Educational Psychology Review (2019) 31:853–874
https://doi.org/10.1007/s10648-019-09497-x

REVIEW ARTICLE

Homo Curious: Curious or Interested?

Dajung Diane Shin [1] · Sung-il Kim [1]

Published online: 29 July 2019

Abstract

This review aims to clarify four perennial issues surrounding the concept of curiosity: its nature, conceptual distinction from situational interest, types, and educational implications. First, we argue that humans have evolved to be deeply curious to adapt to a world of uncertainty. Curiosity can be likened to an appetite for knowledge which can be satiated by specific information that fills a knowledge gap. Information-seeking behavior is determined by the expected availability of information using a cost–benefit analysis. Second, although curiosity and situational interest are often considered synonyms, we show that the two constructs differ in terms of their theoretical account, biological underpinnings, triggering factors, emotional valence, specificity of information searches, and relationship with individual interest. Unlike situational interest, which is the positive affect triggered by a wide variety of sources (e.g., autonomy, relatedness, competence), curiosity is an aversive cognitive state caused by an information gap. Situational interest follows the hedonic principle and is associated with opioid liking system in the brain. Curiosity, by contrast, is understood through drive theory and involves dopaminergic wanting system. Situational interest drives individuals to approach the stimulus while curiosity promotes the active seeking of missing information. Iterative cycles of curiosity resolution can lead to the development of individual interest. Third, we introduce two types of curiosity: curiosity for *what* (forward curiosity) is provoked by unpredictability, whereas curiosity for *why* (backward curiosity) arises from incongruity. Finally, driven by the unique characteristics of curiosity, we suggest ways to design learning environment that can nurture students' curiosity.

Keywords Curiosity · Appetite · Interest · Uncertainty · Incongruity · Fostering curiosity

Introduction

The drive to make sense of an environment, make inquiries, and uncover answers has been crucial to human survival. Curiosity, the desire for knowledge in the absence of extrinsic

✉ Sung-il Kim
sungkim@korea.ac.kr

[1] Department of Education and bMRI (Brain and Motivation Research Institute), Korea University, 145 Anam-ro, Seongbuk-gu, Seoul 136-701, South Korea

reward, is directly related to this drive (Markey and Loewenstein 2014). When individuals feel curious, they engage in persistent information-seeking behavior. Curiosity has been recognized as a powerful motivator for not only learning but also creativity and subjective well-being (Gallagher and Lopez 2007; Hardy III et al. 2017; Von Stumm et al. 2011). Despite its importance in education, the nature and mechanisms of curiosity remain poorly understood. In this review, we seek to address unresolved issues in curiosity, including its conceptual clarity, the distinctions from situational interest, various types, and educational implications. While curiosity is commonly understood with its state and trait forms, in the present review, our discussion on curiosity revolves around the state curiosity.

Various contextual features can evoke curiosity. In describing curiosity, Berlyne (1960, 1978) coined the term "collative variables" to describe factors that can trigger human curiosity, including novelty, incongruity, complexity, and uncertainty. These factors involve the collation of information from different sources, including the individual's own knowledge and perception (Berlyne 1978). Berlyne's conceptualization has been widely accepted, although he considered collative variables to be triggering factors for both curiosity and interest. Following on from this, more specific antecedents of curiosity have been proposed. Day (1982) posited that curiosity arises from the entry into a "zone of curiosity" in response to an optimal level of uncertainty. That is, curiosity dissipates when uncertainty is too high (i.e., there is a high level of collative variability) or too low (i.e., a low level of collative variability), leading to anxiety and boredom, respectively. Loewenstein (1994) pinpointed the information gap, the discrepancy between individuals' current knowledge state and the level of knowledge they wish to attain, as a direct cause of curiosity. Within this framework, the most important factors in the generation of curiosity are an individual's reference point of knowledge and their awareness of the unknown which is raised by curiosity-evoking stimuli (Kang et al. 2009; Markey and Loewenstein 2014). This information gap then creates a sense of deprivation, which naturally instills a desire to learn.

The Nature of Curiosity

Humans are deeply curious by nature. Just as we yearn to sate our hunger, we continuously strive to make sense of the odd, irregular, or novel aspects of the familiar and challenge the limits of our knowledge. Despite the consensus that curiosity is a strong human urge, many of the fundamental questions regarding the nature and mechanism of curiosity remain unanswered. In this section, we extend our understanding of curiosity by addressing three questions: (1) Why are we born to be curious?, (2) Is curiosity a cognitive hunger or appetite?, and (3) What determines information seeking?

Why Are we Born to Be Curious?

Because uncertainty is an aversive and anxious state in the face of new stimuli, the human mind has evolved to eradicate it (Wilson et al. 2005). Curiosity functions primarily as a coping mechanism for uncertainty. For example, when our ancestors came across a novel stimulus (e.g., strange animals, unknown plants, or other tribes), they would have felt the uncertainty or anxiety that naturally springs from a lack of information (James 1890/James 1950; Russell 1973). To reduce uncertainty, they would have needed to actively seek relevant information by approaching that novel stimulus. If this exploratory approach behavior significantly reduced uncertainties (e.g., awareness of harm or a selection of adaptive responses), cognitive equilibrium would have been reinstated, leading to emotional satisfaction.

This learning process based on curiosity and information seeking has long been reinforced by lowering errors and potential danger and increasing their chances of survival. It seems that humans have evolved to be curious to minimize uncertainty and maximize learning to master a dynamic environment. Indeed, curiosity drives individuals to explore and learn specific information in response to prediction error and the violation of expectations. Curious individuals engage in exploratory behaviors and pay close attention to relevant content, use greater resources even when they are scarce, and invest more effort until unknown information is attained (Baranes et al. 2015; van Lieshout et al. 2018).

Curiosity is associated with the primitive biological system that modulates learning and memory, including the hippocampus, noradrenergic system, and dopaminergic system (Kang et al. 2009; Oudeyer et al. 2016). The modulation of the hippocampus allows even irrelevant information associated with questions that provoked high curiosity to be remembered (Gruber et al. 2014). The noradrenergic and dopaminergic systems both have neuroprotective effects that may maintain cognitive function, well-being, and vigor (see Sakaki et al. 2018). Therefore, curiosity may mitigate declines in cognitive functioning with age and keep people healthy and happy by exploring and learning something new (Ruan et al. 2018).

Evolutionary pressure has also made information intrinsically rewarding (Gottlieb et al. 2013; Marvin and Shohamy 2016). This might be because the knowledge of the environment leads to instrumental benefits such as food or other essential resources, an argument that is supported by a number of common observations. For example, humans desire to learn about things that have no apparent utilitarian value or that are dangerous (Hsee and Ruan 2016; Oosterwijk 2017) and strive to collect more information than they need, as if seeking information for its own sake (Loewenstein 1994). In addition, curiosity-driven behaviors (e.g., the gaze of infants) are observed even in young individuals before they have enough experience to form an association between knowledge and practical advantages (Baillargeon and Graber 1987; Wynn 1992). These examples provide evidence that there is an inherent connection between information acquisition and hedonic experience.

The information-as-reward concept also makes biological sense (Kim et al. 2018). For instance, when people feel curious and expect the answers to trivia questions or the clear version of a blurry picture, reward areas in their brains, including the nucleus accumbens, are activated (Gruber et al. 2014; Jepma et al. 2012; Kang et al. 2009), indicating that the human brain responds to information as it does to food or sex.

Is Curiosity a Cognitive Hunger or Appetite?

The most enduring metaphor for curiosity is cognitive appetite (Loewenstein 1994). Both appetite and curiosity are powerful drives that share similar underlying mechanisms (see Fig. 1). Hunger (uncertainty) due to a lack of food (information) stimulates the appetite (curiosity), which leads to food-seeking (information-seeking) behavior and satiation (satisfaction) when food is consumed (the information gap is filled). In other words, appetite is a desire for food in order to reduce the physiological discomfort (i.e., the condition of inadequacy) of hunger, while curiosity is a desire for information in order to reduce the psychological discomfort of uncertainty.

