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Perceptual, phenomenological, and behavioral processes underpinning state and dispositional curiosity.

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy in

Psychological & Brain Sciences

by

Madeleine Elspeth Gross

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Professor Richard Mayer

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December 2022

The dissertation of Madeleine Elspeth Gross.

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Jonathan Schooler, Committee Chair

October 2022

Perceptual, phenomenological, and behavioral processes underpinning state and dispositional curiosity.

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by

Madeleine Elspeth Gross

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“‘Curiouser and curiouser!” cried Alice” – Lewis Carroll, Alice's Adventures in Wonderland,

Through the Looking-Glass.

ABSTRACT

Perceptual, phenomenological, and behavioral processes underpinning state and dispositional curiosity.

by

Madeleine Elspeth Gross

Curiosity has occupied a pivotal position in the study of motivation, emotion, and cognition where it has been associated with an impressive host of positive outcomes; however experimental research is surprisingly limited. Existing methods rely on the induction of deprivation-based curiosity, a subfacet of epistemic curiosity driven by uncertainty and induced via the presentation of information gaps. This facet has been linked to negative affect and, more recently, a host of intellectual shortcomings. Interest curiosity is a subfacet of epistemic curiosity characterized by a positive and appetitive interest in learning and exploration and has been associated with increased general knowledge, creativity, humility, and well-being. Experimental research on this subfacet is almost completely missing, largely due to the difficulty in promoting this state under laboratory conditions. Furthermore, research on epistemic curiosity is limited in that there are no well-validated measures of state curiosity and few objective indicators of trait curiosity beyond self-report. This dissertation research strove to fill these voids by taking a broad behavioral, perceptual, and phenomenological approach to consider what drives individual differences in epistemic curiosity. Study 1 reports on a novel measure for capturing states of interest curiosity, as well as a novel, easily implementable, and effective induction method for promoting it. Study 2, 3, and 4 explore theoretically grounded indicators of state and trait epistemic curiosity including gaze patterns

(study 2) and phenomenological indices (study 3 and 4). In study 2, distinct patterns of salience attribution are found for individuals as a function of trait epistemic curiosity, particularly more consistent prioritization of visual features that may reflect maximal information gain. Using both an ecologically rich experience sampling study and a casually informative experimental study, studies 3 and 4 report robust and striking patterns of associations between everyday features of thought and both trait (study 3 and 4) and state (study 4) epistemic curiosity; here, differences between deprivation and interest curiosity are further revealed. The final study (study 5) brings together many of these elements to examine the role affective, attentional, and phenomenological aspects of interest curiosity may play in driving the positive outcomes associated with it, including learning and information seeking behavior. Here it was found that interest curiosity mediates the effects of the novel curiosity induction on information seeking behavior and positive affect. Interest curiosity is also found to improve attentional engagement during reading, with potential implications for learning. This research made several important empirical, theoretical, and methodological contributions by developing new ways to assess trait and state epistemic curiosity grounded in neurobiological and psychological theory, and using these assessments to run the first ever experimental studies on appetitive states of interest curiosity.

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I. Introduction.

Curiosity has been broadly defined as a desire for knowledge that motivates individuals to gain new knowledge, seek novel experiences, and solve intellectual problems (Litman, 2008). This characteristic in turn plays a central role in motivating behaviors, driving exploration, and learning. For this reason, curiosity has occupied a pivotal position in the study of motivation, emotion, and cognition where it has been associated with an impressive host of positive outcomes including well-being (Gallagher & Lopez, 2007), academic success (Von Stumm et al., 2011), and perceived meaning in life (Kashdan & Steger, 2007). The growing foundation of research relating curiosity to positive outcomes has led to a parallel interest in understanding how to promote it, both as a state and as a trait. However, experimental research in this area is limited, or in some cases entirely missing, as there are few reliable methods for inducing or measuring states of curiosity. Furthermore, measures used to capture trait curiosity rely on self-report methods, which are subject to demand characteristics, among other issues (Gross et al., 2020). In order to address these shortcomings, this dissertation research had the following goals: to develop a reliable induction method for promoting states of curiosity in laboratory controlled settings; to develop measures to capture transitory states of curiosity; to examine objective and ecologically valid indicators of trait curiosity grounded in modern psychological and neurobiological theory; and finally to harness these findings to experimentally test downstream consequences of curiosity on associated outcomes.

The current research was particularly focused on epistemic curiosity. This type of curiosity is characterized by a love of learning and a desire for knowledge, and it comes in two varieties: deprivation and interest. Deprivation curiosity refers to a desire to fill a

specific knowledge gap and is driven by an aversive state of uncertainty; whereas interest curiosity refers to a joyful explorative attitude toward learning and discovery (Litman, 2008). While both types of curiosity are thought to motivate learning, deprivation curiosity has also been found to be associated with negative affect, as well as performance (vs mastery) goals (Gross et al., 2019), and even narcissistic personality styles (Kaufman et al., 2019). Additionally, a recent study from our lab suggests that deprivation curiosity is associated with a host of information processing errors and reduced knowledge in the context of a trivia task (Zedelius et al., 2022). On the other hand, we have found consistent correlations with positive outcomes for interest curiosity, including creativity and learning. Therefore, the studies outlined in this thesis attempted to tease apart the contributions of these two dimensions of epistemic curiosity in driving positive outcomes.

This research took a broad behavioral, perceptual, and phenomenological approach to consider what drives individual differences in epistemic curiosity. Chapter II reports the development of a novel method for effectively promoting interest-based epistemic curiosity (interest curiosity henceforth), as well as the development and validation of a novel measure for capturing transient states of interest curiosity. Chapter III introduces a neurobiologically inspired framework for understanding individual differences in epistemic curiosity. This chapter takes an in-depth look at modern theory of dopamine function and personality neuroscience, and applies this understanding to generate predictions about individual differences in eye movement behavior. The chapter concludes with a study examining how visual features may be differentially prioritized during viewing of natural scenes as a function of the curious personality trait.

Chapter IV continues with the investigation of theoretically grounded objective indicators of epistemic curiosity by considering the phenomenological implications of curiosity. Here the experiential qualities of everyday thought are examined, a research area that has been largely overlooked despite its theoretical relevance to curiosity and its consequential impact on the everyday experiences of individuals. Two studies are reported in this chapter, one that examined relationships between trait curiosity and qualities of thought using a qualitatively rich experience sampling method, and a second experimental study in which state curiosity was induced. In this study, thought qualities were indexed and compared between trait and state epistemic curiosity, as well as between its interest and deprivation facets. The final study, reported in Chapter V, brings together many of the elements discussed in this thesis to examine the role the affective, attentional, and phenomenological aspects of interest curiosity may play in driving the positive outcomes associated with curiosity, including learning, well-being, and information seeking behavior.

II. Methods for promoting appetitive curiosity.

Although epistemic curiosity has long been a research interest for psychologists, most methods for inducing this state rely on the omission of information (i.e. an information gap) in order to create a specific, salient sense of deprivation or uncertainty. Anticipation of withheld information has been used to study information seeking behavior (Brydevall et al., 2018) generally by presenting unanswered trivia questions to participants (e.g. Gruber & Ranganath, 2019; Fandakova & Gruber, 2021; Marvin & Shohamy, 2016; Padulo et al., 2022). This creates a specific curiosity *for* an answer or missing piece of information. It is peculiar that the vast majority of extant findings in the field of curiosity are about this type of curiosity– known as deprivation curiosity (Litman, 2008; also known as deprivation sensitivity; Kashdan et al., 2018, or specific curiosity; Berlyne, 1966; Day, 1969) – as this form of curiosity does not necessarily align with the more general attributes we associate with curiosity, namely, a propensity for exploration, a joyous appetite for knowledge gain, an interest in discovering and experiencing new things, and a *tolerance* for uncertainty and ambiguity (Kashdan et al., 2004; Litman, 2010). These qualities are instead associated with interest curiosity, a characteristic marked by a positive, appetitive stance towards information gain.

A growing body of research suggests that these two forms of epistemic curiosity– deprivation and interest – are in some ways surprisingly distinct. Indeed, the former not only often fails to predict the positive features we associate with curiosity, but even at times predicts the opposite. For example, it has been robustly shown that these two constructs are associated with distinct affective consequences, with deprivation curiosity being associated with a negatively valenced, aversive state of uncertainty and interest curiosity being

associated with a positively valenced, appetitive state of interest (Litman & Jimerson, 2004; Ryakhovskaya et al., 2022). The aversive state of uncertainty that characterizes deprivation curiosity may account for the host of intellectual foibles that were recently discovered in association with it, including an increased propensity to believe fake news and to misremember information (Zedelius et al., 2022). It seems that deprivation curiosity may at times represent a "dark side to curiosity" (Dolan, 2022). On the other hand, interest curiosity has been found to predict openness, well-being, creativity, and learning ability (Karwowski, 2012; Gross et al., 2019; Zedelius et al., 2022). Ironically then, the field of curiosity may have been spending most of the time examining the aspect of curiosity we should be cautious to promote. Developing ways to elicit interest curiosity is of central importance if we are to better understand this beneficial facet of curiosity. In this chapter, the efficacy of a novel induction method for promoting states of interest curiosity is reported.

Study 1. Just ask: A novel interest-based curiosity induction

Interest curiosity is associated with an inquisitive nature and a general sense of wonderment which may manifest behaviorally as a tendency to ask questions (Stokoe, 2012). In particular, researchers propose that curiosity may be associated with *wonderment* questions (Scardamalia & Bereiter, 1992). Wonderment questions, unlike basic-knowledge questions, involve "conceptually higher level" thinking and require "an application or extension of taught ideas" with a focus on "predictions, explanations, and causes instead of facts, or on resolving discrepancies and gaps in knowledge" (page 531, Chin & Brown, 2002).

In the classroom context, question asking has been found to have beneficial effects. For instance, when applying the Questioning the Author technique (Beck, 1997), students are

instructed to interrupt their reading with queries which seed teacher facilitated discussions. In observational studies this technique has been shown to improve student engagement (Beck et al., 1996) and comprehension (Sencibaugh & Sencibaugh, 2015); however most of these studies are limited in their generalizability (e.g. small sample sizes) and lack rigorous, experimentally controlled designs. Furthermore, it is unknown whether any observed effects of this technique are driven by curiosity.

The Question Formulation Technique (QFT; Rothstein & Santana, 2011) is another question-brainstorming technique originally developed to teach students how to ask their own questions during classroom learning. The technique proposes to flip the usual teacher-student dynamic by having students ask the questions in response to a QFocus. The QFocus is a stimulus for jumpstarting student questions. It can be a short statement or a visual/aural aid in any medium or format that can stimulate student thinking expressed through their questions. The method is similar to designing an effective prompt but with the one key difference, that it is *not* a question. Rather, students are asked to brainstorm questions about the topic. In a classroom based study examining the effects of QFT, Clark and colleagues (2019) found that instruction of question formulation was effective in promoting trait curiosity in adolescents over the course of a semester (Clark et al., 2019). The QFT, though promising, requires substantial resources and teacher training and has not been studied in laboratory-controlled environments.

In this chapter, a novel question-asking method is presented in which participants are asked to generate questions while reading articles. The goal of the present research was to develop an easily implementable paradigm which can be empirically tested outside of classroom learning contexts, thereby making for an effective tool for use in experimental

psychology and neuroscience research. The following study drew inspiration from the previously described pedagogical studies, but stripped away the complexity, the guidelines, the need for training, and the need for a moderator or teacher. In essence, the goal was to examine the positive impacts of *just asking*: unconstrained question generation during independent reading.

The relationship between the question-asking strategy and the characteristics of the reading materials being queried was also examined. It is plausible that question-asking would be more effective if the reading material was interesting, offering a naturally more fertile ground in which questions can arise. On the other hand, it is possible that the interestingness of the materials would drive curiosity to the degree that it would overshadow the effects of the question-asking strategy. In that case an interaction might be expected, such that the effects of the question-asking are only observed for uninteresting articles but a ceiling effect is observed for interesting articles. To test these possibilities, interesting and uninteresting articles were included as a further predictor variable. The study used a 2 (task instruction: question asking vs main idea generating) by 2 (article type: interesting articles vs neutral articles) between subjects design to test the effect of these variables on states of curiosity.

1. Materials

For the reading materials, interesting articles were used from the *information foraging paradigm* (described in study 5). The neutral, or uninteresting, articles were taken from standardized reading exam practice websites. Both types of articles were piloted for levels of interestingness.

Trait curiosity was measured using the 10-item epistemic curiosity scale (Litman & Spielberger, 2003). The measure has two subscales for capturing both interest-based

epistemic curiosity, e.g. “I enjoy exploring new ideas”, and deprivation-based epistemic curiosity, e.g. “Difficult conceptual problems can keep me awake all night thinking about solutions.” The items are measured on a 1-4 Likert scale reflecting the following response options: *almost never, sometimes, often, almost always*. This measure has been used extensively in past research and has been shown to have good internal reliability (α range = .82–.87; Litman, 2008).

