensionality. Factor analytic research of curiosity measures has found that I-type and D-type curiosity may be conceptualized as higher-order factors that can be further differentiated into several lower-order dimensions (Litman & Silvia, 2006), each of which appear to map onto seeking out different "formats" of new information, including epistemic ideas, facts, or solutions to problems (Litman, 2012; Mussel, Spengler, Litman & Shuler, 2012); sensory-perceptual stimulation (Collins, Litman, & Spielberger, 2004); information about other people's experiences and feelings (Litman & Pezzo, 2007, 2012); and knowledge about the nature of one's inner self (Litman, Robinson, & Demetre, 2017). These lines of factor analytic research have also shed some light on the degree to which I-type curiosity and D-type curiosity may differentiate in regard to the *forms* of knowledge each motivates seeking out.

While I-type curiosity has been shown to manifest in seeking out virtually all forms of information (Litman & Silvia, 2006), D-type curiosity has been found to play a uniquely important role as a major theme in *intellectual* curiosity (Gruber Gelman, & Ranganath, 2014; Powell, Nettelbeck, & Burns, 2016) and inquisitiveness about *individuals in the social world* – both the self (i.e., intrapersonal) and others (i.e., interpersonal) – as evidenced by their degree of overlapping variance, common correlates, and shared reactions to uncertainty (e.g., Han et al., 2013). Additionally, the lower-order dimensions of curiosity identified in past research have also been found to further subdivide into factors on the basis of selectively targeted "sources" of new knowledge. In the case of intrapersonal curiosity (i.e., inquisitiveness about the inner self), for example, there is evidence of three distinct sub-factors, which include exploring the meaning of events from one's past, pondering one's identity and purpose in life, and endeavoring to make sense of one's feelings and motives (Litman, Robinson, & Demetre, 2017).

Although psychometric studies of I-type curiosity and D-type curiosity have been extraordinarily helpful in clarifying its nature and dimensionality, as noted in the beginning of this section, a major caveat of such research is that it provides mainly *indirect* glimpses of the relevant emotional-motivational states. To conduct a more direct investigation of state curiosity, we must consider not only the nature of the I-type and D-type constructs and their cross-contextual indicators, but also how these constructs *interact with situational phenomena in real time*. In the next section, theory and research findings on the situational determinants of curiosity as an emotional-motivational state, including the association between state curiosity and measures of the thoughts and feelings that are theorized to define the underlying traits, will be addressed.

Situational Determinants of State Curiosity: The Role of Metamemory and Trait Curiosity in the Activation of State Curiosity

Beginning in the late twentieth and early twenty-first century, along with a reassessment of the nature of curiosity and how to more precisely measure it, new theoretical and empirical work in this area also examined the situational determinants of curiosity as a transient emotional-motivational state, including the chain of underlying processes activated by those determinants. Historically, the arousal of state curiosity has been attributed to encounters with stimulus-events characterized as *novel*, *complex*, or *ambiguous* (e.g., Berlyne, 1950, 1960, 1966). These three terms describe situations in which individuals are most likely to recognize that some information pertaining to a relevant stimulus is missing, pointing to a discrepancy between information that is available and information that is currently unavailable but is desired to be known. This conceptualization of the situational determinants of state curiosity suggests that the primary function of curiosity is to energize seeking out and obtaining new information capable of resolving recognized discrepancies in our available knowledge (Litman, 2005; Loewenstein, 1994).[4] However, the stimulus conditions (e.g., novelty) that coincide with discrepancies in knowledge are not *physical* properties like shape or texture, because the extent to which something is regarded as relatively novel, complex, or ambiguous will depend entirely on the past experiences and available knowledge of the individual perceiver (Dember, 1960; Dember & Earl, 1957; Markey & Loewenstein, 2014). Knowledge discrepancies are therefore difficult to precisely control,

4 This view is actually somewhat in opposition to the "positive psychological" definition, which has tended to describe curiosity as a very general positive emotional-motivational approach system oriented primarily toward the overarching end goal of personal growth. Such theoretical approaches also tend to conflate curiosity with other constructs such as *play* and *creativity* (e.g., Kashdan, 2004). See Görlitz (1987) for a great deal of discussion on the pros and cons of taking this theoretical approach.

suggesting that consideration of the processes underlying their identification will be central to understanding the degree to which curiosity states are likely to be aroused.