Three additional properties underline the parallels between curiosity and appetite. First, both desires involve the anticipation of receiving a reward (Rogers and Brunstrom 2016; Oudeyer et al. 2016). The reverse relationship is also true; the anticipation of receiving

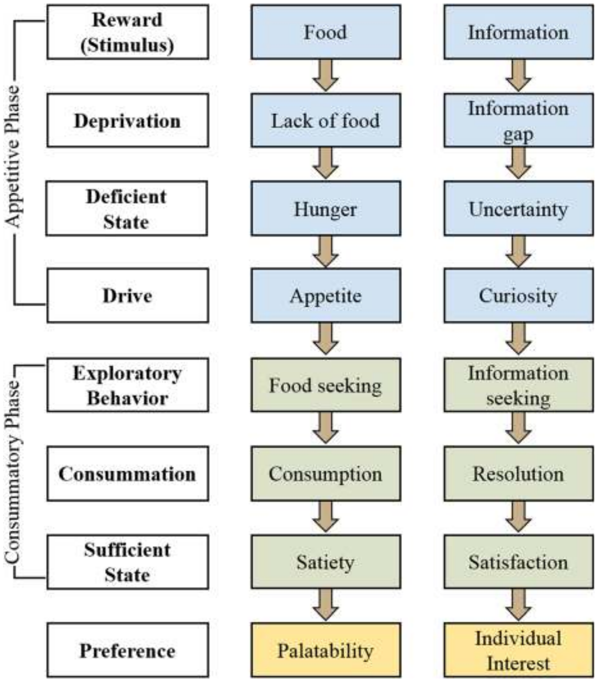

Fig. 1 Appetite analogy for curiosity. Hunger: Appetite :: Uncertainty: Curiosity. Hunger = Physiological discomfort caused by a lack of food. Uncertainty = Psychological discomfort caused by a lack of information. Appetite = Craving for food + Anticipation of reducing hunger. Curiosity = Craving for knowledge + Anticipation of reducing uncertainty

information or food intensifies curiosity and appetite, respectively (Golman and Loewenstein 2016; Weingarten and Elston 1990). Second, the iterative cycle of filling in the information gap or food consumption results in satisfaction, which may lead to the development of individual interest in a specific topic or palatability for a specific food. Third, although uncertainty and hunger are key antecedents of curiosity and appetite, respectively, curiosity and appetite can still arise in their absence (Berlyne 1978; Tiggemann and Kemps 2005). For instance, the presence of a favorite food or watching someone else eating that food can trigger the appetite without hunger. Likewise, exposure to information that matches one's individual interests can prompt the desire to know more without being uncertain. Nonetheless, just as food is most appealing when hungry, information is most valuable when optimally uncertain.

Although the appetite analogy of curiosity is illuminating, subtle differences exist. If an appetite is not satiated, it may lead to the failure of survival, whereas unsatiated curiosity can be dissipated by distraction. In this sense, curiosity is more similar to the sex drive. Another difference is that the intensity of appetite is proportional to the intensity of hunger, whereas the relationship between curiosity and uncertainty follows an inverted U-shaped function. That is, either too much information or too large information gap can kill curiosity.

What Determines Information Seeking?

Theories on curiosity presuppose that organisms engage in exploratory behavior to resolve curiosity (Berlyne 1954; Loewenstein 1994). Nevertheless, individuals do not always act to eliminate the information gap. Individuals are likely to engage in information-seeking behavior when the benefit of resolving curiosity is perceived to be greater than the cost. We explicate the factors that influence an individual's information-seeking behavior in terms of cost–benefit analysis.

The Benefit of Resolving Curiosity

The value of pursuing curiosity rests on how important and useful the information is to the individual in question (Golman and Loewenstein 2016) and how attainable the information is for them (i.e., expected availability; Kim 2013). Individuals tend to feel more curious when sensing an information gap for personally relevant, important, and useful topics and pursue more vigorous search because they expect greater satisfaction of resolving curiosity. Similarly, information expected to help individuals achieve superordinate goals (e.g., information relevant to their career aspirations or building and maintaining social relationships) is perceived to have greater value (Swann et al. 1981; van Lieshout et al. 2018). Individuals are more likely to engage in a curiosity-led search for this type of information.

The subjective value of resolving curiosity changes with the anticipation of acquiring information. Competence and the partial resolution of curiosity contribute to making the missing information more obtainable, thus increasing the value of resolving curiosity. When individuals have the ability to find an answer, they are more likely to perceive the desired information to be more learnable and to purposefully engage with their curiosity (Arnone and Small 2011; Linnenbrink and Pintrich 2003). The partial resolution of curiosity can also boost both an individual's competence and their anticipation of resolving their curiosity and thus induce persistent seeking behavior. Loewenstein and colleagues (1992, cited in Loewenstein 1994) examined the effects of partial resolution on subsequent curiosity by providing corrective feedback either immediately after the participants made a prediction or after all guesses were made. The partial resolution of curiosity through immediate feedback led to greater curiosity than delayed feedback. This suggests that the feeling of coming closer to the answer intensifies curiosity and prompts an individual to explore further. This aligns with the approach gradient, which posits that motivation increases as an organism nears its goal (Hull 1932; Markey and Loewenstein 2014).

The Cost of Resolving Curiosity

If the cost of resolving curiosity is perceived to be high, people are less willing to seek information (Sweeny et al. 2010). Of the various types of cost (e.g., Jiang et al. 2018), effort cost (i.e., the negative appraisal of the effort required to complete a task) and emotional cost (i.e., the negative emotions associated with task engagement) are the two most relevant to the decision to pursue curiosity. Individuals tend to tolerate uncertainty and maintain curiosity only when the effort cost is low. When the required effort to resolve their curiosity is too high, they are likely to abandon their curiosity. Again, competence can play a role here (Pintrich 2003); individuals with high competence in closing the information gap would underestimate the effort cost in the information exploration, whereas those with low competence would overestimate the effort cost and thus avoid information seeking.

Along the same lines, individuals do not approach the unknown without feeling that they are able to cope with it (Noordewier and van Dijk 2017; Sweeny et al. 2010). The expected emotional costs associated with both the process and the outcome of curiosity resolution affect the pursuit of curiosity, with greater emotional costs leading to less of an attempt to seek information. As mentioned above, the zone of curiosity dictates that a high level of uncertainty causes anxiousness and discourages engagement with the stimuli (Day 1982). At the same time, individuals take into consideration the resultant emotion after acquiring missing information. That is, people tend to avoid learning about information that could validate their negative predictions (e.g., gained weight, diagnosis result, cheating of spouse, or unchosen better alternatives) (known as the ostrich effect; Golman and Loewenstein 2016; van Dijk and Zeelenberg 2007).

Boredom-Based Exploration

The tendency of an individual to voluntarily explore and make themselves wonder has drawn research attention (Berlyne 1978; Loewenstein 1994), particularly the role of boredom in this process. For instance, Hsee and Ruan (2016) found that when students were left with no stimulation, they explored the environment more even when it resulted in an aversive outcome (i.e., electric shocks or disturbing sounds). Berlyne (1954) defined this as diversive curiosity, which serves to overcome boredom. This concept dovetails with the boredom drive theory (Myers and Miller 1954), which predicts that people feel an urge to generate tension in the face of monotonous stimulation. Nevertheless, we can cast doubt on whether diversive curiosity should be classified as curiosity because boredom may lead to sensation-seeking behavior without provoking curiosity. Although the relationship between boredom and curiosity remains unclear, it would be interesting to see whether boredom can be a spur for curiosity by driving people to explore their surroundings for novel cognitive stimulation.

Disentangling Curiosity from Interest

Consider three students—Peter, Paul, and Mary—in a science class, learning about the solar system. To facilitate their understanding of the planets, the teacher asks them to draw the eight planets. Peter has long wanted to become an astronomer. As a young kid, Peter was curious about why people do not live on other planets. Thus, he studied the characteristics of different planets and learned about their environment. The more he knows about the universe, the stronger his aspiration to go into space. To achieve his dream, he reads the latest astronomy articles and explores night sky to create his own star map. However, in today's class, Peter is not interested or curious because the content is too basic to him. Both Paul and Mary generally think science is dull but, during the class, Paul remembers hearing on television about nine planets in the solar system. He was surprised that the teacher introduced only eight planets. He wonders why the number of planets differs and what happened to one planet. These conspicuous gaps produce an acute feeling of discomfort in Paul. Paul pays close attention to the class, hoping that the teacher will give an explanation. Mary is fascinated by the group activity because she has a chance to draw with her friends. The teacher compliments her group's drawing for the perfect depiction of the solar system. Mary's interest has increased. At the end of the class, the teacher asks the class if they have any questions. Only Paul raises his hand and asks about the demoted planet.

In this example, Peter, Paul, and Mary represent Mr. individual interest, Mr. curiosity, and Ms. situational interest, respectively, and illustrate how they can arise in isolation, i.e., without any of the two states coinciding. However, debate still exists over the experiences of Paul and Mary, particularly whether curiosity and interest refer to distinct psychological processes (Bowler 2010; McGillivray et al. 2015) or whether they are two names for the same set of experiences (Fastrich et al. 2017; Silvia et al. 2009). Lacking a comprehensive understanding that could lay the confusion to rest, several fields rely on a foggy conceptual foundation that significantly limits educational applicability.

Distinguishing curiosity from situational interest has various advantages both in terms of theoretical and practical aspects. From a theoretical perspective, conflating curiosity and situational interest has hindered research. Situational interest has been broadly defined as a multifaceted, inclusive construct that contains both emotional and cognitive (i.e., curiosity) elements. As a consequence, the field of curiosity lacks even the basic understanding, including its types, measurement, and function. By parsing situational interest into emotional satisfaction and curiosity, we may be able to better conceptualize the genuine characteristics of each construct and advance scientific research in the fields of both curiosity and interest.