Two measures of state curiosity were included which were developed by the author (M. Gross). One measure captured *activity-based curiosity*, in other words, curiosity *about* the articles/questions participants generated. These included 3 items which were asked on a 1-7 scale from *Not at all* to *Extremely*: How curious do you feel? How interesting did you find this topic? How much would you like to read more about this topic?. These questions were asked twice, after each topic was presented (see Figure 1 in *Procedures* for schematic of the study flow). The scores from these items were averaged to create a single activity-based curiosity variable.

As the goal of the curiosity induction was to induce a general state of curiosity that was not tied to a specific activity, a measure of general feelings of state interest curiosity was also included. For this, the interest subfacet of the Epistemic Curiosity scale (Spielberger & Litman, 2003) was adapted to capture present moment feelings of interest curiosity. The items were created by simply rephrasing the trait questions so that they referred to current feelings rather than general tendencies. The instructions for the scale also explicitly asked participants to rate the questions as they pertain to how they feel *right now.* Responses were again measured on a 1-7 scale from *Not at all* to *Extremely.* The 5 adapted items from the epistemic curiosity scale are shown in Table 1. To ensure the conditions were not promoting

any confounding changes in affective state, the brief introspective mood scale (Mayer & Gaschke, 1988) was completed following the state curiosity measure. This scale assesses mood across 16 dimensions (e.g. Lively, Happy, Sad) using a 1-4 Likert scale with endpoints *Not at all* to *Extremely.*

Table 1

State adaptations of the trait interest-based epistemic curiosity subscale

STATE	TRAIT
I currently feel like exploring new ideas.	I enjoy exploring new ideas.
I currently feel like learning about subjects that are unfamiliar to me.	I enjoy learning about subjects that are unfamiliar to me.
I currently would find it fascinating to learn new information.	I find it fascinating to learn new information.
I currently would like to find out more about the topics I read about.	When I learn something new, I would like to find out more about it.
I currently feel like discussing abstract concepts.	I enjoy discussing abstract concepts.

2. Procedures:

The study was designed in Qualtrics and delivered to 238 online participants via Turk prime. After indicating informed consent, participants were randomly assigned to one of four conditions, question asking or main idea generating with either interesting or uninteresting articles. In the experimental conditions (question asking), participants were given question generation instructions for the reading materials. Participants were informed that they would be presented with articles on various topics and would be asked to generate questions using

the text as a springboard. In the control conditions, participants were instead instructed to generate possible main ideas of the text.

Figure 1

Study 1 schematic of study flow



Participants were also randomly assigned to either read interesting or uninteresting articles. In each condition, participants were presented with excerpts from two articles on different topics which were chosen randomly from a larger list of possible articles. Each article topic was divided onto two separate pages, each with 200-300 words from each article. Participants were instructed to engage in their task (question generation or main idea generating) *actively* while reading, and on each page to type out ideas that had come to mind in the text box provided. After each topic (i.e. after the second page of the article), participants were asked to spend an additional 2 minutes generating questions or main ideas, depending on their condition. Following this, they responded to the activity-based curiosity questions. After repeating this procedure twice, participants completed the adapted state interest based curiosity scale, mood scale, trait curiosity scale, and demographics questions.

3. Results

Given data quality concerns in online studies, several checks were included to screen out poor responding. Within the state curiosity scale ("check 1") following the induction and in the trait curiosity scale ("check 2") at the end of the study, participants were asked to select the response option *Extremely* and *Almost always*, respectively, to ensure they were paying attention. Within the demographics questions, participants were also asked the following question: "Is there any reason why we should exclude your data from our analyses? Please answer honestly. This will in no way affect your payment or your eligibility for future studies" ("check 3"). They were given 5 response options, only one of which confirmed that their data should be included. 20 individuals were excluded for not passing all three checks. An additional 3 participants did not pass check 1 only. All participants passed check 2, and an additional 15 participants were excluded for failing to respond or responding incorrectly to check 3. This resulted in a final *N* of 194 (104 in the control condition). Participants were comprised of 121 females, mean age 18.93 years.

The validity of the new state based interest curiosity scale was first assessed. The scale was found to have good internal reliability: a Cronbach's alpha and intraclass correlation coefficient (ICC) of .91.

As the activity-based curiosity scale involved curiosity *about* the task, it could be reasoned that it more closely aligns with deprivation curiosity. Deprivation curiosity is indeed often measured in association with a task; although in past research the task involves information being withheld, for instance, the answer to a trivia question. Although the question-asking paradigm was specifically designed to elicit interest, not deprivation curiosity, it is possible that generating questions – for which one may then like to know the answer – would elicit deprivation curiosity. This possibility was considered unlikely given

that participants were asking broad ranging questions with differing levels of concreteness; thus it is unlikely that this process created a single, salient information gap. To attempt to examine this possibility, however, we examined partial correlations between the state measures of curiosity and both trait deprivation- and interest-based curiosity. As seen in Table 2, only interest curiosity correlated with the measure of curiosity elicited by this task. This provides suggestive evidence that the manipulation did not elicit deprivation curiosity, or at least not to the degree to which interest curiosity was elicited.

Table 2

Partial correlations between trait deprivation- and interest-based curiosity and both state measures of curiosity

	Interest-based curiosity		**Deprivation-based curiosity**	
State curiosity measure	**r**	**p-value**	**r**	**p-value**
Activity-based curiosity	.47	<.001	.13	.075
State interest-based curiosity	.29	<.001	.002	.98

Three main questions were of interest in this study: 1) does formulating questions while reading articles promote state interest and/or activity-based curiosity versus generating answers to the main idea of the article, 2) does the interestingness of the articles lead to state interest and/or activity-based curiosity compared to non-interesting articles, and 3) does the effect of the question-asking paradigm on states of curiosity change depending on the interestingness of the articles?

To examine the first question, an independent samples t-test was run to examine the effectiveness of question-asking, as compared to main-idea generating, for promoting the two state based measures of curiosity. The results confirmed the prediction that generating-questions leads to increases in both activity-related (6-items, or 3-items measured twice), $t(192) = 2.46$, $p=.011$, and general interest state based curiosity (5-items), $t(192) = 2.57$, $p=.011$ (see Table 3 for means of curiosity variables across all conditions).

Table 3

Descriptive states for the curiosity variables across all four conditions

Condition	DV	Mean	SD
Question-asking	State interest curiosity	4.83	1.35
	Activity-based curiosity	3.00	.93
Main-idea generating	State interest curiosity	4.33	1.37
	Activity-based curiosity	2.71	1.00
Interesting articles	State interest curiosity	4.77	1.28
	Activity-based curiosity	3.08	.90
Neutral articles	State interest curiosity	4.33	1.44
	Activity-based curiosity	2.58	.99

To ensure the results were not confounded by other affective states, an independent-samples t-test was run comparing the effect of the condition on mood states. The results indicated that the conditions did not affect any of the moods; see table 4, for summary statistics and t-test results.

Table 4

Independent samples t-tests demonstrates that no other moods, beyond interested, were affected by the induction

	Control		Experimental			
Mood	Mean	SD	Mean	SD	t-statistic	p-value
Lively	2.16	0.89	2.19	0.85	0.2	0.84
Happy	2.6	0.86	2.62	0.88	0.21	0.84
Sad	1.52	0.81	1.6	1	0.62	0.54
Tired	2.19	1.02	2.32	1.1	0.85	0.4
Caring	2.32	1.1	2.67	0.9	-0.48	0.64
Content	2.66	0.88	2.72	0.9	0.46	0.65
Gloomy	1.57	0.89	1.66	0.96	0.66	0.51
Jittery	1.38	0.7	1.44	0.75	0.67	0.51
Drowsy	1.99	0.94	1.99	0.94	-0.01	0.99
Grouchy	1.59	0.8	1.53	0.82	-0.46	0.65
Peppy	1.81	0.79	1.96	0.95	1.19	0.24
Nervous	1.47	0.72	1.43	0.84	-0.34	0.74
Calm	2.92	0.95	3.18	0.83	1.97	0.05
Loving	2.5	1.02	2.48	0.97	-0.15	0.88
Fed up	1.63	0.86	1.44	0.77	-1.62	0.11

Active	2.12	0.91	2.11	1.01	-0.03	0.98

Next, an independent samples t-test was run to determine whether the interestingness of the articles led to increases in the two state measures of curiosity. The results confirmed the prediction that reading interesting articles, compared to neutral articles, leads to increases in both activity-related, $t(193) = 3.67$, $p<.001$, and general interest state based curiosity, $t(193) = 2.26$, $p=.025$.

Next, the interaction between question-asking and the level of interestingness of the article was examined. Here, there was no specific prediction. Rather it was of interest to determine whether question-asking works better when the material itself is interesting, or alternatively, is an effective strategy for promoting curiosity when the reading material is uninteresting. First the interaction between question-asking and interesting articles was examined for state interest-based curiosity. Here no significant interaction was observed, $F(1, 190) = 1.37$, $p=.24$), see Table 5 for full statistics. This indicates that the question-asking manipulation is equally effective regardless of how interesting the articles are (however, note in Figure 2, the effect appears to be in the direction of being larger for the neutral or non-interesting condition). From the graph it can also be observed that generating main ideas for non-interesting articles leads to the lowest level of curiosity, with question-generating for interesting articles scoring highest. Finally, note that when the interaction is modeled, the main effect of the experimental (question-asking vs main idea generating) condition on state interest curiosity becomes stronger, and is larger than the effect of the interestingness of the articles.

Figure 2

Interaction between question-asking condition and interest level of articles on state interest based curiosity

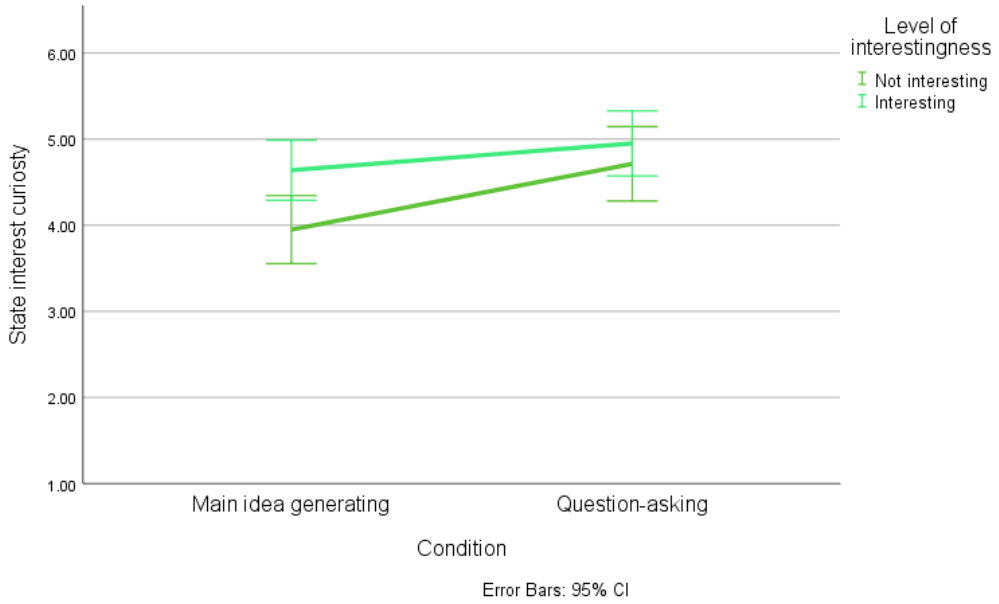


Table 5

Statistics for interaction between question-asking condition and interest level of articles on state interest based curiosity

Condition	β	se	t-statistic	p-value	CI
Question condition	.76	.28	2.75	.006	[.22, 1.31]
Interestingness article condition	.69	.26	2.61	.010	[.17, 1.21]
Question*Interesting	-.45	.39	-1.17	.24	[-1.22, .31]

Finally, the same interaction was examined for activity-based curiosity. Here, similar results were observed and there was no significant interaction, $F(1, 190)=1.78$, $p=.28$, see Table 6 for full statistics. However, unlike in the previous interaction, the interestingness of articles caused the larger effect. Thus, when the dependent variable of curiosity is activity-

related, the interestingness of articles is a more important factor than question-asking. See supplemental materials (Supplementary Table S1) for means of the two curiosity variables across interaction conditions and for graph (Supplementary Figure S1) of the interaction for activity-based curiosity.