Based on the idea that finding knowledge discrepancies requires an individual to evaluate differences between that which is known and unknown, Loewenstein (1994) reasoned that we identify discrepancies by explicit memory control and monitoring processes. In short, determining the magnitude of a knowledge discrepancy – or "information gap" – is a *metacognitive judgment*. As to the impact of that judgment, Loewenstein (1994) hypothesized that the degree to which curiosity is aroused will be inversely related to the magnitude of the perceived knowledge discrepancy. His prediction was rooted in the concept of the *approach gradient* (Miller, 1959), which holds that the intensity of motive-states peaks as one approaches goal achievement. Accordingly, Loewenstein reasoned that the greater the discrepancy, the further away individuals will perceive themselves from accomplishing their goal of discrepancy resolution, hence the anticipated inverse relationship between the size of the information gap and the intensity of state curiosity.

Prior research has shown that metacognitive judgments about the otherwise unretrievable contents of memory via explicit search correspond (albeit imperfectly) to the actual contents of our memory, suggesting that we are able to make generally accurate judgments about what we know and don't know (Koriat, 1998; Koriat & Levy-Sadot, 1999). Crucially, arriving at these judgments is not merely a cold cognitive process. The subjective states that accompany these processes, which individuals mindfully monitor and assess in order to arrive at a judgment, have a clear and distinctive affective component that may be thought of as a "metacognitive feeling state." Moreover, along with awareness and affect, metacognitive judgments about the contents of one's memory are found to energize engaging in either more or less *subsequent* cognitive effort expenditure, in terms of relevant memory search, retrieval, and evaluation of what (if anything) was retrieved. As such, we can consider the end result of these metacognitive processes to generate a specific, subjective *metacognitive experience* (ME) that reflects a categorically distinct form of metacognitive, affect-laden "knowing"[5] (Efklides, 2006, 2009, 2011).

5 Relatively recent work on the concept of knowledge-emotions (e.g., Silvia, 2017; D'Mello & Graesser, 2014) offers a viable framework for addressing the nature of curiosity as a cognitive-affective process that has potential to build on previous work on the role of MEs and state curiosity by endeavoring to account for cognitive processes that carry with them inherent affective meaning. However, at present this approach is not well suited to the study of curiosity; studies of "interest" as a knowledge-emotion overlap with – but do not differentiate between – aspects of both I-type and D-type curiosity as described in this chapter. Related work on "confusion" and "impasse-driven learning" (e.g., VanLehn, 1988), which is aimed at resolving confusion through problem-solving, may point to important analogs associated with expressions of D-type curiosity. I anticipate that work on knowledge-emotion and impasse-driven learning will prove to become important ideas in future work on curiosity.

One possible ME an individual might arrive at is to determine that no information is missing (i.e., aware of no appreciable discrepancy). Such determinations result in an "I *know* this" ME, characterized by varying degrees of confidence and surety in having access to the relevant knowledge. Other times, after a memory search an individual may conclude "I *don't know* this," which also involves subjective feelings that one is certain the information is *not* stored in memory. Both "know" and "don't know" MEs tend to be made rapidly and both typically result in discontinuation of further memory search. Finally, each tends to be predictive of relative recall or recognition accuracy in the expected direction (e.g., Koriat & Lieblich, 1974; Maril, Simons, Weaver, & Schacter, 2005; Maril, Wagner, & Schacter, 2001).