From a practical perspective, with its active seeking for specific knowledge, curiosity often has greater potential to develop into individual interest than situational interest does. In addition, educational practices to harness learners' curiosity may be different from those of situational interest. Strategies that work to elicit situational interest in the classroom could potentially undermine curiosity and vice versa. For instance, providing Paul with an opportunity to investigate the Earth's orbit around the Sun could distract him from exploring his curiosity about Pluto. Likewise, asking Mary a question about the solar system that she does not know could reduce her situational interest. Figure 2 illustrates our proposed distinctions between curiosity and situational interest and their relationship with individual interest.

Situational Interest Versus Individual Interest

Situational and individual interest are widely accepted phases of interest (see Frick 1992 for a different distinction of interestingness and interestedness). Situational interest involves the capture of attention triggered by the hedonic experience of interacting with environmental stimuli (e.g., autonomy, praise, and belongingness; Hidi and Harackiewicz 2000; Hidi and Renninger 2006; Mitchell 1993). Individual interest, by contrast, is a relatively stable characteristic that leads individuals to gravitate toward certain classes of stimuli and to reengage in certain activities (Renninger 1990). Repeated triggering of situational interest and acquisition of knowledge and value can lead to the development of emerging and well-developed individual interest.

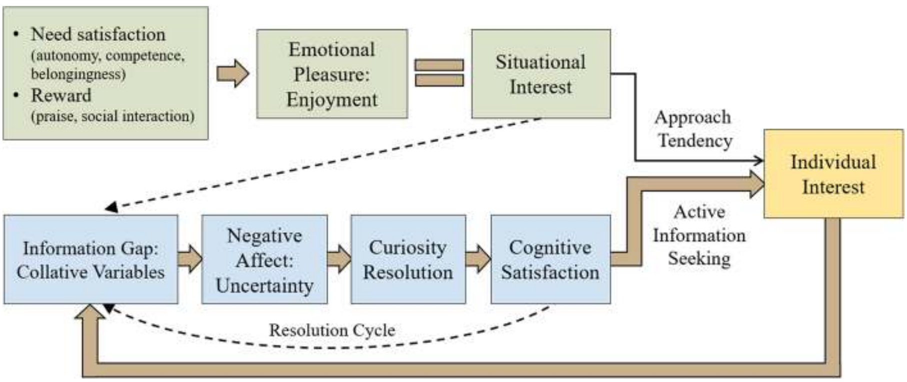

Fig. 2 Relationship between situational interest, curiosity, and individual interest

Situational and individual interest can be more clearly distinguished by the importance of their affective and cognitive components, respectively. Situational interest can be understood primarily with an affective component, whereas individual interest has more salient cognitive components, including stored knowledge and value. Although situational interest has been conceptualized as having both affective and cognitive components (Hidi and Renninger 2006), several evidence suggest that it is more fitting to view situational interest as an emotion (Schiefele 2009; Silvia 2005). For instance, Schiefele (2009) claimed that situational interest demonstrates characteristics typical of an emotion, such as facial expressions, being a physiological state (e.g., the level of activation), subjective experience (e.g., being fascinated or caught up in something), certain behaviors (e.g., time spent reading a text), and goals (e.g., the desire to explore). Neuroscientific evidence also supports this, suggesting that interest can occur without conscious cognitive evaluation (Berridge et al. 2009; Renninger and Hidi 2011). In addition, situational interest is assessed largely by asking people's emotional reactions to a task or topic (see Table 2 in Appendix), including enjoyment (e.g., Chen et al. 1999), fun or entertaining (e.g., Harackiewicz et al. 2008), liking (e.g., Linnenbrink-Garcia et al. 2010), and attractive or appealing (e.g., Zhu et al. 2009), further substantiating the conceptualization that situational interest is a positive emotion (but see Renninger and Hidi 2011 for the limitations of situational interest measures).

In contrast, advanced content knowledge and high value are core components that characterize individual interest (Hidi 2006; Renninger et al. 2002). People with individual interest are committed to deepening their understanding and are able to regulate their learning (Hidi and Renninger 2006; Renninger and Hidi 2019). They can generate own questions and exert effort to seek answers, even in the face of difficulties (Renninger and Hidi 2011). They are knowledgeable about various approaches to find relevant information, which helps them sustain in long-term, creative problem-solving (e.g., Azevedo 2013).

Curiosity Versus Situational Interest

There are cases that epitomize the longstanding confusion between the experience of curiosity and situational interest. For instance, Iran-Nejad (1987) argued that "a snake can be interesting without being liked" (p. 121). However, this may represent the experience of curiosity on the snake, not situational interest, because positive feeling is not present. A complete understanding of curiosity has long been impeded by the conceptual confusion created by the frequent use of situational interest and curiosity as synonyms in empirical studies and general conversation (Grossnickle 2016). Such confusion may have been exacerbated by quantitative measurements of both curiosity and situational interest (Kashdan and Silvia 2009; Alexander and Grossnickle 2016) (see Table 2 in Appendix).

For one thing, measures rely predominately on self-report surveys that are often transparent ("I am interested" or "I am curious"), which are susceptible to social desirability (Alexander and Grossnickle 2016). More problematically, measures of curiosity and situational interest suffer from both jingle (i.e., scales with similar names may measure different constructs) and jangle (i.e., scales with different names may measure similar construct) fallacies (Block 1995; Marsh 1994). Some situational interest measures are more appropriately seen as a measure of curiosity (e.g., "[this text] makes me curious" from Boscolo et al. 2011). The reverse case is also prevalent as some curiosity measures are indistinguishable from situational interest measures (e.g., "[I am] interested in discovering how things work" from Litman and Spielberger 2003). In other measures, curiosity and interest have been construed as a unified construct (e.g., the curiosity/interest dimension of the intrinsic orientation scale by Harter 1981).[1] These items cause researchers to fall into the trap of measuring a construct that is different from its label.

Despite the confused approach to curiosity and situational interest observed in past studies, researchers have recently laid out various dimensions that can be used to distinguish curiosity from situational interest (see Grossnickle 2016; Markey and Loewenstein 2014; Renninger and Hidi 2016). In line with these attempts, we summarize five dimensions that set curiosity apart from situational interest: (1) theoretical account, (2) biological underpinnings, (3) triggering factors, (4) related affect, and (5) information search.

Theoretical Account

Curiosity and situational interest can be distinguished most fundamentally by the diverging theoretical basis for the two constructs. Situational interest follows the general hedonic principle that people approach pleasure and avoid pain (Higgins 1997). Situational interest is positive affect (enjoyment and pleasure) generated by a particular stimulus that makes individuals approach it. Both the direct emotional satisfaction that comes from interacting with a pleasant stimulus and the conditioned positive emotional response to neutral stimuli are thought to strengthen approach tendencies (Berridge 2001).

In contrast, curiosity can be understood through the drive theory, which differs from the hedonic principle in several respects. Drive theory posits that an internal deficit leads to unpleasant arousal, which instigates exploratory behavior to restore the hedonic state of balance (Hull 1952). Curiosity is seen as a standard homeostatic drive (i.e., maintaining a stable internal state) similar to appetite and sexual desire. The curiosity drive is reduced by filling the information gap, resulting in the reestablishment of cognitive equilibrium. This resolution of curiosity reinforces information-seeking behavior in response to an information gap.

Biological Underpinnings

Two distinct neurobiological systems may underlie the experiences of curiosity and situational interest. Wanting and liking are two subcortical systems that constitute incentive processing (Berridge 2004; Berridge et al. 2009). Wanting or incentive salience is mediated by midbrain dopamine projection and elicits seeking behaviors in response to rewarding stimuli. Liking, on the other hand, is encoded by opioid activity in valuation brain regions (i.e., nucleus accumbens) and evaluates the hedonic impact of stimuli. The two processes are known to be cooperative but independent—it is possible to like something without wanting it and vice versa. Litman (2005) suggested that dopaminergic wanting system corresponds to the state of knowledge deprivation that demands satiation whereas opioid liking system corresponds to the state of pleasure expectation from

[1] Given the problems of directly asking the respondents about their curiosity and interest, several comparable approaches have been taken to assess the two constructs (for reviews see Grossnickle 2016; Renninger and Hidi 2011), including measuring related constructs, observation, willingness to spend scant resources (curiosity) and to choose tasks (situational interest), and fMRI imaging. Although these measures are viable alternatives, the validity of each measure is still in question. Triangulating assessment approaches and continuing the effort to develop a valid measure is necessary to accurately capture curiosity and situational interest and discern the subtle distinctions between the two.

engaging in or learning something interesting.[2] Thus, curiosity and situational interest may involve dissociable biological substrates.