Table 6

Statistics for interaction between question-asking condition and interest level of articles on activity-based curiosity

Condition	β	se	F-statistic	p-value	CI
Question condition	.46	.14	5.61	.019	[.083, .85]
Interestingness article condition	.66	.18	14.75	<.001	[.30, 1.02]
Question*Interesting	-.29	.27	1.18	.28	[-.82, .23]

4. Discussion

Although there has been a relatively long standing interest in curiosity, there has been little methodological development in how to measure or induce curiosity, with most studies relying on a 1-item self-report question for measuring curiosity and induction methods that only induce curiosity towards a specific piece of missing information, rather than promoting a more general sense of appetitive interest curiosity. This study demonstrated the effectiveness of a novel measure of state interest curiosity (the adapted trait scale) for capturing momentary fluctuations in states of curiosity, and a novel curiosity induction for promoting states of interest-based curiosity.

It is important to note that the curiosity induction led to increases in reported interest curiosity despite lacking a concrete knowledge gap. Some prominent curiosity theorists propose that curiosity *solely* involves the recognition of a specific, well-defined knowledge gap (Markey & Loewenstein, 2014). Such theories predict that curiosity will be low when the knowledge gap is too wide. The findings from this induction method speak against such theorized constraints given that broad question-asking, without any promise of answers or solutions, was effective in promoting self-reported feelings of curiosity.

Both question-asking and reading interesting articles were effective in promoting activity-based and general interest-based states of curiosity. As expected the interestingness of the articles had a larger effect on activity-based curiosity, while the question-asking instructions had a larger effect on interest-based curiosity, particularly once the interaction effects were modeled and controlled for. Furthermore, the interaction between question-asking and the interestingness of articles was not significant which speaks to the effectiveness of question-asking for promoting curiosity regardless of how interesting the reading material is. This is particularly useful given the inevitability that one will encounter a situation in which they must engage with reading material that is not intrinsically interesting to them, for instance, in educational and workplace settings. Adopting an inquiring mindset and actively generating questions about the text may help to make even uninteresting text spark a seed of curiosity.

II. Curious vision: Integrating personality research with modern dopamine theory.

Evidence from personality neuroscience suggests that dopamine, a broadly acting neurotransmitter, acts as a modulator of exploration, underpinning curious drive and creative thinking. Parallel lines of research in vision science show a central role for dopamine in basic visual processes, such as in directing eye movements towards the most significant or information-rich features of our environment. Given this notable intersection, the lack of research examining the relationship between personality characteristics and eye movement is surprising. In this section, we will take a closer look at modern theory of dopaminergic function and examine implications for higher order cognitive and personality characteristics, particularly curiosity, as well as low level visual processes.

A. Dopamine, incentive salience, and personality

Originally the central role of dopamine was thought to be in facilitating the hedonic impact of rewards. However, pioneering research led to the revised formulation of dopamine as a driver of *seeking* or *wanting* of rewards, rather than *liking* of rewards (Schultz et al., 1997; Berridge, 2007). While it is now widely accepted that midbrain dopamine plays a role in motivating approach behavior towards rewards, it is further understood that dopamine motivates exploration of potentially *informative* cues (Berridge & Robinson, 1998), such as arousing, aversive, or alerting cues. These dopaminergic functions can be broken down into two core systems: the value system, which motivates reward approach behaviors, and the salience system, which is involved in imbuing information with importance or attention-worthiness (Bromberg-Martin et al., 2010). The central role dopamine plays in motivation

and salience processes creates a number of intriguing possible implications for higher level exploration-based cognitive and personality characteristics (e.g. Gross et al., submitted).

Personality can be thought of as a cluster of relatively stable motivational, behavioral, and cognitive tendencies. Midbrain dopamine connections extend to limbic and frontal cortical regions which leads to variation in the expression of these tendencies. DeYoung (2013) published a theoretical framework outlining how the two motivational dopaminergic systems– the value and salience coding systems – may contribute to a considerable number of higher order personality traits. The value system, which is involved in reward learning, motivates the behavioral exploration of specific rewards, whereas the salience system motivates cognitive exploration and information-seeking. Traits that are characterized by a sensitivity to reward, such as extraversion, are therefore suggested to be influenced by the motivational value system. Traits that are characterized by cognitive and behavioral exploration, such as curiosity, openness, and novelty-seeking, are suggested to be linked to the motivational salience system. Viewed in this manner, it may be easier to see how dopamine may play a role in stable individual differences in curiosity, via its role in motivating behavioral and cognitive exploration.

What is particularly appealing about this account, is that it offers an explanation not only of stable *trait* level differences, but also variation within a person, or *state* level differences. Due to the fact that dopamine activity occurs both tonically, at a fairly stable level, and phasically, or in bursts, the activity of this neurotransmitter has the potential to explain variation both across individuals and within an individual. Characteristics that have previously been linked to dopamine function, such as curiosity and creativity, tend to share in

common that they differ stably across individuals and that they occur transiently at different times within an individual. Variation in tonic levels could contribute to variation in stable differences in individuals' motivation, sensation-seeking, extraversion, curiosity, creativity, openness, and other traits related to approaching novel opportunities. However, of course, even highly curious people are not *always* motivated to explore their environment or engage in information seeking. These differences in states can also be explained by dopaminergic activity, as a function of transient, phasic spikes in activity.

Despite these theoretical advancements, there has been hardly any research directly examining the effects of dopamine mediated salience processes in personality research. However, clinical research on schizophrenia-spectrum disorders has considered these processes at length. It has been known for some time that the positive symptoms of schizophrenia are associated with dysfunctional striatal dopamine activity (Corlett & Fletcher, 2012; Kirschner et al., 2016; Ceaser & Barch, 2016). Theoretically grounded behavioral and neuroscientific research has linked this abnormality to *aberrant incentive salience* – the improper imbuement of meaning or significance to innocuous or irrelevant stimuli (Palaniyappan et al., 2013; Kapur, 2003). This low level dysfunction is thought to lead to stable individual differences in higher order characteristics, including differences in individuals' phenomenology, beliefs, and ideas, as well as patterns of attention and perception. In particular, individuals experiencing aberrant salience tend to feel a heightened sense of meaning to atypical information, to hold eccentric or magical beliefs, to direct their attention to task irrelevant information, to experience anomalous perceptions, as well as to show robust abnormalities in eye movement behavior (for review, see Wolf et al., 2021).

Together these patterns make up the personality trait schizotypy, or in more extreme versions, the positive symptoms of schizophrenia (Frith & Friston, 2013).

Schizotypal characteristics have long been found to correlate to creativity (Batey & Furnham, 2008; Schuldberg, French, Stone, & Heberle, 1988), which has itself been linked to the dopaminergic system (e.g. Jauk et al., 2015). This raises the possibility that differences in the functioning of salience processes may contribute to other traits or characteristics beyond schizotypy. Indeed, in a recent, explicit investigation of the salience hypothesis, creativity was found to be associated with neural, psychological (Gross et al., in prep), and phenomenological (Gross et al., submitted) indicators of aberrant salience. Curiosity has also been found to predict subjective experiences of aberrant salience (Gross, unpublished data), in other words, the attribution of meaning or significance to atypical information.

Beyond these initial investigations, salience mechanisms have not been empirically examined in personality research. However, there has been a longstanding and growing consensus that personality traits reflect motivational systems that evolved to increase adaptation to classes of stimuli associated with positive and negative reinforcement (Gray, 1972; Corr, 2004; Corr et al., 2013); these processes implicate salience processes indirectly. Briefly, individual differences in various personality traits are proposed to arise from variation in individuals reward sensitivity to different classes of stimuli. Individual differences in curiosity, specifically, may reflect differences in sensitivity to the reward value of information (FitzGibbon et al., 2020; Kobayashi & Hsu, 2019b). In line with this, closing knowledge gaps activates the reward network in the brain (Brydevall et al. 2018; Kobayashi & Hsu, 2019b). This rewarding experience is thought to be at the core of the sustainable

knowledge-acquisition process because it reinforces the value of new knowledge, motivating further information-seeking behavior.

In the framework of salience processing, the larger the dopamine response following the attainment of new knowledge, the higher degree of incentive salience would be assigned to similar stimuli, thereby resulting in the prioritization of that information in future. Uncertain or novel stimuli, for example, have large potential for information gain which may explain why curiosity is often found to relate to novelty-seeking, given that novel information gain would be inherently rewarding. Encounters with stimuli with high information potential would cause an especially large dopamine response for individuals with reward sensitivities to information (i.e. curious individuals). This would facilitate the assignment of incentive value of such stimuli (Berridge & Kringelbach, 2008), in turn contributing to systematic differences in the prioritization of similar information in the future.

B. Eye movement behavior and visual saliency.

Given that the dopaminergic systems contribute to both the assignment of value and salience to sensory information, there are clear implications for eye movement behavior. In the visual domain, these reward mediated processes could explain differences in the visual priority maps that drive gaze allocation choices during naturalistic vision. Indeed, reward driven salience attribution processes have been shown to be intimately linked to human visual perception (Hickey & Peelen, 2015b). In particular, reward associations have been shown to influence the salience of objects in naturalistic environments; findings which were linked to dopaminergic activity in the midbrain. However, despite growing recognition that

visual salience reflects features of the observer as well as the image, very little research has attempted to examine these processes in the context of individual differences.

Outside of reward learning contexts, however, past research has demonstrated stable individual differences in saccadic eye movement across different tasks (Henerson and Luke, 2014) and different images (Castelhano & Henderson, 2008). Individual differences have further been found in the attribution of salience along a set of fundamental semantic dimensions (De Haas et al., 2019). These individual differences were found to have meaningful perceptual implications, indicating that differences in eye movement behavior may drive broader differences in how individuals perceive and experience the world. Taken together, this research indicates reliable patterns of gaze behavior in the same individual across time, indicating that individuals exhibit systematic idiosyncrasies in eye movement and attentional patterns. However, despite the observance of robust individual differences, few studies have included individual differences *measures*, such as personality measures, to attempt to explain these differences.

Several studies have, however, examined personality driven differences in eye movement during *task linked* paradigms. For example, the personality trait openness to experience has been found to predict attention to "irrelevant" visual information during a visual creativity task; interestingly, this in turn was found to promote creative performance (Agnoli et al., 2015) again suggesting that differences in eye movement behavior can have potentially broader implications. In another study, individual differences in perceptual curiosity were found to predict the number of regions visited during scene viewing (Risko et al., 2012) and epistemic curiosity predicted anticipatory gaze towards trivia answers (Baranes et al., 2015). These early studies are suggestive of the idea that personality might drive

differences in natural eye movement behavior. These studies however were task-linked and did not examine differences in visual behavior during free viewing of scenes. Eye movement patterns during task-linked viewing paradigms differ from free viewing paradigms (e.g. Andrews & Coppola,1999; Mills et al., 2011), making it likely that task-driven paradigms recruit different mechanisms (Gottlieb et al., 2013) and allow for less idiosyncrasies between individuals to be captured.

To explore possible contributions of personality to natural eye movement behavior, an exploratory study was run to examine relationships between eye movement, curiosity, creativity, and schizotypy in 88 undergraduate students (Gross et al., 2019). Creativity was measured using validated, domain-general performance tasks which measure a person's ability to think creatively regardless of skills or expertise, while curiosity and schizotypy were measured using validated questionnaires. A free-view paradigm was used in which individuals were instructed to view images naturally, in any way they choose. The image set included 62 color images which were presented for 8s each followed by a blank screen with a central fixation cross, which was presented for 2s. Individuals were separated into two groups based on curiosity level and compared across several metrics. Possible differences in the characteristic patterns of visual attention were examined by examining eye movement behavior metrics as well as by computing salience maps, i.e. heat maps of where individuals look. By comparing across high and low groups, it was examined whether there was more consistency in where individuals look when comparing within-group (high curiosity compared with high curiosity, and low compared to low) than between-group (low curiosity compared to high curiosity). Here the area under the receiver operating curve (AUC) was

used as the metric to compare each individual subject to a group. Essentially, this measure indicates how well the fixation map of each subject can be predicted by a group fixation map.

Striking patterns of behavior across several eye movement measures were observed. Individuals scoring high in curiosity differed in *how* they viewed images, displaying more explorative, higher entropy (i.e. less predictable) eye movements. The results also indicated that there may be systematic differences in *where* people look– i.e. what visual information is assigned salience when comparing salience maps – as a function of curiosity. In other words, individuals scoring higher in curiosity also looked at parts of images that were not as likely to be viewed by individuals lower in curiosity. These initial findings suggested that curiosity may be associated with how people view their surroundings and take in visual information (Gross et al., 2019).

The first study presented here extended this research by examining what specific visual *features* of images differentially draw attention. Specifically, it is possible that the differences in salience maps observed in the first study were driven by differential assignment of salience to pixel level features which represent *intrinsic* properties of stimuli like color and intensity. On the other hand, semantic level properties, such as emotion or faces, may be assigned salience to a different degree depending on trait curiosity levels. The question regarding what level of visual salience plays the largest role in guiding visual behavior relates to a large, on-going debate in the field of vision science. Before examining the first study, therefore, this debate will be outlined in order to contextualize the significance of this question in the broader field of vision science.