Other MEs involve determining that the targeted information is indeed stored *somewhere* in memory, but can only be *partially* retrieved, generating a "*feeling of knowing.*" Like "don't know" MEs, "feeling of knowing" also involves unsuccessful attempts to retrieve specific targets. However, unlike "don't know" states, "feeling of knowing" MEs are found to result in the retrieval of *some* knowledge from long-term storage, such as a close associate (Hart, 1965; Brown & McNeill, 1966; Mangan, 2000), to be further processed in working memory. Closely related to "feeling of knowing" is the tip-of-the-tongue (TOT) ME, which gives rise to very intense feelings that retrieval of the presently unavailable target is imminent (Brown, 1991; Burke & James, 2000; Widner, Otani, & Winkelman, 2005). Similar to "feeling of knowing" MEs, TOTs also involve either the incomplete activation of a target or the retrieval of strong associates rather than the desired target. Typically, greater overall activation and more robust affective experiences are associated with TOTs as compared to "feeling of knowing." Both "feeling of knowing" and TOT are positively correlated with recognition accuracy in subsequent memory tests. Particular to these "partial retrieval" MEs, both require individuals to carefully evaluate whatever they had retrieved into working memory – a situation that results in troublesome uncertainty and cognitive conflict that individuals are motivated to eliminate. Consequently, as compared to "don't know" or "know" MEs, TOT and "feeling of knowing" MEs are found to motivate individuals to expend additional time and effort searching for the desired target (Pannu, Kaszniak, & Rapcsak, 2005; Maril, et al., 2001, 2005; Young, 2004).

In keeping with Loewenstein's (1994) theoretical views about the impact of perceived relative magnitude of knowledge gaps on state curiosity, we would expect individuals to feel relatively close to their goal of discrepancy elimination during feeling of knowing and (especially) TOT MEs and experience very high levels of curiosity. However, during "don't know" MEs, individuals should feel relatively far from eliminating their knowledge discrepancy and, therefore, feel less curious. Finally, given that a "know" ME suggests that no appreciable amount of information is perceived as missing (i.e., essentially zero knowledge discrepancy), very little or no state curiosity should be activated. Only a few studies have tested these hypotheses to date, but they have all found essentially the same result: individuals experience more intense levels of state curiosity for learning new information when they report partial retrieval MEs (e.g., TOTs), an intermediate degree of curiosity for "don't know" MEs, and the lowest levels of state curiosity when they have "know" MEs (Kang et al., 2009; Gruber Gelman, & Ranganath, 2014; Litman, Hutchins, & Russon, 2005; Loewenstein, 1992, 1994; Metcalfe, Schwartz, & Bloom, 2017).

Building on Loewenstein's (1994) theoretical and empirical work,; Litman, Hutchins, and Russon (2005) asked participants whether they knew the answers to a series of general knowledge questions and examined the relationships between "know," "don't know," and TOT states for correct answers, self-reports of how much they wanted to find out the answers (i.e., state curiosity), and actual information-seeking behavior, based on tracking which answers each participant chose to look up by actively seeking them at the end of the study. Additionally, they examined whether individual differences in dispositional levels of I-type and D-type curiosity (in this case, intellectual or epistemic curiosity, as measured by two self-report scales) were positively associated with the intensity of state curiosity experiences and, as would be predicted by the state-trait theory of personality and emotional-motivational states (Spielberger & Starr, 1994).

First, consistent with Loewenstein's (1994) predictions, Litman and colleagues found that the highest levels of state curiosity were associated with TOT MEs, an intermediate level of state curiosity was aroused during "don't know" MEs, and the lowest levels were found for "know" MEs. Moreover, as would be expected, the extent to which participants engaged in information-seeking behavior at the conclusion of the study followed this pattern as well. In determining whether trait levels of I-type or D-type curiosity predicted the intensity levels of curiosity-states, separate path analyses conducted for each ME (i.e., TOT, "don't know," and "know") revealed that the relationships between state and trait curiosity depended on the specific ME that was reported.