Triggering Factors

Although both curiosity and situational interest are assumed to share antecedents, it is possible to identify different triggering factors (Hidi and Anderson 1992; Markey and Loewenstein 2014). First, content that is well organized and informationally complete is ideal for generating situational interest, while curiosity can be activated by incomplete and/or poorly organized material that creates an information gap. That is, comprehensibility is an essential requirement for situational interest (Kintsch 1980; Silvia 2008) whereas incompleteness and ambiguity are important sources of curiosity as they produce gaps in an individual's knowledge.

Second, the sources that generate situational interest are more diverse than those for curiosity. A wide range of sources that generate emotional satisfaction can trigger situational interest, including social interaction (Bergin 2016), availability of choice (Patall 2013), praise (Deci et al. 1999), and relevance (Cordova and Lepper 1996). In contrast, triggering of curiosity involves very specific factor—a recognizable information gap. Providing surprising, novel, incongruous, complex, and ambiguous stimuli can induce curiosity only when one recognizes an information gap. Even when curiosity-inducing stimuli are present, curiosity will not spark if the individual is unaware of the information gap. Riddles, questions, or stories with a twist are effective structures for triggering curiosity because the information gap is more noticeable (Kang et al. 2009; Stahl and Feigenson 2015).

Related Affect

Curiosity and situational interest are marked by contrasting emotional valence (Markey and Loewenstein 2014; Renninger and Hidi 2016). Situational interest is mostly associated with the experience of positive affect (Silvia 2005), while curiosity itself is an aversive state caused by information deprivation (Loewenstein 1994). The cognitive disequilibrium brought on by the lack of sufficient information leads to a feeling of discomfort. Fowler (1967) asserted that incomplete information inherently puts an organism in an aversive state, compelling it to alter the associated stimuli. A recent neuroimaging study has provided evidence that the brain regions associated with conflict and negative affect, such as the anterior insula and anterior cingulate cortex, are activated by curiosity about a blurry object (Jepma et al. 2012).

Curiosity is often confused for a positive experience because the anticipation of resolving curiosity, like the anticipation of reward, leads to positive affect. Several neuroimaging studies have provided evidence that curiosity activates reward-related brain regions when participants knew that they would be given the answers immediately after the presentation of trivia questions, which must have raised their anticipation level (Gruber et al. 2014; Kang et al. 2009).

One frequent misunderstanding regarding situational interest is that it can have a negative emotional valence (e.g., Ainley et al. 2005; Turner Jr. and Silvia 2006). However, we think that situational interest has a positive emotional valence, and situational interest toward an aversive

[2] Litman defined the two states as types of trait curiosity, former as curiosity as a feeling of "deprivation" (CFD) and the latter as curiosity as a feeling of "interest" (CFI). Our conceptualization of state curiosity is similar to the CFD, and we view that the CFI is similar to situational interest.

topic (e.g., horror movie or snake) involves satisfying curiosity. That is, if there is no curiosity about the topic or if curiosity is not resolved, situational interest would not arise. For example, despite negative features, a horror movie may be interesting only when the viewers' curiosity is aroused and resolved (e.g., identifying the killer, learning the killer's hidden motives, or knowing how the movie ends). Thus, the consequent situational interest in aversive stimuli may be the result of curiosity resolution, not the stimuli per se.

Information Search

The patterns of behavior generated by curiosity and situational interest differ from each other. Situational interest drives individuals to approach a stimulus in order to increase their enjoyment. The acquisition of a broad range of related information could be considered valuable and would be sufficient to produce emotional satisfaction. For instance, a student who feels situational interest in an astronomy class might approach general knowledge about astronomy rather than actively seeking specific information. Although increased tendency to approach knowledge is deemed beneficial for the development of individual interest (Hidi and Renninger 2006), a pitfall of this approach tendency is that it can easily ebb if the engagement is no longer satisfactory.

Curiosity, on the other hand, leads people to actively seek specific information until either that knowledge is gained or the curiosity is dissipated (Markey and Loewenstein 2014). This active exploration could be the genesis for learning and the development of individual interest. Individuals are not completely satisfied until they discover the information that restores cognitive equilibrium. For example, a student who is curious about why the moon shines only at night would strive to find a precise explanation. This curiosity would not be satisfied by obtaining peripheral information, such as the size and gravitational field of the moon. In research by Jepma et al. (2012), the activation of brain regions associated with reward processing was observed when participants saw a corresponding clear version of a blurred picture, not an unrelated clear picture. The participants also reported that they were disappointed when their curiosity in the blurred picture was not satisfied.

Curiosity: The Pathway to Individual Interest

The resolution of curiosity not only involves the acquisition of knowledge about the topic at hand but also enhances the value gained from satisfaction (Arnone et al. 2011; Loewenstein 1994). Successful resolution also leads to the expectation of satisfaction in future encounters and thereby encourages further curiosity, deeper information seeking, and subsequent resolution. Through this iterative curiosity–resolution cycle, individuals may construct a more elaborative knowledge network and build a foundation for individual interest[3] (Arnone et al. 2011; but see Renninger and Hidi 2011 for a different account).

The pathway from situational interest to individual interest, on the other hand, follows the Four-Phase Model of Interest Development (Hidi and Renninger 2006). Situational interest can develop into individual interest only when, in addition to positive affect, knowledge, and value are acquired (Renninger and Hidi 2011). Many processes of interest development are

[3] However, if the resolution of curiosity is found to be unsatisfying (e.g., the answer is dull), the expectation of satisfaction in future encounters would be low, thus discouraging the engagement in and resolution of similar curiosity experiences. In other words, the curiosity resolution cycle would weaken.

externally supported by features of the environment, such as other people, activities, and resources (Renninger and Hidi 2016). Without support, opportunities, or task affordance (e.g., challenges), there may be no re-engagement with the content, and interest in the topic may decline (Renninger and Hidi 2011). This contrasts with the development of curiosity in which the acquisition of value and knowledge occurs naturally after curiosity resolution and thus has a greater potential to instigate individual interest.

Both situational and individual interest may offer an opportunity to stoke curiosity. The more one enjoys a task, the more he approaches it and the greater the chance for him to become curious about the task. Here, individual interest would have a stronger potential to trigger curiosity than situational interest. Both the high value and extensive knowledge that are characteristic of individual interest encourage individuals to deliberately explore, pay attention, persist, and employ a wider range of approaches to find out more about the content of interest (Mikkonen et al. 2013; Renninger 1992), which consequently increases the frequency at which they experience curiosity (Loewenstein 1994). Furthermore, people with individual interest can purposefully create a knowledge gap using stored knowledge alone in the absence of curiosity-inducing stimuli by recognizing holes in their own schemata and activating currently unknown supplementary information that can be gained in theory (Coenen et al. 2018). Consistent with this argument, Boscolo et al. (2011) reported that when readers have high topic interest in a text, their curiosity ratings for paragraphs are significantly higher. For people with individual interest, generating curiosity through both external and internal means is an epistemic activity that enhances knowledge and satisfaction (i.e., it promotes voluntary exposure to curiosity) (Schiefele 2009). As such, these self-generated questions are assumed to require more in-depth and longer-term problem-solving.

Curiosity About What and Why

The experience of curiosity can take many forms, such as eagerly trying to recall someone's name, wanting to know the ending of a popular Netflix drama, searching the mechanism of a particular phenomenon on Google, and solving creative problems. However, this diversity is often explained away as individual differences, even though findings have suggested that an individual's curiosity can differ from moment to moment (Loewenstein 1994). Furthermore, unlike the predisposition form of curiosity (i.e., trait curiosity; the enduring propensity of an individual to seek new information; Kashdan et al. 2004; Litman and Silvia 2006), for which several frameworks have been suggested to account for its multifaceted nature (Litman 2005, 2010; Reio et al. 2006), comparable attempts have been scarce for state curiosity (Kidd and Hayden 2015). We thus propose a conceptual distinction of forward and backward curiosity according to its two primary determinants, unpredictability and incongruity. We believe that this distinction offers a more consistent set of principles that can categorize a diverse range of curiosity-like experiences and lay out important directions for future research.

Forward Versus Backward Curiosity

Of the various situational factors known to stimulate curiosity, uncertainty or unpredictability and incongruity are regarded as the two most direct ones (Berlyne 1962; Boykin and

Harackiewicz 1981; Kagan 1972). However, the curiosity elicited by these two sources differs in several respects, as summarized in Table 1. We refer to the curiosity elicited by unpredictability and incongruity as *forward* and *backward* curiosity, respectively.[4]

Unpredictability is similar to uncertainty which refers to a state in which an organism is devoid of information regarding when, where, or how an event has occurred or will occur (Berlyne 1960; Bar-Anan et al. 2009). Unpredictability contributes to distinct informational and subjective components of forward curiosity. The informational component is that forward curiosity is evoked by the lack of desired knowledge, while the subjective component is that forward curiosity involves an aversive feeling of uncertainty or anxiety (Kagan 1972). These characteristics provoke individuals to take action to understand what information is missing. However, given that we cannot possibly know everything, not all examples of unpredictability lead to forward curiosity unless a discernable information gap is created. Once this is established, a broad range of *what* questions can be generated, from simple yes/no to specific interrogative questions (Berlyne and Frommer 1966). Questions like "What is the oldest tree?", "Where do bugs go in the rain?", and "How do planes fly?" reflect forward curiosity.