C. Which visual features guide eye movements?

A large body of research has investigated the relative contribution of top-down and bottom-up visual salience on guiding eye movement behavior. Bottom-up visual salience in this context refers to the raw, sensory characteristics of stimuli, such as luminance, color, and intensity of an object relative to surrounding objects. Some studies have found that regions fixated tend to be higher in saliency than non-fixated regions (Niu, Todd, Kyan, & Anderson, 2012); however, accumulating evidence suggests a large contribution of context, and other top-down influences, such as emotional valence (Niu et al., 2012), meaningfulness (Henderson & Hayes, 2017) or novelty (Foley et al., 2014). Indeed, many investigations suggest that bottom-up characteristics alone account for relatively little variation in naturalistic eye movement behavior (e.g. Henderson, Malcolm, & Schandl, 2009). Sophisticated techniques, such as the employment of signal detection, have found very low predictive power for feature based saliency in predicting fixation behavior (Einhäuser et al., 2008). Furthermore, the performance of competing models which incorporate contextual information, such as novelty and emotional valence, tend to greatly outperform bottom-up, feature based models.

The structural organization of eye movement circuitry and its associated inputs provides further evidence for a central top-down influence. Cortical saccade related areas, such as the frontal eye fields, lateral intra-parietal cortex and DLPFC, all project inputs to the caudate nucleus which in turn projects to the superior colliculus (SC), the key site for controlling saccadic eye movements (Parr & Friston, 2017). These cortical areas provide feedback pathways which have been suggested to play a role in informing eye movements

based on working memory, contextual relevance, and expectation, as well as monitoring the outcome of saccades, in terms of whether the previous saccade was successful (e.g. in reducing uncertainty or providing information; Hayhoe & Ballard, 2005). Furthermore, ample evidence suggests that ongoing cognitive goals influence gaze behavior, even dynamically impacting the receptive field to meet the demands of the ongoing perceptual task (Gilbert & Li, 2013). Even in earliest visual cortical areas, such as V1, neuronal responses are sensitive to the specified task (Hayhoe & Ballard, 2005).

In select cases, bottom-up visual saliency may be more predominant. For instance, inter-individual differences in scene-viewing tend to be smallest at stimulus onset and then become greater as time goes on. It may be the case that initially bottom-up saliency characteristics play a larger role, and over time top-down influences predominate (Le Meur, Olivier, and Thierry Baccino. 2013). In general, and unsurprisingly, feature based saliency models tend to work best in situations such as these where eye movement behavior is guided by bottom up influences (Koehler et al., 2014). Furthermore, the presence of certain types of stimuli reliably enhance the congruence of inter-individual gaze patterns. For instance, when a human face is present, fixations are likely to occur there independent of context. However, stimuli such as faces would not be bottom-up in the traditional sense of visual saliency; rather meaningful and affective content, such as faces, would suggest an influence from top-down attentional biases.

In order to clarify the relative influence of these types of features, Xu and colleagues (2014) annotated a large database of images for features at the pixel level (corresponding to bottom up visual salience, such as luminance and intensity), object level (characteristics of

objects, such as size and shape), and semantic level. Semantic categories included features that held such information as sensory characteristics (e.g. food relates to the semantic category “taste”, an instrument relates to the semantic category “sound”) or other motivationally relevant information like “operability” or “emotion”. They found both the object and semantic level features contributed significant predictive power in determining where viewers look. In addition, they compared the effectiveness of incorporating object level and semantic level features with several other notable computational models, such as the SUN model and the Itti & Koch model. They found that their well-specified model did the best job of all the models in classifying fixations, suggesting that object level and semantic level features also play a large role in determining human gaze.

To summarize, debate continues in the field of vision science as to the relative contributions of *bottom up* and *top down* sources of visual salience; however, existing evidence seems to converge on the notion that under most circumstances both sources play a role, with *top down* sources playing a larger role. In an exploratory study examining relationships between natural eye movement behavior and dopamine-related personality characteristics (Gross et al., 2019), individuals differed in *where* they looked as a function of trait levels of curiosity. However, it was unclear *which visual features* attract attention differentially, and whether these differences were driven more by bottom up level sources of visual salience, such as pixel level features (e.g. color and intensity), or more top down sources of visual salience, such as semantic level features (e.g. emotion and sound). To address this, the first study reported in this dissertation used the image set previously described (annotated for its pixel-level, object-level, or semantic-level features; Xu et al.,

2014) in order to determine which level of visual salience may drive the curiosity-based differences in visual attention previously observed.

D. Study 2. Does curiosity predict pixel-, object, and semantic-level salience?

The main goal of this study was to examine salience maps for each pixel-, object- and semantic-level feature and to determine whether the salience maps of a given feature better predict individuals high vs low in trait curiosity. In the previous discussion on *incentive salience* it was suggested that the dopaminergic systems may contribute to the assignment of salience to visual sensory information, thereby influencing priority maps that guide eye movement behavior. It was further proposed that these systems may play a role in driving the reward value of information, in turn driving the motivation and drive for information-seeking as observed in curious individuals. In line with this, past research suggests that curiosity tracks semantic information gain in contexts in which perceptual information is slowly revealed (Van de Cruys et al., 2021). Given this, it was predicted that higher level visual features (object and/or semantic level features) rather than low level visual features (pixel level features) would likely play a larger role in explaining the previously observed differences in gaze allocation based on curiosity.

1. Materials

350 color images annotated for pixel-level, object-level, and semantic-level features were used (Xu et al., 2014). Images were presented on a 17 inch screen integrated with a Tobii T120 eye tracking system using Tobii Studio 3.4.5 software. Curiosity was again measured using the Epistemic Curiosity scale (Litman & Spielberger, 2003, see study 1 for details).

2. Procedures

After approval by the ethics review board at UC Santa Barbara, 174 undergraduates (104 females, mean age: 18.99 years old) were recruited in exchange for research credits. As in Gross et al. (2019), a free-view paradigm was used. Participants were seated 65cm from the screen and were instructed to view the images naturally in any way they choose. Each image was presented for 5 seconds, and participants were asked to limit blinking during image presentation. A fixation slide was presented between each image which was self-paced to allow participants the time they needed to rest their eyes between images. After a brief practice trial to ensure participants understood to move forward from the self-paced fixation screen, the first block began. The images were presented in 5 blocks of 70 images each, with block presentation counterbalanced and a 9-point calibration performed before each block. Participants took a break between each block and then underwent calibration again. Finally, participants completed the trait questionnaires.

As in Gross et al. (2019), the area under the receiver operating curve (AUC) was used to examine differences between salience maps by group. Area under the ROC curve (AUC) was computed for each individual as well as for the high and the low curiosity group. This allows us to measure how well the fixations of each subject can be predicted by those of the other n – 1 subjects in that group (high or low curiosity) for that feature. We can then determine whether high curiosity individuals (versus low curiosity individuals) better predict a given high curiosity individuals fixation map for a given feature, and similarly, whether a low curiosity individuals' fixation maps are better predicted by the low curiosity group. Put another way, the AUC tells us how well the fixations of each subject can be predicted by the

rest of the groups subjects fixation maps. Smaller values mean that the differences between individuals was higher, or that each individual is less likely to be predicted by their corresponding groups (high or low curiosity) fixation maps.

3. Results

T-tests were run to compare the average AUC for the high and low scoring curiosity groups, see Table 7. If one group is significantly higher, it means their fixations are better predicted by the rest of the individuals in that group for that feature. Using a bonferroni corrected p-value of <.0024, it can be observed that individuals high in epistemic curiosity show greater consistency in gaze allocation for text and objects high in watchability. They also tended to look more consistently at several object-level features while looking less at semantic-level features, particularly semantic level features associated with people (face, emotion, gazed, touch). Note, no significant differences were observed for the nonvisual semantic features of sound, smell, touch, taste, nor motion or operability. Further, no significant effects were observed for pixel level features of intensity and orientation.

Table 7

T-tests comparing average AUC for high and low curiosity groups

Visual feature	t-statistic	p-value	df	95% CI	Mean AUC high group	Mean AUC low group
Text	3.95	0.00012	157	[0.00313, 0.00940]	0.6569	0.6506
Eccentricity	3.83	0.00015	349	[0.00141, 0.00440]	0.8316	0.8287
Complexity	3.55	0.00044	349	[0.00118, 0.00412]	0.8323	0.8297

Convexity	3.37	0.00082	237	[0.00108, 0.00411]	0.8419	0.8393
Watchability	3.35	0.00093	349	[0.00179, 0.00691]	0.6592	0.6549
Size	3.26	0.0012	349	[0.00094, 0.00379]	0.8302	0.8279
Solidity	3.21	0.0014	349	[0.00096, 0.00398]	0.8430	0.8405
Gazed	-2.94	.0039	114	[-0.00801, -0.00156]	0.6372	0.642
Face	-2.68	0.0078	296	[-0.00511, -0.00078]	0.6905	0.6935
Color	2.67	0.0079	349	[0.00068, 0.00418]	0.6877	0.6853
Touched	-2.53	0.012	168	[-0.00626, -0.00077]	0.6404	0.6439
Emotion	-2.36	0.021	77	[-0.00968, -0.00082]	0.6588	0.6640

Note. Object level features are in blue, semantic level features are in orange, and pixel level features are in green.

One potential interpretation for the smaller mean values for faces (and other social semantic level features) for the high curiosity group is that this feature may reflect a trade-off for viewing other objects. Social visual features, such as faces, tend to highly attract visual fixation, so any fixations to other features or objects would come at the cost of looking at these normative locations for fixating. To test this possibility, fixation proportions for each feature were computed; this represents the proportion of fixations allocated to a given feature over all other features. Note, the proportion of fixations on each feature map is not exclusive to each other, i.e. a single fixation can simultaneously lie on more than one feature map if there's overlap. Here it was found that curiosity did not significantly predict differences in the

proportion of fixations to the socially relevant semantic features. This suggests that rather than a decreased allocation of attention to these features, there is instead a generally broader attentional scope but the relative interest in faces is still preserved (see Table 8 for t-tests comparing fixation proportions between high and low curiosity groups).

Table 8

Independent samples t-tests comparing fixation proportions for high and low curiosity groups.

Visual feature	t-statistic	p-value	df	Prop. mean high group	Prop. mean low group
Text	.57	0.57	120	0.08817	0.08603
Eccentricity	.27	.78	120	0.2665	0.2664
Complexity	.66	0.51	120	0.2215	0.2168
Convexity	-.064	.95	120	0.3168	0.3175
Watchability	.64	.53	120	0.1307	0.1265
Size	.48	.63	120	0.1633	0.1607
Solidity	-.097	.92	120	0.3241	0.3253
Gazed	-.88	.38	120	0.04881	0.05071
Face	-.78	.44	120	0.1978	0.2057
Color	1.26	.21	120	0.09610	0.09330

Touched	-.37	.71	120	0.06366	0.06456
Emotion	-.57	.57	120	0.04680	0.01395

Note. Object level features are in blue, semantic level features are in orange, and pixel level features are in green.

4. Discussion

The present study represents the first attempt to examine differences in salience attribution in naturalistic viewing as a function of personality characteristics. The findings indicate that curiosity predicts systematic differences in salience attribution reflected by a greater prioritization of object level over semantic level features, particularly semantic level features associated with people (face, emotion, touch, gazed). Individuals high in epistemic curiosity also looked more consistently at *text* and the semantic level feature *watchability*, which refers to man made objects designed to be viewed (e.g. paintings and televisions).

These results could indicate that the personality trait of curiosity leads to a relatively greater prioritization of (i.e. attribution of salience to) visual features that are likely to derive maximal information gain. Objects are one of the most meaningful visual features for gaining information in real world environments which may explain why object level features were more consistently viewed by individuals high in curiosity. It was additionally observed that the semantic level features of text and watchability were more consistently viewed by individuals high in curiosity. Text and manmade objects that are made to be watched both provide rich sources of semantic information. Given that curiosity is associated with the reward value of information (Marvin & Shahomy, 2016), this characteristic may in turn

motivate inspection of visual features that are expected to derive more information. Within the framework of incentive salience, this motivation may reflect differences in the assignment of salience to classes of stimuli that are likely to derive greater information or resolve uncertainty.

At first glance the current results seem to indicate a relatively lower prioritization of social information (e.g. faces and emotion); however, it is important to note that these features were still highly predictive of fixations across all participants. The pattern of results alternatively could be viewed as a relatively reduced bias towards social information for individuals high in curiosity. Given the typical strong attentional bias humans display towards faces, this decrease may represent relatively non-normative visual behavior. Put another way, individuals scoring higher in curiosity tend to fixate regions of the visual scene that are not as likely to be viewed by individuals lower in curiosity, but at the expense of viewing time for typically high salience features such as faces.