When participants reported TOT MEs, the intensity of associated curiosity states was significantly predicted by the D-type scale but *not* the I-type scale; when participants reported "don't know" MEs, state curiosity was predicted by the I-type scale but *not* the D-type. For "know" MEs, state curiosity levels were found to be unrelated to *either* I-type or D-type curiosity. The relationships between the trait and state measures of curiosity that were empirically found are highly instructive in that they offer some additional insight into the relative affective tone of the curiosity states that were activated during the TOT and "don't know" MEs. These findings suggested that during TOT MEs, state curiosity tended to involve bothersome feelings associated with perceived information deprivation, as evidenced by the significant relationship with D-type trait curiosity. This is also consistent with prior work on TOTs that have described these MEs as characterized by feelings such as "tingling, torment, or turmoil" (Schwartz, Travis, Castro, & Smith, 2000, p. 19). In contrast, during "don't know" MEs, curiosity-states were more likely to involve pleasurable feelings of situational interest, given the significant relationship to I-type trait curiosity. Thus, Litman, Hutchins, and Russon's (2005) study not only further demonstrated that MEs influence the extent to which state curiosity is aroused, it also provided evidence that MEs can influence the *affective tone and subjective experience of state curiosity* as well, consistent with the I/D distinction.

Additionally, Litman, Hutchins, & Russon's (2005) findings raised important questions about why partial retrieval MEs (e.g., TOTs) and "don't know" MEs would be differentially related to D- or I-type curiosity, respectively; the findings also raised questions about why *neither* I- or D-type trait curiosity was predictive of levels of inquisitiveness for "know" MEs. First, D-type curiosity experiences are theorized to involve tension and reflect a motive to seek specific pieces of information in order to solve problems and reduce uncertainty; as previously noted, partial retrieval MEs (especially TOTs) are found to generate considerable cognitive conflict associated with approaching closure of a knowledge gap in order to arrive at an accurate conclusion, which is highly consistent with the concept of D-type curiosity. Second, D-type curiosity is theorized to correspond to an especially intense desire for missing information and greater determination and perseverance in resolving unknowns; partial retrieval MEs are found associated with especially strong levels of state curiosity and also to predict continued searching for targeted information in memory, which is also highly consistent with the D-type concept. Thus, both theoretical and empirical assessments of curiosity and metacognition suggest that partial retrieval MEs may underlie activation of D-type curiosity-states.

Turning to the degree of state curiosity associated with "don't know" MEs, why would there be a unique association with I-type curiosity but not D-type? Unlike partial retrieval MEs, "don't know" states do not involve being explicitly aware of having retrieved *any* potentially relevant knowledge, and therefore should not be associated with experiences of cognitive conflict or being motivated to continue searching in hopes of resolving uncertainty. It is therefore quite reasonable to expect that individuals would only be likely to choose to search for the missing information based on its expected ability to stimulate pleasurable states of situational interest, once discovered. As such, these findings are consistent with both the theorized affective nature of I-type curiosity and the hypothesized strength of I-type curiosity as a relatively weaker motive to seek-out new information. Thus, the findings suggest that "don't know" MEs may underlie activation of I-type curiosity states.

Lastly, the lack of *any* significant relationship between state and trait curiosity for "know" states raised questions about what, if anything, could be inferred about the nature of the curiosity-states associated with this ME? One possibility is that being curious about the correct answers during "know" MEs might reflect a desire for *performance feedback* (Park, Schmidt, Scheu, & DeShon, 2007). Put another way, if these answers were believed to have been already known *and* successfully retrieved, the only new information to be gained in seeking them out would be verification of questioned accuracy. Measures of relative certainty for a "know" ME that were taken in the study were negatively associated with levels of state curiosity, so this interpretation is logical. Although desiring performance feedback information could be construed as a kind of curiosity (i.e., wondering "how many did I get right?"), it might reflect acting primarily on ulterior motives associated with, say, self-esteem protection rather than a desire to learn new knowledge for its own sake.