Incongruity is another primary source of curiosity (Loewenstein 1994). It represents the contrast between expectations and unusual events, obvious mismatches, or unlikely pairings of cause and effect—all of which violate normal expectations (Bruner and Postman 1949). Backward curiosity, which arises from incongruity, has several unique characteristics that distinguish it from forward curiosity. First, incongruity occurs when an individual's prediction is proven incorrect (Brod et al. 2018). This differs from forward curiosity, which does not require a prediction to be made nor the accuracy of the prediction to be known. Second, backward curiosity requires a certain level of relevant knowledge (cf. the paucity of knowledge in forward curiosity) to make appropriate predictions and recognize incongruity (Ceci et al. 1981; Kim 1999). Thus, the conditions required for backward curiosity are more stringent than those for forward curiosity. Third, backward curiosity is marked by acute feelings of surprise followed by confusion (Brod et al. 2018; D'Mello et al. 2014; Kamin 1969). Fourth, whereas forward curiosity and unpredictability exhibit an inverse U-shaped relationship, backward curiosity has a linear relationship with incongruity; as the latter increases, the former becomes more intense in the search to explain the unexpected (Charlesworth 1964). Finally, backward curiosity leads individuals to actively search for the reasons why something has happened. Questions such as "Why do people enjoy fear?" and "Why is some inflation good?" reflect backward curiosity. Individuals make causal bridging inferences that link outcomes with potential causes and revise their knowledge after identifying the incident that fits the event structure.

Although forward and backward curiosity are distinguishable, the two have a reciprocal relationship and can occur together (see Fastrich et al. 2017 for a similar conceptualization). It is common for multiple forms of curiosity to be activated simultaneously in a sequence of events. For example, curiosity regarding the unknown outcome (forward curiosity) coincides with a desire to know whether the guess is correct (forward curiosity). Exposure to an unexpected outcome subsequently leads them to wonder why (backward curiosity) and can

[4] We use the term forward and backward to imply the different directions of inference or reasoning when individuals feel curious—i.e., reasoning forward to reach the answer vs. reasoning backward from the answer to understand the explanation. This distinction comes from studies on text comprehension (e.g., McKoon and Ratcliff 1992), which posit that readers engage in two types of inferences while reading: forward (i.e., predicting an upcoming event) and backward (i.e., bridging a current event to prior ones).

Table 1 Differences between forward and backward curiosity

	Forward curiosity	Backward curiosity
Question elicited	What	Why
Cause	Unpredictability	Incongruity or violation of expectations
Relationship with the cause	Inverted U	Linear
Knowledge	Minimal knowledge	Moderate to high knowledge
Prediction	Not necessary	Necessary
Affect	No surprise	Surprise
Purpose of exploration	Knowledge acquisition	Knowledge revision (reconstruction)
Cognitive engagement	Relatively superficial	Deeper engagement

generate another case of forward curiosity based on the lack of explanation as well as the accuracy of the ensuing causal inferences.

The Power of Surprise

A valid reason to distinguish between forward and backward curiosity, even though they have a close phenomenological relationship, is to highlight the power of backward curiosity in learning. Incongruity has been regarded as essential to learning. Formal models of reinforcement learning and reward prediction error have postulated that learning will not occur if there is no violation of expectations (Kim 2013; Schultz 2006; Oudeyer et al. 2016). This notion has consistent empirical support, with a rich body of behavioral and neuroscientific evidence indicating that prediction errors releases dopamine and triggers new learning (e.g., the hypercorrection effect; Butterfield and Metcalfe 2006; Schultz et al. 1997; Marvin and Shohamy 2016). This is because incongruity spurs greater cognitive engagement from making predictions, more active causal searches when expectations are not met, and conceptual change after a resolution is found (Brod et al. 2018; Butterfield and Metcalfe 2006; Greenberger et al. 1967; Itti and Baldi 2009). Unlike unpredictability, people inevitably engage in effortful causal searches once presented with incongruity, even when the resultant inferences are of little practical importance to them (Berlyne and Frommer 1966; Maheswaran and Chaiken 1991). This evidence suggests that backward curiosity may be an optimal starting point when seeking to promote student learning.

Despite these advantages, students are ignorant about the benefits of backward curiosity and naively believe that immediate certainty would be of greater aid to their learning (Huelser and Metcalfe 2012), suggesting the need for educational guidance geared toward nurturing students' backward curiosity. We outline some practical ways to foster backward curiosity in the following section.

Curiosity in Practice

Learning without curiosity is like eating without appetite. Despite the widespread acceptance of curiosity as a potent motivator for learning, little effort has been spent in designing learning environment that cultivates learners' curiosity. Rather, schools tend to suppress student curiosity by not allowing mistakes or the opportunity to explore and think deeply (Archer et al. 2017). Here, we identify factors that discourage student curiosity and suggest ways to promote it (see also Shin et al. 2019).

Optimal Knowledge Gap

The first step to instigate curiosity is creating an optimal knowledge gap and helping students to be aware of it. A simple way to achieve this is to introduce cognitive incongruity immediately after providing students with basic knowledge in a particular subject. Presenting an exception that deviates from previously learned knowledge surprises learners and leads them to ask for further explanation (i.e., backward curiosity). This is likely to result in deep cognitive exploration and superior learning. Providing ill-defined problems or implementing problem-based learning are also effective strategies that can generate knowledge gap. Alternatively, teachers can pose provocative questions that contradict learners' common sense or intentionally withhold critical information instead of introducing it all at once (Wright et al. 2018).

The Value and Cost of Information-Seeking

Even if learners are aware of the information gap, they will not pursue curiosity unless they believe that the missing information is valuable. Questions which students can work on progressively can increase the value of the answers at each step. Students can learn to value the information gained more by successfully resolving each step of their curiosity. Another way to increase the value of gaining information is to enhance the personal relevance of the information. For instance, personalizing the learning material (e.g., Cordova and Lepper 1996) or explaining the real-world applications or instrumentality of the learned material in attaining the students' superordinate goals (Coenen et al. 2018; Swann et al. 1981) have been found to work effectively in increasing the value of learning material.

The process of searching for information to resolve curiosity requires the investment of cognitive effort. However, if perceived effort cost is too high, it prevents learners from engaging in cognitive exploration. To reduce this, enhancing the interest and competence of the learner is critical in the initial stages of curiosity development. Presenting questions with interesting classroom activities or appropriate scaffolding can promote student interest (Song 2015) and competence (Linnenbrink and Pintrich 2003; Meyer and Turner 2002), respectively, and thus reduce the perceived effort cost. Ultimately, learners will realize that accepting the immediate cost in resolving their curiosity will lead to long-term benefits such as cognitive satisfaction and better learning.

The Art of Feedback

To pursue their curiosity, students must learn to enjoy being curious. Feedback from teachers and classroom assessment can inspire students to view curiosity as an enjoyable and helpful experience for their learning and reinforce the processes of generating and maintaining curiosity. For instance, if students are complimented for asking questions or attempting a new exploration, they are likely to develop a positive attitude toward being curious and engage in curiosity-related behavior more frequently (Saxe and Stollak 1971). Prompt informative feedback on errors (as opposed to a delayed and simple indication of whether something is right or wrong), such as the timely identification of incongruity and the reasons for an error, can encourage reflexive perception of backward curiosity and lead to in-depth cognitive exploration to rectify their mistakes and to close the knowledge gap (Crooks 1988; Kim et al. 2018; Mullaney et al. 2014).

The outcome-oriented assessment and normative evaluation can undermine students' curiosity. Excessive competition stemming from normative evaluation may promote anxiety about competence and a tendency to avoid novel and challenging tasks because those tasks can lead to failure (Kim et al. 2010; Lee and Kim 2014). Thus, assessments should be criterion-referenced rather than norm-referenced in order to minimize concern about relative performance and focus on individual improvement (Ames 1992; Crooks 1988). In this learning environment, learners are more likely to perceive unexpected novel information as a curious problem and actively seek solution instead of being intimidated by potential failure.