Under the incentive salience model, dopamine-mediated reward signals may bias attention towards stimuli that have previously been experienced as rewarding (Berridge & Robinson, 1998). Consistent with this, Hickey and colleagues (2015a) found that previously rewarded objects drive attention in real world scenes; importantly, this object bias extended to other members of the object category. This suggests that previously rewarded stimuli have substantial impacts on how future, similar objects are prioritized in attention.

Given the role dopamine plays in reward learning it is important to ask the question: what do dopamine neurons find rewarding in real world contexts (Bromberg-Martin et al., 2010)? In other words, in cases where reward learning is not explicit (i.e. during perception

of everyday objects), what constitutes a reward? The answer may be implicit reductions in uncertainty promoted by information gathering, the reward value of which may differ across individuals based on reward sensitivities to information gain. If it is the case that personality factors predict variation in such sensitivities, this could explain the observed differences in explorative eye movement behavior across individuals within free viewing paradigms. Applied to the present study, curious individuals may assign greater incentive salience to objects and other information rich features would in turn drive gaze allocation patterns towards these stimuli, and stimuli with similar features.

This pattern of behavior could be intrinsic or learned. Over time, we learn how to sample our environment in order to reduce uncertainty and to perform tasks optimally. Eye movements are reinforced when the previous saccade has been rewarded– this occurs when dopamine activation increases while the spatial information is being encoded. In other words, when phasic dopamine activity occurs concurrently with the encoding of spatial information, then the saccade is reinforced and will be more likely to occur in future. Given that the reward learning system is involved in directing eye movements, it follows that individual differences in activity of dopamine in these systems may contribute to variation in learned eye movement behavior.

The results of this study imply that variation in dopamine-related traits may contribute to differences in gaze behavior in free viewing paradigms. Visual behavior should be further studied in the context of stable individual differences in order to determine whether additional systematic differences are observed as a function of personality, as well as in the context of state changes or manipulations, such as under contexts of enhanced curiosity

or creativity. Researchers may consider probing individuals during free viewing to measure their states, such as motivation or curiosity, and to use subjective reporting methods to determine whether participants find specific images differentially interesting/rewarding. It may be possible that transient changes in these higher level cognitive states reflect changes in associated dopaminergic processes; if this is the case, then this could in turn influence eye movement behavior which are linked to the same midbrain structures.

Eye movements play a critical role in attention, cognition, and behavior, driving how we act and interact with the world by selectively prioritizing information for processing and mediating action selection processes. Despite the foundational role these micro-behaviors play in our everyday lives, this powerhouse of information has yet to be fully drawn upon in the fields of cognitive and personality research. The mesocortical dopamine circuit plays a role in reward sensitivity of information with implications for personality traits, particularly exploration-driven and information-seeking traits such as curiosity, as well as for salience driven saccadic eye movement (Parr & Friston, 2017). The role salience processing plays in eye movements has been studied in reward cued contexts, however very little research has examined incentive salience processes in naturalistic vision. Further, almost no research has examined this simultaneously in the context of individual differences, such as personality traits that reflect differences in reward sensitivity of information gain (i.e. curiosity). Such research is necessary to determine how curiosity may affect perceptual encoding and prioritization of visual information. By exploring this underappreciated avenue, the present study contributes to the development of a neurobiologically-driven theory to describe the nature of curiosity and its association with visual behavior.

Chapter IV: A phenomenal characteristic: Curiosity and the qualities of everyday thought.

In the previous chapter, we considered how dopamine driven salience processes may drive the perceptual consequences of attention, i.e. where we look. In this chapter, we will consider the phenomenological consequences of attention, i.e. what we think.

Thinking, and the experience of spontaneous thoughts, makes up a central part of our inner life. Indeed, resting states associated with the generation of spontaneous thoughts are so fundamental that the underlying neural network that supports them is known as the default mode network. The spontaneous thoughts generated during these states result from a wide range of higher level mental processes (Morewedge et al, 2014), and provide important functions, such as planning for the future (Baird et al., 2011; Stawarczyk et al., 2011). Despite the fact such states play a central role in the human mind and our everyday experiences, surprisingly little research has sought to examine how the characteristics of thought differ across individuals nor to understand how these differences may be driven by personality characteristics.

What might drive personality driven differences in the phenomenology of thought? Recall that individual differences in personality have been attributed to differences in the functioning of the dopaminergic reward system. In particular, it was suggested that differences in the motivational drives that underlie personality may be attributed to dopamine mediated salience processes which imbue raw sensory information with meaning or value. These processes determine which information becomes prominent enough to capture our attention in turn influencing our ideas, thoughts, and behaviors.

Recent theory has explicitly attempted to extend the incentive salience framework to phenomenological considerations. As discussed briefly in the previous chapter, contemporary theory in schizophrenia spectrum research has attempted to unite the phenomenological, perceptual, behavioral, and biological manifestations of psychosis under a theory of *aberrant* incentive salience. The theory suggests that overactive dopamine activity can lead to an aberrant assignment of incentive salience to information, which in turn can lead individuals to have unusual ideas, perceptions, and attentional behavior. This is experienced phenomenologically as a heightened sense of meaning towards atypical information or a sense that the world is "pregnant with significance" (Howes & Nour, 2016). Growing empirical and psychological evidence has accumulated in support of this model (Van Os, 2009). Furthermore, the subjective experiences reported by schizotypal or schizophrenic individuals mirrors those predicted by the aberrant salience model. Indeed, in an experience sampling study examining individuals in the early stages of psychosis, individuals reported daily phenomenological experiences of aberrant salience, i.e. a strong sense of meaning or significance towards innocuous or atypical stimuli (Reininghaus et al., 2016).

The role of incentive salience in driving spontaneous thoughts has also recently been considered in normally functioning individuals. Rice and Fredrickson (2017) reasoned that positive spontaneous thoughts may mediate the relationship between liking and wanting of rewards in much the same way that incentive salience processes drive organisms towards stimuli and situations that have previously been experienced as rewarding. In other words, both incentive salience and positive spontaneous thoughts may function to drive goal directed human behavior. It was further suggested that this parallel role of spontaneous thoughts and incentive salience processes may not be superficially similar; rather the quality and content

of spontaneous thoughts may reflect information that is valued or has previously been experienced as rewarding. In line with this, spontaneous thoughts have been observed to mediate the relationship between liking and wanting of real world activities (Rice & Frederickson, 2017). A follow up study further found diminished relationships between these variables as a function of schizotypal personality characteristics, potentially evidencing aberrant incentive salience processing (Li et al., 2020). Furthermore, spontaneous thoughts have been shown to reflect physiological needs (Rummel & Nied, 2017) and play a central role in driving future behaviors (Stawarczyk et al., 2011). These results lend initial support to the theory that the phenomenology of spontaneous thoughts may act as a psychological indicator of incentive salience by mediating the link between liking and wanting, and thereby driving approach behavior towards rewards (Rice & Fredrickson, 2017).

As mentioned in Chapter III, personality is proposed to reflect individuals' sensitivities to different classes of reward. In particular, curiosity was suggested to reflect sensitivity to the reward value of information. Such differences in turn may drive differences in individuals' everyday interests and concerns, which in turn may be reflected in the phenomenology of their everyday thought. Given the theoretical role incentive salience processes may play in curiosity and spontaneous thoughts, as well as the relative dearth of research examining qualitative features of thought, this chapter is dedicated to further exploring how the characteristics of everyday thought might be differentiated as a function of curiosity.

A. Personality and phenomenological qualities of thought

The qualitative aspects of our thoughts can fluctuate widely across a broad range of phenomenological, or experiential, dimensions; sometimes pleasant or fantastical, such as

when we are daydreaming, and sometimes unpleasant or dysfunctional, as when we ruminate about concerns. Spontaneous thoughts can be tied to the present moment, or they can be about the past or the future. But do such qualities of thoughts differ as a function of our personality styles? Some recent work in our lab indicates this may be so. A recent study examining associations between creativity and daydreaming observed that curious and fantasy-prone daydreams predict creativity (Zedelius et al., 2021). Further, when comparing the daydreams of professional creative writers and non-writers, writers were found to report more curious and more fantastical daydreams than non-writers. These recent findings suggest that the experiential qualities of thoughts may differ between individuals, and further, that these qualities of thought may signal what they value (i.e. individuals interests).

Curiosity is a particularly relevant trait for this research as its characteristics lend it to phenomenological considerations. Curiosity is characterized by approach behavior and exploration, but research to date has largely overlooked the phenomenology of the emotional, cognitive, and motivational features underpinning these tendencies. Curious individual's willingness to pursue information with no immediate benefit is good evidence that a phenomenological experience is present. Indeed it has been proposed that curiosity is *defined* by the phenomenological experience of pursuing information for its own sake (FitzGibbon et al., 2020; Liquin & Lombrozo, 2020). However, there is hardly any empirical work on how it feels to be curious, much less how it feels to be a curious person (Noordewier & van Dijk, 2017).

The current proposed study strove to fill this void by examining relationships between the phenomenology of thought and trait epistemic curiosity. For this investigation, the deprivation and interest subfacets were also explored separately given that the two subfacets

may reflect different emotional-motivational qualities (Litman, 2005) which are themselves driven by separable biological substrates. Under Litman's framework, deprivation curiosity is associated with dopamine mediated *wanting* of information, while interest curiosity is associated with subcortical systems that mediate *liking*, or the hedonic impact of rewarding stimuli. This distinction is supported by substantial research showing that dopamine affects wanting, or the desire to pursue reward, independently of liking (hedonic pleasure) (e.g. Smith, Berridge & Aldridge, 2011; for review, see Berridge, 2006). Thus if dopamine-driven incentive salience processes promote the desire for information, we should not expect this to always be tied to increased enjoyment or liking (Litman, 2005).

Based on this distinction, the phenomenology of spontaneous thoughts for individuals high in interest curiosity may be likely to reflect the rewarding nature of information gain and to be associated with a positive emotional quality. Whereas, the phenomenology of spontaneous thoughts for individuals high in deprivation curiosity may reflect a strong desire towards goal fulfillment, while being less positively emotionally valenced. Indeed, given that the desire for information in these individuals is driven by an aversive sense of uncertainty, we may even expect more frequent negatively valenced spontaneous thoughts, which in turn serve to motivate knowledge acquisition behaviors.

The research presented in this chapter addressed this by considering: 1) What phenomenological characteristics of everyday thought are associated with the curious personality trait? (study 3), 2) How do these associations change when examining the deprivation and interest facets of trait curiosity separately (study 3), and 3) How are these characteristics similar or different to those associated with states of curiosity (following the novel curiosity induction)? (study 4).

B. Study 3. Experiential qualities of the curious person

A 7-day experience sampling study was conducted to capture thoughts occurring outside of the laboratory. Thought qualities were assessed pseudo-randomly throughout the day in order to capture qualities of thought during various circumstances in everyday life. Trait curiosity was measured prior to the start of the experience sampling procedure. A broad range of potentially relevant qualities of thought were chosen for examination. Given the theorized relationship between curiosity and the reward value of novel information, thought qualities that reflect a tendency to attribute value to greater breadth of information were chosen, including the thought qualities *novel* and *topic shifting*. Furthermore, given the role incentive salience processes play in imbuing significance and motivational relevance to sensory information, thought qualities that reflected these processes were also selected, including *meaningfulness* and *goal-directedness*.

Following approval by the Institutional Review Board of Duke University and the University of California, Santa Barbara (UCSB), 140 participants (81 females, mean age 19.3 years) were recruited (47 at Duke). However, 9 were dropped as they did not complete the study resulting in a final N of 131.

1. Materials

Thought probes were delivered via Metricwire, a third party, Smartphone-based, response collection software. Each probe assessed thoughts across 10 dimensions using 8 dichotomous (Yes/No) and 2 multiple choice questions; see Table 9 for questions and responses. These dimensions were chosen mostly due to their relevance with the motivational and cognitive properties of curiosity, namely goal-directedness, meaningfulness of thoughts, valence, and topic shifting, or how much thoughts jump from topic to topic. Given the

exploratory nature of this research, not all dimensions included were associated with specific predictions. To examine the association between thought and curiosity, trait curiosity was measured using the 10-item Epistemic Curiosity scale (Litman & Spielberger, 2003)[1].

Table 9

List of thought qualities assessed in each of the experience-sampling surveys

Thought Quality	Actual Question
Fluidity	My thoughts were moving freely (i.e., I wasn't guiding them) [Y/N]
Novelty	My thoughts were novel [Y/N]
Meaningfulness	The content of my thoughts was important and meaningful to me [Y/N]
Topical shifts	My thoughts were jumping from topic to topic [Y/N]
Goal-directedness	My thoughts were focused on uncompleted personal goals [Y/N]
Bizarreness	My thoughts were bizarre and unusual [Y/N]
Emotional	My thoughts were emotional [Y/N]
Spontaneous	My thoughts [came to mind spontaneously | were engaged deliberately, with intention]
Emotional valence	The content of my thoughts was… [positive, negative, neutral]
Temporality	My thoughts were focused on the…[past, present, future, atemporal]

2. Procedure

Following informed consent, participants completed the trait questionnaires. They were then given instructions on the experience sampling procedure they were to engage in for the week. Briefly, they were instructed to respond to thought probes delivered via their smartphones 8 times a day for 7 days. Upon receiving a survey probe, participants were instructed to report on the thought they were just having, no more than 5 seconds prior to

[1] several other personality scales were included for exploratory purposes, and are not reported here.

being prompted. To ensure comprehension of the study instructions, participants completed a comprehension check with accuracy feedback. They then downloaded the Metricwire app on their phone and logged into the study. A practice trial of the phone survey was then completed, at which point the lab session was concluded. Participants then completed the experience sampling procedure remotely from their phones over the following week.