Although the above commentary is primarily concerned with epistemic (i.e., intellectual) curiosity, as previously noted, D-type curiosity has been found to overlap with curiosity about other people (Litman & Pezzo, 2007; Han et al., 2013), and also about the inner self (Litman, Robinson, & Demetre, 2017), pointing to a common motive of closing knowledge gaps across these different expressions of inquisitiveness (Litman, Robinson, & Demetre, 2017). Accordingly, although most research on metacognitive processes has focused on linguistic representations of knowledge (i.e., words), the findings of several studies indicate that individuals engage in similar MEs for other kinds of information as well, including odors (Jönsson & Olsson, 2003) and visual images (Pannu, Kaszniak, & Rapcsak, 2005). There is also evidence that such monitoring processes are activated when attempting to solve mathematical or logical problems (Metcalfe & Wiebe, 1987), thus these phenomena are of potential value in studying many (if not all) dimensions of curiosity. In studies of sensory-perceptual curiosity, in which respondents attempt to arrive at a meaningful interpretation of an image, information gap magnitude has been operationalized in terms of the ratio of visual information that is available to that which is unavailable or blurred. These studies have also found that when individuals are working with a relatively small knowledge gap, they tend to experience greater levels of state curiosity (Jepma, Verdonschot, van Steenbergen, Rombouts, & Nieuwenhuis, 2012; Markey & Loewenstein, 2014).

Recent research also finds that even visual attention directed toward desired knowledge is reinforced via the anticipated satiation of curiosity states (Baranes, Oudeyer, & Gottlieb, 2015). Moreover, studies that have examined experiences of subjective activation have found evidence of improved memory for the relevant linguistic or visual information that was learned in the process of satiating those curiosity states (e.g., Gruber Gelman, & Ranganath, 2014; Jepma, Verdonschot, van Steenbergen, Rombouts, & Nieuwenhuis, 2012; Kang et al., 2009; McGillivray, Murayama, & Caste, 2015). Thus, there is a growing body of evidence that suggests satiating curiosity is a highly rewarding experience that plays an important role in directing our attention to new sources of knowledge and in successfully encoding that knowledge into memory, pointing to an *incentive-salience model* of curiosity and learning (e.g., Fowler, 1967; Marvin & Shohamy, 2016; Berridge & Robinson, 1998; Berridge, 2007, 2012).

Research findings on the situational determinants of curiosity that utilize the information gap/ME approach are highly consistent with findings on the nature and dimensionality of curiosity. However, while a consideration of the role of MEs, such as those reviewed in this section, provides a potentially fruitful set of methodological approaches to studying the situational determinants of emotional-motivational states of I-type and D-type curiosity, a clearer understanding of the neuroanatomical systems that ultimately underlie these cognitive-affective processes remains unclear but has attracted a great deal of attention recently by neuroscientists (Kidd & Hayden, 2015; Gottlieb, Oudeyer, Lopes, & Baranes, 2013). As such, the latest theory and research on likely candidates for the major brain substrates of curiosity beg some consideration, and will be addressed in the next section.

Underlying Neural Mechanisms: Advances in Neuroscience and Our Understanding of Reward Systems Involved in Curiosity

As with many phenomena of relevance to psychologists, identifying the major neurobiological systems that underlie the activation of emotional-motivational curiosity states, and the subsequent reward experienced by satiating such states, has been of great interest, particularly over the last decade. As noted in the first section, drive-based and optimal-arousal-based approaches to conceptualizing curiosity remain quite popular to this day. However, due to their many limitations, and to new findings in the field of affective neuroscience, these approaches have been largely abandoned as explanatory theories for emotional-motivational states and consequent experiences of reward when satiated (see Litman, 2005 for more commentary); curiosity should not be treated as an exception.

Recent research has suggested that an incentive-salience approach to evaluating curiosity may help clarify the nature of its experience and expression. In keeping with this approach, work by Berridge and colleagues on *wanting* and *liking*, a complex neural system that underlies the arousal of different appetites and their satiation, has been especially enlightening. "Wanting" refers to mesolimbic dopamine receptor activity and is theorized to underlie experiences of desire that motivate expressions of behavioral approach; "liking" corresponds to the activity of opioid receptors in the nucleus accumbens, for which greater activity corresponds to higher levels of hedonic impact (Berridge, 2012; Berridge & Robinson, 1998). Additionally, the amygdala, strongly implicated in subjective experiences of tension and distress (Shin & Liberzon, 2010), and the pre-frontal cortex, which plays an important role in impulse-modulation and associative learning (Berridge & Robinson, 2003a,b), are major components of the complete wanting-liking system.