Conclusion

In this review, we have addressed some unanswered issues regarding human curiosity, including its nature, distinct features, and pedagogical strategies to promote it. Four insights can be offered based on our review. First, curiosity allows us to remain adaptive through constant learning. We learn more and learn better, in a world of uncertainty, by pursuing our motivation to understand unknown phenomena. Second, despite the confusion to date, curiosity and situational interest should not be considered interchangeable; they differ in their generation, procession, and development into individual interest. Differentiating curiosity and situational interest can pave the way for theories and measures to be refined, ultimately leading to design optimal learning environment. Third, classifying forward and backward curiosity provides a deeper understanding of the different properties of curiosity. Fourth, pedagogical strategies designed to nurture curiosity require a careful approach in terms of material, context, and feedback. Teachers and parents should surprise learners with meaningful contradictions in their schemata and inspire them to search for answers.

Although research on curiosity has been reviving its momentum in recent years, further study is needed to provide theoretical and practical advances in the field. Future research should focus on identifying factors that influence the pursuit or avoidance of information that satisfies curiosity, comparing the effects of the immediate versus delayed resolution of curiosity, examining the relationship between boredom and curiosity, and investigating individual differences in terms of curiosity initiation and maintenance. Another important avenue of systematic research is investigating the outcomes of curiosity. For example, future work can examine the effects of curiosity on problem-solving, creativity, and well-being, and how the iterative resolution of curiosity for one specific topic can lead to individual interest.

Acknowledgments We thank Hyun Ji Lee and Glona Lee for sharing their thoughts on distinguishing curiosity from interest.

Funding This research was supported by the College of Education, Korea University Grant in 2019.

Appendix

Table 2 Self-report measures of situational interest and curiosity

Citation	Sample item
Situational interest	
Mitchell 1993	– Our class is **fun**. – This year I **like** math.
Schraw et al. 1995	– I thought the story's topic was **fascinating**. – The story really grabbed my attention.
Chen et al. 1999	– This activity is interesting. – It is **fun** for me to try this activity.
Harackiewicz et al. 2008	– I think the lectures are interesting. – I **enjoy** coming to lecture.
Tsai et al. 2008	– I **liked** the topic. – The topic was interesting to me.
Zhu et al. 2009	– My physical education classes are … very **fun** ~ very boring.
Rotgans and Schmidt 2009, 2011	– I will **enjoy** working on today's topic. – *I want to know more about today's topic*
Boscolo et al. 2011	– [The text] makes me *curious*. – [The text] strikes me.
Linnenbrink-Garcia et al. 2010	– I **enjoy** coming to lecture. – This year, my math class is often **entertaining.**
Tapola et al. 2013	– Working on these tasks seems to be … not at all interesting ~ very interesting.
Knogler et al. 2015	– When you think of the previous module's sessions, to what extent were the sessions **exciting** for you? – When you think of the previous module's session to what extent did you *want to find out more* about the topics in the sessions?
Fastrich et al. 2017	– *How curious are you about the answer*? – What level of interest did you feel when you were presented with the answer?
Curiosity	
Harter 1981	– Does child *read out of interest*? – Does child ask questions to learn?
Naylor 1981	– I *feel interested in things*. – I want to know more.
Kashdan et al. 2004[a]	– I would describe myself as someone who actively seeks as much information as I can in new situation. – When I am *actively interested in something*, it takes a great deal to interrupt me.
Litman and Jimerson 2004; Litman and Spielberger 2003[a]	– *Enjoy learning about subjects* which are unfamiliar. – Conceptual problems keep me awake thinking about solutions.
Baranes et al. 2015; Gruber et al. 2014; Kang et al. 2009	– How curious are you about this question?
Marvin and Shohamy 2016; Mullaney et al. 2014; Noordewier and van Dijk 2017	– How curious were you to find out the answer/To what extent are you eager to find out [the answer]?
Wright et al. 2018	Indicate your… – *Interest in* [the topic] – Curiosity toward [the topic]

Note. Scales are organized by year of the citation. Words that are boldfaced and shaded indicate the predominant use of emotional terms to assess situational interest. Items that are underlined and italicized represent jingle-jangle fallacies

[a] Trait curiosity measures

References

Ainley, M., Corrigan, M., & Richardson, N. (2005). Students, tasks and emotions: Identifying the contribution of emotions to students' reading of popular culture and popular science texts. *Learning and Instruction, 15*(5), 433–447.

Alexander, P. A., & Grossnickle, E. M. (2016). Positioning interest and curiosity within a model of academic development. In K. R. Wentzel & D. B. Miele (Eds.), *Handbook of motivation at school* (pp. 188–208). New York, NY: Routledge.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology, 84*, 261–271.

Archer, L., Dawson, E., DeWitt, J., Godec, S., King, H., Mau, A., Nomikou, E., & Seakins, A. (2017). Killing curiosity? An analysis of celebrated identity performances among teachers and students in nine London secondary science classrooms. *Science Education, 101*(5), 741–764.

Arnone, M., & Small, R. (2011). Arousing and sustaining curiosity: Lessons from the ARCS model. *Proceedings of the Annual National Conference of the Association of Educational Communications and Technology (AECT)*, Anaheim, CA, 1995. Available at SSRN: https://ssrn.com/abstract=1782259

Arnone, M., Small, R., Chauncey, S., & McKenna, H. (2011). Curiosity, interest and engagement in technology-pervasive learning environments: A new research agenda. *Educational Technology Research and Development, 59*(2), 181–198.

Azevedo, F. S. (2013). The tailored practice of hobbies and its implication for the design of interest-driven learning environments. *The Journal of the Learning Sciences, 22*(3), 462–510.

Baillargeon, R., & Graber, M. (1987). Where's the rabbit? 5.5-month-old infants' representation of the height of a hidden object. *Cognitive Development, 2*(4), 375–392.

Bar-Anan, Y., Wilson, T. D., & Gilbert, D. T. (2009). The feeling of uncertainty intensifies affective reactions. *Emotion, 9*(1), 123–127.

Baranes, A., Oudeyer, P. Y., & Gottlieb, J. (2015). Eye movements reveal epistemic curiosity in human observers. *Vision Research, 117*, 81–90.

Bergin, D. A. (2016). Social influences on interest. *Educational Psychologist, 51*(1), 7–22.

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*, 180–191.

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. New York, NY: McGraw-Hill.

Berlyne, D. E. (1962). Uncertainty and epistemic curiosity. *British Journal of Psychology, 53*(1), 27–34.

Berlyne, D. E. (1978). Curiosity and learning. *Motivation and Emotion, 2*(2), 97–175.

Berlyne, D. E., & Frommer, F. D. (1966). Some determinants of the incidence and content of children's questions. *Child Development, 37*(1), 177–189.

Berridge, K. C. (2001). Reward learning: Reinforcement, incentives, and expectations. In D. L. Medin (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 40, pp. 223–278). San Diego, CA: Academic Press.

Berridge, K. C. (2004). Motivation concepts in behavioral neuroscience. *Physiology & Behavior, 81*(2), 179–209.

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: 'Liking', 'wanting', and learning. *Current Opinion in Pharmacology, 9*(1), 65–73.

Block, J. (1995). A contrarian view of the five-factor approach to personality description. *Psychological Bulletin, 117*(2), 187–215.

Boscolo, P., Ariasi, N., Del Favero, L., & Ballarin, C. (2011). Interest in an expository text: How does it flow from reading to writing? *Learning and Instruction, 21*(3), 467–480.

Bowler, L. (2010). The self-regulation of curiosity and interest during the information search process of adolescent students. *Journal of the American Society for Information Science and Technology, 61*(7), 1332–1344.

Boykin, A. W., & Harackiewicz, J. (1981). Epistemic curiosity and incidental recognition in relation to degree of uncertainty: Some general trends and intersubject differences. *British Journal of Psychology, 72*(1), 65–72.

Brod, G., Hasselhorn, M., & Bunge, S. A. (2018). When generating a prediction boosts learning: The element of surprise. *Learning and Instruction, 55*, 22–31.

Bruner, J. S., & Postman, L. (1949). On the perception of incongruity: A paradigm. *Journal of Personality, 18*(2), 206–223.

Butterfield, B., & Metcalfe, J. (2006). The correction of errors committed with high confidence. *Metacognition and Learning, 1*(1), 69–84.

Ceci, S. J., Caves, R. D., & Howe, M. J. (1981). Children's long-term memory for information that is incongruous with their prior knowledge. *British Journal of Psychology, 72*(4), 443–450.

Charlesworth, W. R. (1964). Instigation and maintenance of curiosity behavior as a function of surprise versus novel and familiar stimuli. *Child Development, 35*, 1169–1186.

Chen, A., Darst, P. W., & Pangrazi, R. P. (1999). What constitutes situational interest? Validating a construct in physical education. *Measurement in Physical Education and Exercise Science, 3*(3), 157–180.

Coenen, A., Nelson, J. D., & Gureckis, T. M. (2018). Asking the right questions about the psychology of human inquiry: Nine open challenges. *Psychonomic Bulletin & Review*, 1–41.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology, 88*, 715–730.