3. Results

First descriptive statistics were run to determine the average frequency of responses for which each thought feature was reported, see Figure 3 for graphical representation. Table 10 lists the descriptive statistics for each quality: mean, standard deviation, skewness and kurtosis. The two non-binary variables (emotional valence and temporal orientation) were made into 3 and 4 separate binary variables, respectively. Emotional valence was separated into three variables: positive, neutral, and negative valence, while temporal orientation was separated into past, present, future, and atemporal variables. As a result, all variables presented below represent binary variables. The average frequencies represent the number of occurrences in which participants reported in the affirmative for the quality (i.e. a Yes response).

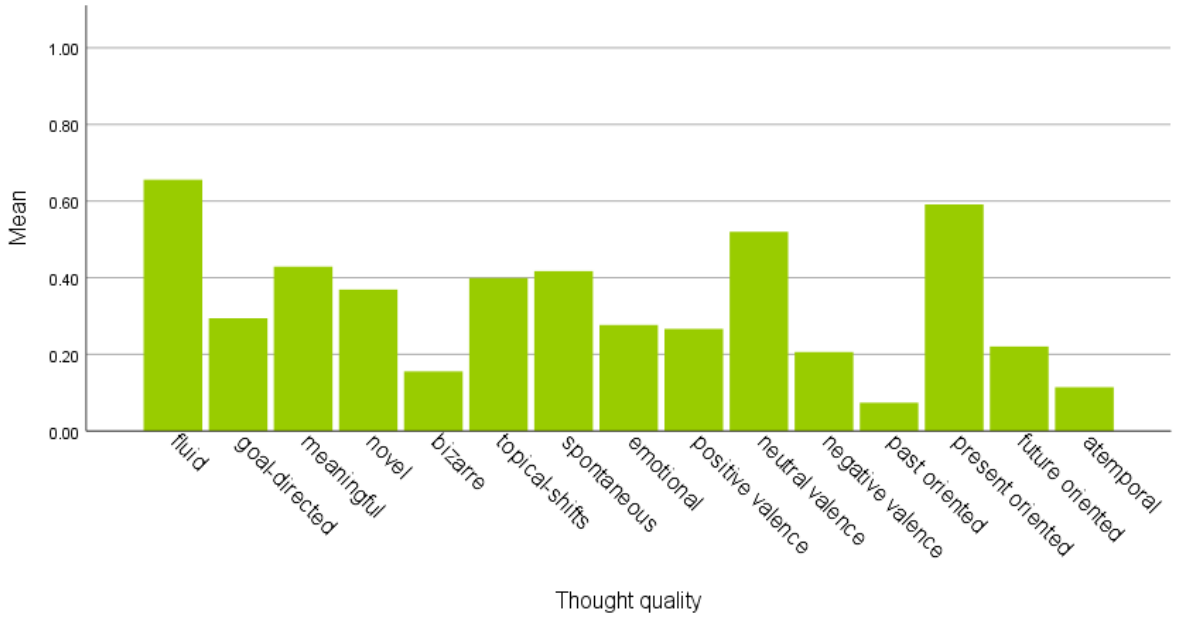
Table 10

Summary statistics for the thought qualities across participants

Thought quality	Mean (%)	SD	Skewness	Kurtosis
Novelty	36.9	0.25	0.40	-0.87
Fluid	65.6	0.20	-0.19	-0.82
Meaningful	42.9	0.21	0.095	-0.56
Topic-shifting	39.9	0.21	0.20	-0.25
Goal-oriented	29.4	0.20	0.75	0.51
Bizarre	15.5	0.19	1.86	3.77
Spontaneous	41.7	0.16	0.049	0.003
Emotional	27.6	0.19	1.01	1.43
Negative valence	20.6	0.17	1.28	1.79
Neutral valence	52.0	0.22	-0.038	-0.55
Positive valence	26.6	0.17	0.66	0.029
Past oriented	7.4	0.072	1.07	0.96
Present oriented	59.1	0.19	-0.49	0.51
Future oriented	22.1	0.16	1.15	3.64
Atemporal	11.5	0.15	2.18	6.50

Figure 3

Graphical representation of average frequency each thought dimension was reported across participants.



The data was analyzed using multilevel binary logistic regression, given that prompts were nested within subjects across days. Random intercepts were included to allow participants to randomly vary. Epistemic curiosity predicted several key qualities of thought; fluidity, or how freely moving the thoughts were, meaningfulness of the thoughts, how much the thoughts were shifting from topic to topic, and how goal directed the thoughts were, see table 11.

Table 11

Results of binary logistic regression predicting thought qualities by epistemic curiosity.

Thought quality	B (Coefficient)	p-value	CI
Fluid	**.34**	**.043**	**.011, .67**
Novel	.30	.16	-.11, .70
Meaningful	**.42**	**.008**	**.74, 1.53**
Topical shifts	**.43**	**.005**	**.13, .73**
Goal-directed	**.52**	**.002**	**.19, .85**
Bizarre	.32	.20	-.17, .81
Spontaneous [vs deliberate]	-.053	.63	-.27, .16
Emotional	**.44**	**.005**	**.14, .75**
Emotional valence: negative	-.053	.75	-.38, .27
Emotional valence: neutral	.023	.88	-.27, .32
Emotional valence: positive	-.017	.90	-.30, .26
Temporal orientation: past	.075	.66	-.26, .41
Temporal orientation: present	-.071	.61	-.34, .20
Temporal orientation: future	.22	.14	-.073, .52

Note. Bold indicates significant effects, italics indicates marginally significant effects.

Given that disassociations often occur between the two subcomponents of epistemic curiosity – interest and deprivation curiosity – the analyses were re-run with both of these sub-components separated and included simultaneously in the model. As can be observed in Table 12, interest-based curiosity appears to drive some of the effects previously seen for the combined epistemic curiosity scale, although not robustly enough for the associations to remain significant once deprivation curiosity is partialed out. The previously non-significant relationship between epistemic curiosity and positive thought valence, on the other hand, became significant when interest and deprivation were partialed out. However, the effects were in opposite directions; there was a positive association between positive emotional valence of thoughts and interest curiosity, and negative association between positive emotional valence of thoughts and deprivation curiosity.

Table 12

Results of multilevel binary logistic regression predicting thought qualities by interest and deprivation curiosity

	Interest-based curiosity			Deprivation-based curiosity		
Thought quality	β	p-value	CI	β	p-value	CI
Fluid	.18	.32	-.17, .53	.17	.30	-.15, .48
Novel	*.39*	*.080*	*-.046, .82*	-.056	.77	-.44, .33
Meaningful	*.27*	*.12*	*-.068, 61*	.16	.28	-.13, .46
Topical shifts	*.31*	*.061*	*-.015, .63*	.14	.34	-.15, .43
Goal-directed	.22	.23	-.14, .57	*.30*	*.063*	*-.016, .61*
Bizarre	-.097	.71	-.62, .42	.38	.11	-.084, .84

Spontaneous [vs deliberate]	.039	.73	-.19, .27	-.082	.42	-.28, .12
Emotional	.20	.24	-.13, .53	.24	.10	-.048, .53
Emotional valence: negative	-.17	.34	-.51, .18	.097	.54	-.21, .41
Emotional valence: neutral	-.14	.37	-.46, .17	.15	.31	-.13, .42
Emotional valence: positive	**.30**	**.043**	**.010, .59**	**-.27**	**.038**	**-.53, -.014**
Temporal orientation: past	.043	.82	-.33, .40	.033	.84	-.28, .35
Temporal orientation: present	-.19	.20	-.47, .098	.094	.47	-.16, .35
Temporal orientation: future	.18	.27	-.14, .50	.057	.40	-.22, .34
Temporal orientation: atemporal	.30	.23	-.19, .79	**-.44**	**.047**	**-.88, -.006**

Note. Bold indicates significant effects, italics indicates marginally significant effects.

4. Discussion

This study revealed that the curious personality trait may be associated with differences in several key experiential qualities of everyday thought. This suggests that the mental experiences of curious individuals may differ in important ways. It is possible that the positive outcomes that have previously been associated with curiosity are reflected even in the characteristic qualities of everyday thought, which in turn may support a more positive inner mental life.

Spontaneous thoughts have a consequential impact on our emotions, pursuits, judgments and behaviors (Killingsworth & Gilbert, 2010; Morewedge et al., 2014; Jubera-García et al., 2020). Indeed, past research suggests that the content of our thoughts has a bigger impact on our emotional state than the activities we are engaging in (Killingsworth & Gilbert, 2010). Unfortunately, everyday thoughts are often unpleasant (Killingsworth & Gilbert, 2010), or even, at the extreme, ruminative. Our thoughts often cycle on present concerns or past failures with important consequences on our mental and even physical health (Ottaviani et al., 2011). The present study brings new light to these findings by suggesting that personality may play an important role in driving these features. Curiosity was linked to a greater frequency of fluid, topic shifting, meaningful and goal-directed thoughts, which may indicate less circular, mundane, and ruminative thoughts. These features may reflect greater diversity and breadth of thoughts which in turn may contribute to a more productive and dynamic inner life. However, future research is necessary to untangle the many possible implications of the current findings.

When examining the unique contributions of interest- and deprivation-based curiosity, the results indicated that while both subfacets appear to contribute to the observed findings for epistemic curiosity, each facet may contribute to particular features more than the other. Although many of the findings did not reach significance for either subfacet, it appears that interest curiosity may contribute more to novel and topic shifting qualities of everyday thought, as well as more frequent positively valenced thoughts. This thought content may be reflective of the incentive salience these individuals attribute to novel and diverse information. Recall that spontaneous thoughts have been posited as reflecting incentive salience (Rice & Frederickson, 2017) given that an individual's thought content

likely reflects what they value while also motivating behaviors to attain more of what they value. In the case of individuals high in interest curiosity, novel and diverse thought content could reflect their tendency to attribute reward value to new and wide ranging information. For these individuals, gaining such information is experienced as inherently rewarding which may also explain the generally positive emotional valence associated with their everyday phenomenology. Just as incentive salience motivates behavior, positive spontaneous thoughts about novel and diverse information may motivate exploratory behavior to perpetuate further pleasurable knowledge acquisition.

On the other hand, deprivation-based curiosity appeared to predict more frequent goal-directed thoughts and less frequent positively valenced thoughts. Deprivation curiosity is characterized by a tenacious and persistent drive to solve problems and is driven by an aversive sense of uncertainty. Under the incentive salience framework, this sensitivity to information gaps may drive thought content that is more goal-directed, which in turn would function to motivate individuals toward problem solving and uncertainty reducing styles of information seeking behavior. Given that deprivation-based information seeking is associated with an aversive affective response, such goal-directed thoughts may be less positively valenced. Further research should continue to examine the possibility that individuals' spontaneous thoughts represent the phenomenological consequences of the affective and motivational features of incentive salience processes.

The observed thought qualities may not only drive the behaviors that are characteristic of this trait but may also explain some of their associations with other positive characteristics. For instance, interest curiosity is more closely linked with openness and

creativity (Koutstaal et al., 2022; Hardy III et al., 2017) which may be supported by more novel and topically broad thought content. However, given that none of the qualities observed for epistemic curiosity remained significant for either facet when controlling for the influence of the other, it seems likely that the combination of interest and deprivation curiosity may best explain the current observed findings. Despite the fact that these facets differentiate on several outcomes when partialed out, it is important to note that the two facets are fairly highly correlated and generally co-appear within individuals.

The curious personality trait is often assumed to reflect increased daily experiences of curiosity. This suggests that the current findings may have been driven by everyday fluctuations in curiosity; in other words, the observed qualities may reflect individuals' thought characteristics during variable levels of state curiosity. In line with this, a subset of notable researchers suggest that trait and state curiosity are "psychologically equivalent" (Kashdan et al., 2018, p. 131), such that trait curiosity is nothing more than a predisposition towards experiencing frequent and/or intense states of curiosity (Grossnickle, 2016; Horstmeyer, 2022). However, given the correlational nature of the present study and the fact that state curiosity was not assessed during the thought surveys, the present study cannot speak to this interesting possibility. To investigate this, study 4 experimentally induced a state of curiosity and examined whether this state promoted similar qualities in spontaneous thoughts as observed in relation to trait curiosity.