The wanting and liking system has been implicated in desire and pleasure for food, water, drugs, and even sensory stimulation (e.g., Berridge & Winkielman, 2003). Berridge and colleagues find that greater wanting activation (i.e., appetite) corresponds to greater liking activity (i.e., pleasure) in response to receipt of the rewarding stimulus. Moreover, very high levels of wanting activation can create incentives for potential rewards akin to an organism being drawn to the desired stimulus as if it was a "motivational magnet." When wanting is high in a given situation, it may elicit compulsive approach; in the face of delayed reward, as when faced with momentary goal frustration (i.e., partial reinforcement effects), high levels of wanting activation correspond to response perseveration, which may be construed as "determination" to continue pursuing a wanted stimulus even if satiation is uncertain (c.f., Anselme, 2015).

However, research on wanting and liking finds that while the associated processes work cooperatively, their activity and impact on behavior can also be dissociated, meaning there can be a relative disparity between wanting and liking activity, which does not necessarily change in a one-to-one ratio (i.e., it is possible to be relatively high in one while being lower in the other). This finding points to a mechanism by which individuals can experience a wide range of different subjective states attributed to mismatches between the intensity of appetites and the subsequent pleasure derived from their satiation (Berridge, 2004; Berridge & Robinson, 2003a,b). Although liking will tend to be greater when preceded by higher levels of wanting (i.e., the old adage "hunger is the best spice" turns out to have a basis in neuroscience), rewarding stimuli can generate pleasure in the absence of any appreciable appetite. Using hunger and food consumption to illustrate these ideas, experiencing a high degree of wanting activation followed by equally high levels of liking might map onto conditions of sodium or glucose deprivation, for which the associated intense craving is expected to result in extreme pleasure once satiated by the desired nutrient, while low levels of wanting followed by relatively higher levels of liking would be analogous to snacking on chips or sweets in the absence of nutrient deprivation, because the salty or sweet taste is still inherently pleasurable. In short, research shows that while greater wanting makes a pleasurable stimulus more motivationally salient, more attractive, and more rewarding when attained, the experience of desire is dissociable from the hedonic (i.e., pleasure) value of a desired stimulus.

Regarding the subjectively felt affective experiences associated with wanting and liking, Berridge (2004, 2009) posits that liking is the primary neural substrate of pleasure from reward, and explicitly differentiates it from wanting (i.e., desire). However, Berridge tends to hedge his bets on attributing any specific subjective affective experience to wanting – at least in regard to dopamine receptor activity – and he describes it purely in relation to motivational intensity as evidenced by behavioral choice and the expenditure of effort in the pursuit of a reward (e.g., Berridge & Robinson, 2003a,b). This begs the question of what affective experience might be tentatively hypothesized as an analog of wanting.

As previously noted, another critical brain region in wanting and liking is the amygdala, the activation of which is strongly implicated in subjective experiences of tension, distress, and anxiety (e.g., Shin & Liberzon, 2010). In past research, lesions of the amygdala have been found to reduce or eliminate wanting specific stimuli, though such lesions have no impact on liking (Berridge & Robinson 1998). Related research also finds that amygdala stimulation can increase incentive salience – including guiding organisms to target and selecting a specific desired stimulus, even at the cost of eschewing other possible rewards. (Robinson, Warlow, & Berridge, 2014; Kumar et al., 2014; Mahler & Berridge, 2012). By contrast, amygdala stimulation can reduce the hedonic experiences that reflect liking, indicating that amygdala activity is central to wanting but not to liking (Kumar et al., 2014). Thus, consideration of the role the amygdala plays in wanting and liking potentially elucidates how the neural substrates of desire and reward map onto the conventional idea that appetites become gradually more uncomfortable as they increase in intensity, and that satiating such appetites with the relevant "to be liked" stimulus brings about both pleasure and, for more intense appetites, hedonic experience in the form of *both* pleasure and relief.