Crooks, T. J. (1988). The impact of classroom evaluation practices on students. *Review of Educational Research, 58*(4), 438–481.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153–170.

Day, H. I. (1982). Curiosity and the interested explorer. *Performance and Instruction, 21*(4), 19–22.

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*(6), 627–668.

Fastrich, G. M., Kerr, T., Castel, A. D., & Murayama, K. (2017). The role of interest in memory for trivia questions: An investigation with a large-scale database. *Motivation Science, 4*(3), 227–250. https://doi.org/10.1037/mot0000087.

Fowler, H. (1967). Satiation and curiosity: Constructs for a drive and incentive-motivational theory of exploration. *Psychology of Learning and Motivation, 1*, 157–227.

Frick, R. W. (1992). Interestingness. *British Journal of Psychology, 83*(1), 113–128.

Gallagher, M. W., & Lopez, S. J. (2007). Curiosity and well-being. *The Journal of Positive Psychology, 2*(4), 236–248.

Golman, R., & Loewenstein, G. (2016). Information gaps: A theory of preferences regarding the presence and absence of information. *Decision, 5*, 143–164.

Gottlieb, J., Oudeyer, P. Y., Lopes, M., & Baranes, A. (2013). Information-seeking, curiosity, and attention: Computational and neural mechanisms. *Trends in Cognitive Sciences, 17*(11), 585–593.

Greenberger, E., Woldman, J., & Yourshaw, S. W. (1967). Components of curiosity: Berlyne reconsidered. *British Journal of Psychology, 58*(3-4), 375–386.

Grossnickle, E. M. (2016). Disentangling curiosity: Dimensionality, definitions, and distinctions from interest in educational contexts. *Educational Psychology Review, 28*(1), 23–60.

Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. *Neuron, 84*(2), 486–496.

Harackiewicz, J. M., Durik, A. M., Barron, K. E., Linnenbrink-Garcia, L., & Tauer, J. M. (2008). The role of achievement goals in the development of interest: Reciprocal relations between achievement goals, interest, and performance. *Journal of Educational Psychology, 100*, 105–122.

Hardy, J. H., III, Ness, A. M., & Mecca, J. (2017). Outside the box: Epistemic curiosity as a predictor of creative problem solving and creative performance. *Personality and Individual Differences, 104*, 230–237.

Harter, S. (1981). A new self-report scale of intrinsic versus extrinsic orientation in the classroom: Motivational and informational components. *Developmental Psychology, 17*(3), 300–312.

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review, 1*(2), 69–82.

Hidi, S., & Anderson, V. (1992). Situational interest and its impact on reading and expository writing. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 215–238). Hillsdale, NJ: Lawrence Erlbaum.

Hidi, S., & Harackiewicz, J. M. (2000). Motivating the academically unmotivated: A critical issue for the 21st century. *Review of Educational Research, 70*(2), 151–179.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.

Higgins, E. T. (1997). Beyond pleasure and pain. *American Psychologist, 52*, 1280–1300.

Hsee, C. K., & Ruan, B. (2016). The Pandora effect: The power and peril of curiosity. *Psychological Science, 27*(5), 659–666.

Huelser, B. J., & Metcalfe, J. (2012). Making related errors facilitates learning, but learners do not know it. *Memory and Cognition, 40*(4), 514–527.

Hull, C. L. (1932) The goal-gradient hypothesis and maze learning. *Psychological Review, 39,* 25-43

Hull, C. L. (1952). *A behavior system; an introduction to behavior theory concerning the individual organism*. New Haven, CT, US: Yale University Press.

Iran-Nejad, A. (1987). Cognitive and affective causes of interest and liking. *Journal of Educational Psychology, 79*, 120–130.
Itti, L., & Baldi, P. (2009). Bayesian surprise attracts human attention. *Vision Research, 49*(10), 1295–1306.
James, W. (1950). *Principles of psychology (Vols. 1 & 2)*. New York: Dover **(Original work published 1890)**.
Jepma, M., Verdonschot, R. G., Van Steenbergen, H., Rombouts, S. A., & Nieuwenhuis, S. (2012). Neural mechanisms underlying the induction and relief of perceptual curiosity. *Frontiers in Behavioral Neuroscience, 6*(5), 1–9.
Jiang, Y., Rosenzweig, E. Q., & Gaspard, H. (2018). An expectancy-value-cost approach in predicting adolescent students' academic motivation and achievement. *Contemporary Educational Psychology, 54*, 139–152.
Kagan, J. (1972). Motives and development. *Journal of Personality and Social Psychology, 22*(1), 51–66.
Kamin, L. J. (1969). Predictability, surprise, attention and conditioning. In B. Campbell & R. Church (Eds.), *Punishment and aversive behavior* (pp. 279–296). New York: Appleton.
Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T. Y., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science, 20*(8), 963–973.
Kashdan, T. B., & Silvia, P. J. (2009). Curiosity and interest: The benefits of thriving on novelty and challenge. In S. J. Lopez & C. R. Snyder (Eds.), *Oxford handbook of positive psychology* (pp. 367–374). New York, NY: Oxford University Press.
Kashdan, T. B., Rose, P., & Fincham, F. D. (2004). Curiosity and exploration: Facilitating positive subjective experiences and personal growth opportunities. *Journal of Personality Assessment, 82*(3), 291–305.
Kidd, C., & Hayden, B. Y. (2015). The psychology and neuroscience of curiosity. *Neuron, 88*(3), 449–460.
Kim, S. (1999). Causal bridging inference: A cause of story interestingness. *British Journal of Psychology, 90*(1), 57–71.
Kim, S. (2013). Neuroscientific model of motivational process. *Frontiers in Psychology, 4*, 98.
Kim, S., Lee, M., Chung, Y., & Bong, M. (2010). Differential brain activation during norm-referenced versus criterion-referenced feedback: The moderating role of perceived competence and performance-approach goals. *Contemporary Educational Psychology, 35*(2), 141–152.
Kim, S., Hwang, S., & Lee, M. (2018). The benefits of negative yet informative feedback. *PLoS One, 13*(10), e0205183. https://doi.org/10.1371/journal.pone.0205183.
Kintsch, W. (1980). Learning from text, levels of comprehension, or: Why anyone would read a story anyway. *Poetics, 9*(1-3), 87–98.
Knogler, M., Harackiewicz, J. M., Gegenfurtner, A., & Lewalter, D. (2015). How situational is situational interest? Investigating the longitudinal structure of situational interest. *Contemporary Educational Psychology, 43*, 39–50.
Lee, W., & Kim, S. (2014). Effects of achievement goals on challenge seeking and feedback processing: Behavioral and fMRI evidence. *PLoS One, 9*(9), e107254. https://doi.org/10.1371/journal.pone.0107254.
Linnenbrink, E. A., & Pintrich, P. R. (2003). The role of self-efficacy beliefs in student engagement and learning in the classroom. *Reading and Writing Quarterly, 19*(2), 119–137.
Linnenbrink-Garcia, L., Durik, A. M., Conley, A. M., Barron, K. E., Tauer, J. M., Karabenick, S. A., & Harackiewicz, J. M. (2010). Measuring situational interest in academic domains. *Educational and Psychological Measurement, 70*(4), 647–671.
Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition & Emotion, 19*(6), 793–814.
Litman, J. A. (2010). Relationships between measures of I- and D-type curiosity, ambiguity tolerance, and need for closure: An initial test of the wanting-liking model of information-seeking. *Personality and Individual Differences, 48*(4), 397–402.
Litman, J. A., & Jimerson, T. L. (2004). The measurement of curiosity as a feeling of deprivation. *Journal of Personality Assessment, 82*(2), 147–157.
Litman, J. A., & Silvia, P. J. (2006). The latent structure of trait curiosity: Evidence for interest and deprivation curiosity dimensions. *Journal of Personality Assessment, 86*(3), 318–328.
Litman, J. A., & Spielberger, C. D. (2003). Measuring epistemic curiosity and its diversive and specific components. *Journal of Personality Assessment, 80*(1), 75–86.
Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116*(1), 75–98.
Maheswaran, D., & Chaiken, S. (1991). Promoting systematic processing in low-motivation settings: Effect of incongruent information on processing and judgment. *Journal of Personality and Social Psychology, 61*(1), 13–25.
Markey, A., & Loewenstein, G. (2014). Curiosity. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 246–264). London and New York, NY: Routledge.

Marsh, H. W. (1994). Sport motivation orientations: Beware of the jingle-jangle fallacies. *Journal of Sport and Exercise Psychology, 16*(4), 365–380.

Marvin, C. B., & Shohamy, D. (2016). Curiosity and reward: Valence predicts choice and information prediction errors enhance learning. *Journal of Experimental Psychology. General, 145*(3), 266–272.