C. Study 4. Comparing the qualities of state and trait curiosity

In Study 4, thought content was assessed before and after the novel interest-based curiosity induction (see study 1, chapter II) in order to examine the phenomenological

features of states of curiosity. Recall that the interest curiosity induction involves question generation, a process which has been theorized to promote interest, curiosity, learning, and even the core processes related to creativity (i.e. divergent thinking). It is likely that such outcomes are promoted via shifts in the thinking styles of individuals, leading to broader, deeper processing of information. The question generation strategy may indeed catalyze the salience generation processes described earlier, by creating a heightened state of arousal or interest in the presented information.

Participants' thoughts were sampled twice during the course of the single session, as well as retrospectively at the end of the session. The goal of this study was fourfold: 1) to determine whether associations between trait curiosity and qualities of thought content assessed in a single thinking session yield comparable results to those observed in the extended experience sampling procedure, 2) to compare the thought qualities associated with trait and state curiosity in order to determine potential similarities, 3) to determine whether the novel state curiosity induction drives changes to the phenomenology of thought content, and 4) to assess whether any such effects of the induction are mediated by states of curiosity.

A mixed design 2(state curiosity: induction vs control) by 2(thinking session: pre vs post) study was conducted to examine whether states of curiosity lead to phenomenological changes in the qualities of thought following the induction. Participants were randomly assigned to either the curiosity induction condition or the control (between subjects). Thought qualities were assessed in a thinking session before and after the curiosity induction or control.

1. Materials

The question-generation curiosity induction presented in study 1 was used to promote state curiosity. In the experimental condition, participants were asked to generate questions about the content of articles both while they were reading (e.g. "actively ask questions about what you are reading") and after reading. The control condition was instead asked to determine the main ideas presented in the text. In the initial testing of the curiosity induction, the interestingness of the articles used additionally promoted curiosity (see Results, study 1). Given the difficulty in successfully capturing downstream effects experimentally, these elements were combined for the curiosity condition in the current study in order to maximize the power of it. In other words, individuals were given both interesting articles and question formulation in the experimental condition, versus uninteresting articles and main idea generation in the control condition.

As in study 1, state curiosity was assessed in two ways; activity based curiosity and general interest curiosity. Activity based curiosity was again measured with 3 activity-related curiosity on a 1-7 scale (*Not at all* to *Extremely*), measured twice during the curiosity induction task (see study 1 materials for items). The scores from these items were averaged to create a single activity-based curiosity variable. States of general interest curiosity were measured using the state interest-based curiosity scale developed in study 1 (e.g. I currently feel like discussing abstract concepts); for full list of items see Table 1 in Chapter II.

Participants engaged in the thinking sessions before and after the reading task, in which they were given 10 minutes to sit without a task and allow any spontaneous thoughts to arise. The thinking task was interrupted twice with thought probes assessing the qualitative features of thought. The included features were largely the same as those included in study 3:

meaningful, novel, topic shifting, goal-directed, fluid, bizarre, emotional valence, temporal dimension. Given the previous findings, the emotional valence thought quality was simplified to only include positive emotional valence. One more thought quality that was considered likely to be relevant to states of curiosity was also included: how engaging thoughts are. The items used the same response options described in study 3. These qualities assessed using the probes were also assessed at the end of the thinking session, retrospectively. Here, participants were asked to estimate the frequency with which their thoughts took on the given qualities on a scale from 1 (*Never*) to 6 (*Very frequently*).

2. Procedures

Participants first engaged in a thinking session. Thought probes were delivered twice during this period. Participants were then randomly assigned to either the curiosity condition, where they read interesting articles and generated questions, or the control condition, where they read uninteresting articles and generated main ideas. After each reading topic (total of 2) participants responded to activity-based curiosity questions. Afterwards, state curiosity was assessed using the 5 item adapted measure described previously and the second thinking session began. Finally participants completed the trait epistemic curiosity scale as well as a brief set of demographics questions. See Figure 4 for schematic of the study flow.

Given that the thought probes and retrospective thought questions were given on a different response scale, the scores were z-scored and combined to create averages. Difference scores for thinking session 1 and 2 were created to compare the effects of condition across time. To compare states and traits of curiosity, thought qualities during thinking session 2 were compared (post curiosity induction).

Figure 4

Study 3 schematic of study flow



3. Results:

First, the effects of the novel curiosity induction on state curiosity was examined. To test this, state interest curiosity and activity-based curiosity were compared across the between-subject experimental (curiosity induction vs control) conditions in separate independent t-tests. The curiosity manipulation led to a large increase in state interest curiosity (compared to generating main ideas), $t(146)= 6.80$, $p <.001$, as well as activity-based curiosity, $t(146)= 8.82$, $p <.001$. See Table 13 for descriptives of curiosity variables across conditions.

Table 13

Descriptives for curiosity variables across conditions

Condition	DV	Mean	SD
Experimental	State interest curiosity	4.53	1.20
	Activity-based curiosity	4.30	1.30
Control	State interest curiosity	3.13	1.28
	Activity-based curiosity	2.52	1.15

Next, we examined whether there were similar associations with qualities of thought and state curiosity, as observed between qualities of thought and trait curiosity. To test this, partial correlations were run between thought qualities at time 2 (following the induction) and state curiosity while holding trait curiosity constant, and vice versa. Here we observed something interesting and unexpected. There was little overlap in the qualities of thought when comparing states and traits of interest curiosity. States of interest curiosity were only associated with how engaging thoughts were, when holding trait interest curiosity constant. On the other hand, trait interest curiosity was associated with many of the same thought qualities observed in the previous experience sampling study: meaningfulness, topical shifts, and goal directedness of thoughts, see Table 14. In the present study trait interest curiosity was also marginally associated with bizarre and positively valenced thoughts when partialing out state interest curiosity.

Table 14

Partial correlations assessing the contribution of state vs trait interest curiosity on each experiential thought quality

	State interest curiosity		Trait interest curiosity	
Thought dimension	Pearson's r	p-value	Pearson's r	p-value
Fluidity	-.011	.90	**.17**	**.049**
Novelty	-.011	.90	.11	.18
Meaningful	.062	.47	**.27**	**.001**
Topical shifts	-.024	.78	**.25**	**.003**
Goals	-.10	.23	**.31**	**<.001**

Bizarre	.042	.62	*.16*	*.061*
Emotional valence: positive	.097	.25	*.15*	*.075*
Engaging	**.26**	**.002**	**.20**	**.020**

Note. Significant effects are indicated in bold, marginal effects in italics.

Next, trait interest was compared to trait deprivation curiosity by once again partialing out the other to examine the unique contributions of each. Here we see a similar pattern as observed in the previous study (see Table 12, study 3) in that interest curiosity appears to be more highly associated with meaningfulness, topical shifts, and positive emotional valence, while deprivation curiosity is more highly associated with goal oriented thoughts but negatively associated with positive thoughts, see Table 15. In this study, interest curiosity is also marginally associated with fluid thoughts, while also being significantly positively associated with engaging and goal-directed thoughts (though to a lesser degree than deprivation curiosity). Unlike in the previous study, associations with novelty of thought were not observed for interest curiosity.

Table 15

Partial correlations assessing the contribution of trait interest vs deprivation curiosity on the each experiential thought quality

	Trait interest curiosity		Trait deprivation curiosity	
Thought dimension	Pearson's r	p-value	Pearson's r	p-value
Fluidity	*.15*	*.072*	.008	.93
Novelty	.066	.44	.12	.16

Meaningful	**.24**	**.005**	.13	.13
Topical shifts	**.20**	**.019**	.10	.22
Goals	**.18**	**.035**	**.32**	**<.001**
Bizarre	*.14*	*.088*	.061	.47
Emotional valence: positive	**.25**	**.003**	**-.22**	**.009**
Engaging	**.26**	**.002**	-.001	.99

Note. Significant effects are indicated in bold, marginal effects in italics.

Next, we examined whether there was a main effect of condition (curiosity induction vs control) on qualities of thought. To test this, an ANOVA was run with condition as the IV and each quality of thought as the DV. Here it was observed that there was a significant main effect of condition on engagingness of thoughts, $F(1, 146)= 4.41$, $p = .037$, such that the curiosity induction condition experienced more engaging thoughts following the induction.

Given the previously observed association with engageness of thoughts and state interest curiosity, we examined whether states of curiosity drove this effect. To examine this, state interest curiosity and activity-based curiosity were added as mediators to the model using PROCESS macros, a series of customizable scripts for running mediation analyses in SPSS. The results indicated that the effect was fully mediated by state interest curiosity, indirect effect *B*= .54(*SE:* .17), CI[.22, .91], but not activity-based curiosity, *B*= -.071(*SE:* .20), CI[-.48, .32]. The direct effect became non-significant once the state curiosity variables were simultaneously modeled, *B*= -4.72(*SE:* .24), CI[-.94, .0009].

4. Discussion

Using an experimental design that allowed for the simultaneous examination of state and trait curiosity, this study revealed a distinct and surprising pattern of results in the phenomenological characteristics of thought. Whereas state interest curiosity was associated only with engaging thoughts, trait interest curiosity was additionally associated with goal-directed, fluid, meaningful, topic-shifting thoughts, and, less robustly, with bizarre and positively-valenced thoughts. This distinction lends interest to current debates over the nature of the relationship between states and traits of curiosity.

In particular, we do not find evidence of the psychological equivalence of trait and state curiosity, as has been proposed by notable modern theorists (Kashdan et al., 2018). Rather, we put forward a more complex holistic view of curious traits. Curious minds may involve a web of cognitive, emotional, and motivational qualities (Horstmeyer, 2022) that link together states of curiosity and move individuals towards these states more readily. For instance, curious individuals' tendency toward goal-directed thoughts may reflect a motivational quality that drives individuals towards situations that promote curiosity.

We further found that the curiosity induction promoted curiosity-mediated changes in the phenomenological quality *engagement*. Engagement of thoughts may be the seed for catalyzing the productive potential of states of curiosity. For instance, the engagingness of thoughts may explain the association between states of curiosity and feelings of interest or absorption, as well as deepened processing of, and engagement with, novel information leading to greater learning, exploration, and wondering: key outcomes associated with states of curiosity.

Curiosity is associated with a host of positive outcomes such as greater life satisfaction and perceived meaning in life. These outcomes may be reflected even in the characteristic qualities of everyday thought which in turn may support more dynamic (topic shifting), productive (goal-directed), and positive (meaningful and positive emotionally valenced) inner mental life. Further research should attempt to understand the role spontaneous thoughts may play in the relationship between personality characteristics and associated life outcomes. Such work will help to bridge the dynamics of everyday experience with stable, lifespan aspects of personality.

To conclude, using both an ecologically rich experience sampling study and a casually informative experimental study, we observed a striking pattern of associations between curiosity and a host of key experiential qualities of thought. This marks a largely unexplored territory for personality research with important implications, as much of our waking life is spent in thought. More research is necessary to understand not only how the qualities of thought differ based on personality, but interactions with context and the situations people find themselves in. Past studies exploring the phenomenology of mind wandering also highlight the importance of its content and relation to meta-cognition in determining its functional outcomes. These two factors should be further explored when considering personality driven differences in the experiential quality of everyday thought.

V. Interest curiosity, information seeking, and learning.

Curiosity is theorized to be fundamental to information seeking behaviors and learning (Holm et al., 2019), yet there has been surprisingly little experimental research in this area (Gruber et al., 2019). As previously mentioned, our understanding of curiosity to date is specific to *deprivation* curiosity given that methods for inducing states of curiosity have so far relied on the creation of defined information gaps. Existing mechanisms for information seeking and learning observed under the aversive state of deprivation curiosity might not apply to the appetitive state of interest curiosity. In this chapter, research on the link between curiosity, information seeking, and learning is interpreted in the context of incentive salience processing. Possible mechanisms for information seeking and learning that are specific to interest based states of curiosity are then proposed. Finally, a final study is reported that examines the attentional, emotional, and phenomenological consequences of interest curiosity along with possible downstream effects on learning and information seeking behavior.

According to the incentive salience theory of dopamine function, approach behavior to rewards is driven by dopamine-mediated incentive salience processes (e.g. Berridge, 2007). In this framework, the motivation to pursue rewarding outcomes is triggered by exposure to stimuli that have previously been associated with the reward. In the current thesis, these processes have been considered in the context of curiosity in which information is considered as a reward. Existing theoretical accounts of curiosity consider information seeking to be driven specifically by the rewarding consequences of *uncertainty reduction*, in other words, the relief of an information gap is experienced as rewarding. This mechanism fits well with our understanding of deprivation curiosity given that it is considered an

aversive state of uncertainty that is relieved by information gain. Under this interpretation, information seeking behavior is not driven by the reward of gaining information per se, but rather the reduction of an acute state of uncertainty regarding a specific piece of missing information.