According to Litman (2005, 2010), the qualitative and quantitative differences found between I-type and D-type curiosity reflect subjective experiences that emerge due to the degree of an individual's initial wanting of new information and the relative degree of subsequent liking that results from learning it. In this context, the high levels of wanting activation are theorized to underlie the affective tone of emotional-motivational D-type curiosity-states (i.e., increasingly bothersome until sated), the intensity of the associated emotional-motivational states (i.e., strong), the expected degree or likelihood of engaging in information-seeking behaviors energized by those states (more persistence and greater likelihood, respectively), while approximately matched levels of liking account for the magnitude of reward value experienced when the desired knowledge is obtained (high degree of pleasure).

Accordingly, relatively low levels of initial wanting are theorized to underlie the affective tone of emotional-motivational I-type curiosity-states (generally pleasant), the intensity of the associated emotional-motivational states (modest), and the expected degree or likelihood of engaging in information-seeking behaviors energized by those states (less determined and lower likelihood, respectively), while comparatively high levels of liking account for the magnitude of reward value when desired knowledge is obtained (moderate degree of pleasure). Litman (2005) reasoned that these same wanting and liking processes might also correspond to the phenomenon of *processing fluency* (e.g., Reber, Schwarz, & Winkielman, 2004); I-type in regard to aesthetic appreciation and D-type in terms of sense-making (Chatterjee & Vartanian, 2014; Chater & Loewenstein, 2016).

Although the degree to which the neuroscience of wanting and liking maps onto the experience and expression of curiosity is still very much in its infancy, recent research has been promising. Gruber Gelman and Ranganath (2014), for example, found strong evidence that dopamine activity was positively associated with information search associated with a desire to find out answers to questions, while earlier work by Biederman and Vessel (2006) has shown that opioid activity occurs when we learn new information and incorporate it with knowledge stored in memory.

Concluding Thoughts

The preceding sections of this chapter addressed in some detail the long road in transitioning from early work on the nature and dimensionality of curiosity and different methodological approaches to studying its major situational determinants and subsequent outcomes to the current state of the science in the twenty-first century. In brief, the archaic and incompatible drive and arousal theories have begun to diminish in importance as explanatory models, while new work that builds on the relatively recently proposed I/D model, which incorporates and extends beyond classic approaches, has gained ground and proven to be quite fruitful. Moreover, the I/D model has shown promise in guiding the development of new valid and reliable psychometric instruments. Reconceptualizing novelty, complexity, and ambiguity in terms of metamemory rather than stimulus features has broken new ground in the study of curiosity's determinants (e.g., Metcalfe, Schwartz, & Bloom, 2017), and helped guide new work on the underlying reward mechanisms involved in curiosity based on the methods of contemporary affective neuroscience (e.g., Gruber Gelman, & Ranganath, 2014). Given that recent advances in a range of fields (such as psychometrics, assessment, metamemory, and neuroscience) over the last decade have opened many new paths to be explored in furthering our scientific understanding of curiosity, in the remaining sections I will elaborate on a few specific recommendations for scientists looking to conduct new research on curiosity.

Developmental Course of the Experience and Expression of I-type and D-type Curiosity

Along with a reevaluation of the nature, dimensionality, situational determinants, and underlying mechanisms associated with the experience and expression of curiosity, there has been a renewed interest in exploring the developmental course of curiosity (e.g., Jirout, & Klahr, 2012; Oudeyer & Smith, 2016). In consideration of the I/D distinction and earlier work in this area (e.g., Penny & McCann, 1964; Henderson & Moore, 1979), Piotrowski, Litman, and Valkenburg (2014) recently developed and validated new psychometric tools for assessing I-type and D-type dimensions of curiosity in children as young as three years of age. Building on the psychometric work by Piotrowski, Litman, and Valkenburg (2014), Sullivan and Litman (2017) very recently began reevaluating archival data on the facial expressions of *infants*, previously identified as conveying cognitive-perceptual engagement, and which have been variously labeled as expressing either "curiosity" or "interest."