McGillivray, S., Murayama, K., & Castel, A. D. (2015). Thirst for knowledge: The effects of curiosity and interest on memory in younger and older adults. *Psychology and Aging, 30*(4), 835–841.

Mckoon, G., & Ratcliff, R. (1992). Inferences during reading. *Psychological Review, 99*(3), 440–466.

Meyer, D. K., & Turner, J. C. (2002). Using instructional discourse analysis to study the scaffolding of student self-regulation. *Educational Psychologist, 37*(1), 17–25.

Mikkonen, J., Ruohoniemi, M., & Lindblom-Ylänne, S. (2013). The role of individual interest and future goals during the first years of university studies. *Studies in Higher Education, 38*(1), 71–86.

Mitchell, M. (1993). Situational interest: Its multifaceted structure in the secondary school mathematics classroom. *Journal of Educational Psychology, 85*, 424–436.

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 and Cognition, 42*(8), 1273–1284.

Myers, A. K., & Miller, N. E. (1954). Failure to find a learned drive based on hunger; evidence for learning motivated by "exploration." *Journal of Comparative and Physiological Psychology, 47*(6), 428–436.

Naylor, F. D. (1981). A state-trait curiosity inventory. *Australian Psychologist, 16*(2), 172–183.

Noordewier, M. K., & van Dijk, E. (2017). Curiosity and time: From not knowing to almost knowing. *Cognition & Emotion, 31*(3), 411–421.

Oosterwijk, S. (2017). Choosing the negative: A behavioral demonstration of morbid curiosity. *PLoS One, 12*(7), e0178399.

Oudeyer, P. Y., Gottlieb, J., & Lopes, M. (2016). Intrinsic motivation, curiosity, and learning: Theory and applications in educational technologies. *Progress in Brain Research, 229*, 257–284.

Patall, E. A. (2013). Constructing motivation through choice, interest, and interestingness. *Journal of Educational Psychology, 105*, 522–534.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*, 667–686.

Reio, T. G., Petrosko, J. M., Wiswell, A. K., & Thongsukmag, J. (2006). The measurement and conceptualization of curiosity. *The Journal of Genetic Psychology, 167*(2), 117–135.

Renninger, K. A. (1990). Children's play interests, representation, and activity. In R. Fivush & K. Hudson (Eds.), *Knowing and remembering in young children* (pp. 127–165). New York: Cambridge University Press.

Renninger, K. A. (1992). Individual interest and development: Implications for theory and practice. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 361–396). Hillsdale, NJ: Lawrence Erlbaum.

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist, 46*(3), 168–184.

Renninger, K. A., & Hidi, S. (2016). Interest, attention, and curiosity. In K. A. Renninger & S. Hidi (Eds.), *The power of interest for motivation and engagement* (pp. 32–51). New York, NY: Routledge.

Renninger, K. A., & Hidi, S. (2019). Interest development and learning. In K. A. Renninger & S. E. Hidi (Eds.), *The Cambridge handbook of motivation and learning* (pp. 265–290). Cambridge: Cambridge University Press.

Renninger, K. A., Ewen, L., & Lasher, A. K. (2002). Individual interest as context in expository text and mathematical word problems. *Learning and Instruction, 12*(4), 467–490.

Rogers, P. J., & Brunstrom, J. M. (2016). Appetite and energy balancing. *Physiology & Behavior, 164*, 465–471.

Rotgans, J., & Schmidt, H. (2009). Examination of the context-specific nature of self-regulated learning. *Educational Studies, 35*(3), 239–253.

Rotgans, J. I., & Schmidt, H. G. (2011). The role of teachers in facilitating situational interest in an active-learning classroom. *Teaching and Teacher Education, 27*(1), 37–42.

Ruan, B., Hsee, C. K., & Lu, Z. Y. (2018). The teasing effect: An underappreciated benefit of creating and resolving an uncertainty. *Journal of Marketing Research*. https://doi.org/10.1509/jmr.15.0346.

Russell, P. A. (1973). Relationships between exploratory behaviour and fear: A review. *British Journal of Psychology, 64*(3), 417–433.

Sakaki, M., Yagi, A., & Murayama, K. (2018). Curiosity in old age: A possible key to achieving adaptive aging. *Neuroscience and Biobehavioral Reviews, 88*, 106–116.

Saxe, R. M., & Stollak, G. E. (1971). Curiosity and the parent–child relationship. *Child Development, 42*(2), 373–384.

Schiefele, U. (2009). Situational and individual interest. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 197–222). New York, NY: Routledge.

Schraw, G., Bruning, R., & Svoboda, C. (1995). Sources of situational interest. *Journal of Reading Behavior, 27*(1), 1–17.
Schultz, W. (2006). Behavioral theories and the neurophysiology of reward. *Annual Review of Psychology, 57*(1), 87–115.
Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science, 275*(5306), 1593–1599.
Shin, D. J. D., Lee, H. J., Lee, G., & Kim, S. (2019). The role of curiosity and interest in learning and motivation. In K. A. Renninger & S. E. Hidi (Eds.), *The Cambridge handbook of motivation and learning* (pp. 443–464). Cambridge: Cambridge University Press.
Silvia, P. J. (2005). What is interesting? Exploring the appraisal structure of interest. *Emotion, 5*(1), 89–102.
Silvia, P. J. (2008). Appraisal components and emotion traits: Examining the appraisal basis of trait curiosity. *Cognition & Emotion, 22*(1), 94–113.
Silvia, P. J., Henson, R. A., & Templin, J. L. (2009). Are the sources of interest the same for everyone? Using multilevel mixture models to explore individual differences in appraisal structures. *Cognition & Emotion, 23*(7), 1389–1406.
Song, J. (2015). Effect of interest on the perception of effort cost and academic engagement. (Doctoral thesis, Korea University, Seoul, Korea). **Retrieved from** https://library.korea.ac.kr/search/detail/SATTOT000019387904?briefLink=/searchMain/mashupResult?q=Effect%20of%20interest%20on%20the%20perception%20of%20effort%20cost%20and%20academic%20engagement#.W0t7itUzZpg
Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. *Science, 348*(6230), 91–94.
Swann, W. B., Stephenson, B., & Pittman, T. S. (1981). Curiosity and control: On the determinants of the search for social knowledge. *Journal of Personality and Social Psychology, 40*(4), 635–642.
Sweeny, K., Melnyk, D., Miller, W., & Shepperd, J. A. (2010). Information avoidance: Who, what, when, and why. *Review of General Psychology, 14*(4), 340–353.
Tapola, A., Veermans, M., & Niemivirta, M. (2013). Predictors and outcomes of situational interest during a science learning task. *Instructional Science, 41*(6), 1047–1064.
Tiggemann, M., & Kemps, E. (2005). The phenomenology of food cravings: The role of mental imagery. *Appetite, 45*(3), 305–313.
Tsai, Y. M., Kunter, M., Lüdtke, O., Trautwein, U., & Ryan, R. M. (2008). What makes lessons interesting? The role of situational and individual factors in three school subjects. *Journal of Educational Psychology, 100*, 460–472.
Turner, S. A., Jr., & Silvia, P. J. (2006). Must interesting things be pleasant? A test of competing appraisal structures. *Emotion, 6*(4), 670–674.
Van Dijk, E., & Zeelenberg, M. (2007). When curiosity killed regret: Avoiding or seeking the unknown in decision-making under uncertainty. *Journal of Experimental Social Psychology, 43*(4), 656–662.
van Lieshout, L. L., Vandenbroucke, A. R., Müller, N. C., Cools, R., & de Lange, F. P. (2018). Induction and relief of curiosity elicit parietal and frontal activity. *Journal of Neuroscience, 38*(10), 2816–2817. https://doi.org/10.1523/JNEUROSCI.2816-17.2018 .
Von Stumm, S., Hell, B., & Chamorro-Premuzic, T. (2011). The hungry mind. *Perspectives on Psychological Science, 6*(6), 574–588.
Weingarten, H. P., & Elston, D. (1990). The phenomenology of food cravings. *Appetite, 15*(3), 231–246.
Wilson, T. D., Centerbar, D. B., Kermer, D. A., & Gilbert, D. T. (2005). The pleasures of uncertainty: Prolonging positive moods in ways people do not anticipate. *Journal of Personality and Social Psychology, 88*(1), 5–21.
Wright, S. A., Clarkson, J. J., & Kardes, F. R. (2018). Circumventing resistance to novel information: Piquing curiosity through strategic information revelation. *Journal of Experimental Social Psychology, 76*, 81–87.
Wynn, K. (1992). Addition and subtraction by human infants. *Nature, 358*(6389), 749–750.
Zhu, X., Chen, A., Ennis, C., Sun, H., Hopple, C., Bonello, M., Bae, M., & Kim, S. (2009). Situational interest, cognitive engagement, and achievement in physical education. *Contemporary Educational Psychology, 34*(3), 221–229.