Sullivan and Litman (2017) discovered two expressions in particular "leapt out" as potential indicators that may discriminate between I-type and D-type curiosity, respectively: one labeled as "Open Wonder" (OW) and a second that has been labeled as "Knit Brow" (KB) (Sullivan & Lewis, 2003). The OW face is notable for raised brows, wide open eyes, which is a common expression of positively valenced interest in adults (e.g., Kenza, Mohamed, & Hacene, 2015; Reeve, 1993), and for an absence of tension, as measured by stable vagal tone. The OW face is typically accompanied by positive affective vocalizations and little fussing. Quite different from the OW face, the KB expression was marked by lowering of the brows, and is typically found in situations hallmarked by challenge and uncertainty, accompanied by evidence of some tension on the basis of an unstable vagal tone. Moreover, when KB faces are displayed, infants will appear to engage in intense concentration (i.e., negatively valenced "interest"). Consistent with this interpretation of KB faces, in adults such expressions are commonly associated with the exertion of mental effort (e.g., Schwartz, 2005). If indeed these faces can be more clearly validated as expressions of infant I-type and D-type curiosity, it would provide a very useful tool for assessing the developmental course of experiences and expressions of I-type and D-type forms of inquisitiveness.

What is especially exciting is that there is clear evidence of the importance of these same facial expressions in inquisitive adults that has also been largely overlooked in regard to curiosity. Specifically, there are two highly relevant forms of non-manual grammatical facial expressions used cross-culturally in sign language when asking questions of others: the "Yes/No" (Y/N) expression and the "Who/What/Why/When/Where?" (Wh?) (Nguyena & Ranganath, 2010; Zeshan, 2004). The Y/N face is characterized by raised brows and wide eyes, quite similar to the infant OW expression, and is explicitly used to make queries when the inquisitive person has a complete lack of any appreciable knowledge relative to the topic in question. The Wh? face is characterized by lowered brows and narrowed eyes, and is explicitly aimed at inquiring about highly specific details to "flesh out" a partially known or understood topic for which there are specific information gaps to be filled; it is very similar to the infant KB expression. Moreover, all of these facial expressions show considerable overlap with expressions empirically found to be associated with thinking and problem-solving in previous research (e.g., King, 1996).

While it has been generally recognized that facial expressions are important for conveying both ideas and emotion to others in sign language (e.g., Benitez-Quiroz, Gökgöz, Wilbur, Martinez, 2014; Elliott & Jacobs, 2013), the degree of potential overlap between the Y/N and Wh? faces and interest/curiosity – and their apparent relatedness to distinct expressions of I-type and D-type curiosity as described in this chapter – has not been explored. Research is currently underway that will investigate the role of these "questioning" expressions in infants and adults, which point as potential windows into “the face of curiosity” (Litman, Russon, & Litman, 2017).

Thoughts on Curiosity in the Digital Age of Information

An especially important idea to keep in mind moving forward on studying curiosity into the twenty-first century is that due to the extraordinary access to information ushered in by the digital era of modern information technology, Millennials (and their younger siblings, “Generation Z,” as they are sometimes labeled) are able to chase new ideas or immerse themselves in research in a way that has simply not been possible for previous generations. Modern information storage and exchange has effectively created an “age of information,” radically altering the potential to explore the new, as well as delve much more deeply into any given topic, and to do so with far greater anonymity and freedom from social constraints (e.g., Schneider, Krogh, & Jäger, 2013; Spielberger & Starr, 1994) that might inhibit inquisitiveness from being expressed.

In the “information age,” individuals can easily search for almost anything they are curious about. This has impacted how we seek out and utilize information relevant to the arts, the sciences, human interaction, entertainment, investigation, design – virtually everything! This greater access to information has been transformative, opening the floodgates on our ability to act on I- and D-types of curiosity in ways only just beginning to be understood and utilized. Bearing these notions in mind, if the twenty-first century can be defensibly construed of as the “Information Age,” it has surely ushered in a “Curiosity Age” as well.

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