It is likely that other processes drive information seeking under states of general interest curiosity. Unlike derivation curiosity, interest curiosity is associated with positive affect and an appetitive stance towards information gain suggesting that other aspects of the epistemic process may be rewarding [beyond uncertainty reduction]. Learning new information may be a positive experience unto itself; indeed, the attainment of new knowledge may drive rewarding feelings of wonder, interest, or even awe. To illustrate this point, imagine the sense of curiosity a child may feel when she is driven to dig her hands into a puddle of mud. The information gain from this experience is minimal and lacks utility. But the phenomenological experience achieved by pursuing this novel experience may contribute to the desire to further explore other possible sensory experiences which hold promise of further wonder or delight.

To explore the possibility of interest based information seeking, the present study examined information seeking behavior following the interest curiosity induction. The induction method previously described was used which asks participants to read interesting articles with an active inquiring stance in order to maximally stimulate interest and feelings of epistemic reward. It was anticipated that this induction would be associated with a more positive mood and a state of interest (relative to the control condition) which in turn would promote information seeking behavior in a subsequent reading activity. States of deprivation curiosity were also measured in this study using a novel state measure which partially

adapted items from the trait deprivation curiosity scale. This measure was included in order to rule out the possibility that the question asking induction promotes a state of deprivation, and further, to rule out the possibility that any effects observed from the induction (i.e. on learning and information seeking) were caused by deprivation curiosity rather than interest.

In the present study, the interest curiosity induction parallels the information seeking task. The motivation to pursue information (the reward) should be triggered by situations or stimuli that have previously offered high information gain (high reward). If the interest curiosity induction is effective in promoting a rewarding epistemic experience, as demonstrated by increases in positive affect, this should drive motivation to explore similar situations or stimuli with the potential for offering further rewarding epistemic experiences. In the incentive salience framework, this would be anticipated due to a dopamine driven motivation to pursue rewarding experiences.

This final study additionally examined whether interest curiosity facilitates learning. Experimental research examining the effect of curiosity on learning indicates a causal relationship (e.g. Wade & Kidd, 2019). As noted, however, existing research on state curiosity focuses entirely on deprivation based curiosity; therefore it is unclear the degree to which appetitive states of interest curiosity drive learning or the degree to which interest curiosity driven learning would be promoted by the same mechanisms as deprivation based curiosity learning. Theoretically, however, it seems unlikely that the same mechanism that drives learning under states of deprivation curiosity would also drive learning under states of interest curiosity. Deprivation curiosity has been suggested to promote learning via information predictor errors (Marvin & Shohamy, 2016), which are defined as the difference between expected and actual information. In order for an information prediction error to

occur there must be a fairly well-defined prediction; this would easily be generated via presentation of a specific information gap. Interest curiosity, on the other hand, is associated with a general desire to learn, rather than a desire to reduce an acute state of uncertainty related to a specific knowledge gap. It is therefore unclear the degree to which predictions about to-be-learned information arise during states of interest curiosity.

The mechanisms by which learning driven by interest-based curiosity occurs may require an expansion of existing curiosity-based learning models. Interest curiosity instead may promote learning via its influence on attention. In both reading and film paradigms, situational and topic interest has been found to promote comprehension via reductions in mind wandering (Fulmer et al., 2015; Kopp et al., 2016; Soemer & Schiefele, 2019; Unsworth & McMillan, 2013). Although topic interest is not equivalent with a state of interest curiosity, it is possible that interest curiosity similarly promotes learning by increasing engagement with information and focusing attention. In line with this, a recent study found that instructing participants to approach a text with an attitude of curiosity caused a reduction in mind wandering while reading (Zedelius et al., 2020).

Another possibility is that the phenomenal qualities associated with interest curiosity drive learning. It has previously been proposed that the sense-making process reflects phenomenal qualities which aid in learning (Sandberg & Tsoukas, 2020), particularly qualities such as absorption. Given our previously observed finding that the thought quality *engaging* increases during states of interest curiosity, it is plausible that the curiosity induction would promote characteristics of thought that correspond with sense-making processes and thereby facilitate learning. This possibility was tested by determining the degree to which the thought quality *engaging* predicts reading comprehension in a surprise

recall test following the curiosity induction. Two further thought qualities related to *engaging* were also added, namely, *interesting* and *boring* (the latter as the antithesis of engaging).

Together, the following study tests several predictions which have not been examined in the context of interest curiosity. Using the novel interest curiosity induction, the effects of interest curiosity on mind wandering and task engagement (self-reported), positive mood, information seeking, and learning are explored. It is predicted that interest curiosity will drive the positive effects of the experimental induction on these positive outcomes. It is further predicted that these associations will not be observed for state deprivation curiosity, once states of interest curiosity are partialed out.

A. Study 5. Effects of curiosity induction on phenomenology, learning, and well-being

This study measured the effects of interest curiosity on several key outcomes: information seeking, mind wandering/task engagement, phenomenology of thought, and learning. 300 participants were recruited online through Amazon's mechanical turk. Several attention and bot checks were used to ensure data quality. Participants had to pass two checks prior to participating in the study. Of the participants who made it through these checks, a further 9 participants were excluded during data analysis for failing to pass quality checks embedded in the study itself. This resulted in a final N of 291.

1. Materials

The curiosity induction described in study 1 (Chapter II) was used to promote curiosity. State interest curiosity was again assessed using the activity-based measure and the 5-item adapted interest curiosity scale. A state deprivation curiosity was developed and also included in this study. The items in this scale were adapted or inspired from the trait

deprivation curiosity subscale of the Epistemic Curiosity scale, see Table 16 for state items and existing trait items for reference.

Table 16

State adaptations of the trait deprivation-based epistemic curiosity subscale

STATE	TRAIT
I currently feel great pressure to gain new information.	I work like a fiend at problems that I feel must be solved.
I currently have the sense that I won't be able to rest until I get more answers.	I can spend hours on a single problem because I just can't rest without knowing the answer.
I currently feel an aversive sense of uncertainty.	Difficult conceptual problems can keep me awake all night thinking about solutions.
I currently have a strong nagging sensation that I am missing an important piece of information.	I brood for a long time in an attempt to solve some fundamental problem.
I currently feel frustrated by not having more information.	I feel frustrated if I can't figure out the solution to a problem, so I work even harder to solve it.

Positive and negative mood was assessed using the Scale of Positive and Negative Experience (SPANE; Diener et al., 2010) which includes 6-items for measuring positive emotional states (e.g. good, pleasant, joyful) and 6 items for measuring negative emotional states (e.g. bad, unpleasant). Following the induction, participants were also asked to retrospectively evaluate their mind wandering during the experimental reading task (during which they either asked questions or produced main ideas).

Participants were then presented with another short article and were asked to simply read the article for the next activity. The article's content was tested in a surprise memory/comprehension test later in the study. The article and 12 Multiple Choice recall questions were taken from the Gernsbacher Multi-media Comprehension Battery

(Gernsbacher & Varner, 1988). The story was a 633 word short story entitled *The Most Precious Possession* (access for these materials can be requested directly from Gernsbacher).

As this study was conducted online, a minimal task was used during the thinking sessions to ensure participants were engaged in the activity. An adapted Simple Reaction Time task (SRT; e.g. Deary et al., 2001) was used in which participants were instructed to respond with a key press as fast as possible upon the presentation of a stimulus (yellow circle) on the screen. Only key presses were collected for this task (not RT measures) given the primary goal was to ensure participants were engaged in the thinking session and had not walked away from their computers.

Behavioral curiosity was assessed using a novel *information foraging task* developed in our lab. This task taps curiosity by examining individuals' choice to continue to read interesting articles. Fifteen articles covering broad topic areas, from science, culture, and anthropology, were included in the study; these articles had previously been piloted for, on average, high levels of interestingness. Each article was split across 6 pages, with 200-300 words on each page. The article that participants started on was randomized. On each page, participants made a choice from three options: continue reading the same article, skip to a new article, or do a word search. Two studies using this measure in our lab confirmed that choosing the word search option is negatively associated with both state and trait curiosity. Therefore the variable of interest in this task was the total number of times participants chose a reading option (either continue reading the same article or read a new article) as opposed to the wordsearch.

2. Procedure

After indicating informed consent, participants were randomly assigned to either the experimental (question asking and interesting articles) or control (main idea generating and uninteresting articles) conditions. Following this, curiosity and mood were measured, as well as retrospective reports of mind wandering. To measure curiosity driven effects on learning, participants in both conditions then read an article from a standardized reading exam which they were later tested on with a surprise recall and comprehension test. The article was presented with the following minimal task instructions, "Please read the following article for the next activity". After reading the article, participants engaged in the thinking session during a simple reaction time (SRT) task. The task was interrupted twice with thought probes (equivalent to those used in study 4), which were additionally presented at the end of the thinking session, at which point participants were asked to estimate the frequency of which the thought qualities occurred over the entire session. The 12-item comprehension and recall test for the article was then delivered. Participants then engaged in the *information foraging task* for 10 minutes. Finally, participants completed the trait epistemic curiosity scale and demographics questions.

3. Results

This study examined the effects of the interest curiosity induction on phenomenological qualities of thought as well as on information seeking (behavioral curiosity), mind wandering, learning, and mood. First partial correlations were run to examine the relationships between the outcome variables and states of interest and deprivation curiosity. As shown in Table 17, the two subtypes of curiosity markedly differed in their associations with the key dependent variables. State interest curiosity was positively

associated with information seeking and positive mood, and negatively associated with mind wandering [during the reading activity] and negative mood. On the other hand, state deprivation curiosity was negatively associated with information seeking and positively associated with negative mood. While the relationships with learning were not significant, the direction of the effects were similar: the association with learning was in the positive direction for interest curiosity while being in the negative direction for deprivation curiosity.

Table 17

Partial correlations between state interest and deprivation curiosity, and the key dependent variables

	State interest curiosity	State deprivation curiosity
Information seeking	**.22, p < .001**	**-.12, p=.043**
Learning	.083, p=.16	-.096, p=.10
Mind wandering	**-.35, p<.001**	**.22, p<.001**
Positive mood	**.36, p<.001**	.022, p=.71
Negative mood	**-.33, p<.001**	**.35, p<.001**

Next, an independent samples t-test was run to determine whether the curiosity induction was effective in promoting curiosity. For this analysis, state interest, state deprivation, and activity-based curiosity were added as DVs. As shown in Table 18, the

induction uniquely promoted states of interest and activity based curiosity, but did not have a significant effect on deprivation curiosity.

Table 18

The effect of the curiosity induction on the key curiosity variables

Curiosity dependent variables	t(df)	Sig.	Mean(SD) experimental condition	Mean(SD) control condition
State interest curiosity	**3.48(292)**	**.001**	**4.75(1.41)**	**4.15(1.55)**
State deprivation curiosity	.74(292)	.46	2.85(1.44)	2.72(1.36)
Activity-based curiosity	**6.39(287)**	**<.001**	**4.83(1.49)**	**3.67(1.57)**

An independent samples t-test was then run to examine the effect of the condition on the 5 outcome variables: learning (number of correct responses), mind wandering [during the reading activity], information seeking (proportion of choices to read versus do a wordsearch), positive mood, and negative mood. As seen in Table 19, the curiosity induction led to significantly greater information seeking in the information foraging task as well as greater positive mood. However, there were no direct effects of the condition on learning, mind wandering, or negative mood.

Table 19

Independent samples t-test of the effects of condition on learning, mind wandering, information seeking, positive and negative mood.

Key outcomes	t	sig.	Mean(SD) experimental condition	Mean(SD) control condition
Learning	-.25	.80	6.81(2.12)	6.86(2.19)
Mind wandering	1.13	.26	1.62(.71)	1.70(.73)
Information seeking	**-2.20**	**.028**	**6.94(4.64)**	**6.27(4.97)**
Positive mood	**-2.23**	**.026**	**3.44(1.03)**	**3.21(1.10)**
Negative mood	.87	.39	1.34(.63)	1.36(.58)

Mediation models were run to examine whether state interest curiosity drove the observed significant effects of condition on information seeking and positive mood. As seen in Table 20, the effects of condition on information seeking and positive mood were fully mediated by state interest curiosity; the mediated direct effect was non significant at the 0.05 level (p=.079 two-tailed and p=.57 for direct effect of condition on information seeking and positive mood, respectively). This analysis used a bootstrap approximation obtained by constructing two-sided bias-corrected confidence intervals. The standardized indirect (mediated) effect of condition on information seeking was significantly different from zero at the 0.01 level, β = .033, p=.006, 95% CI [.007, .080] and positive mood, β = .079, p=.003, 95% CI [.035, .13]. See Figure 5 and 6 for figural demonstration of the mediation models and Table 20 and 21 for full statistics of the direct and indirect paths for each model, respectively.

Figure 5

Mediation model demonstrating the full mediation effect of condition on information seeking by states of interest curiosity

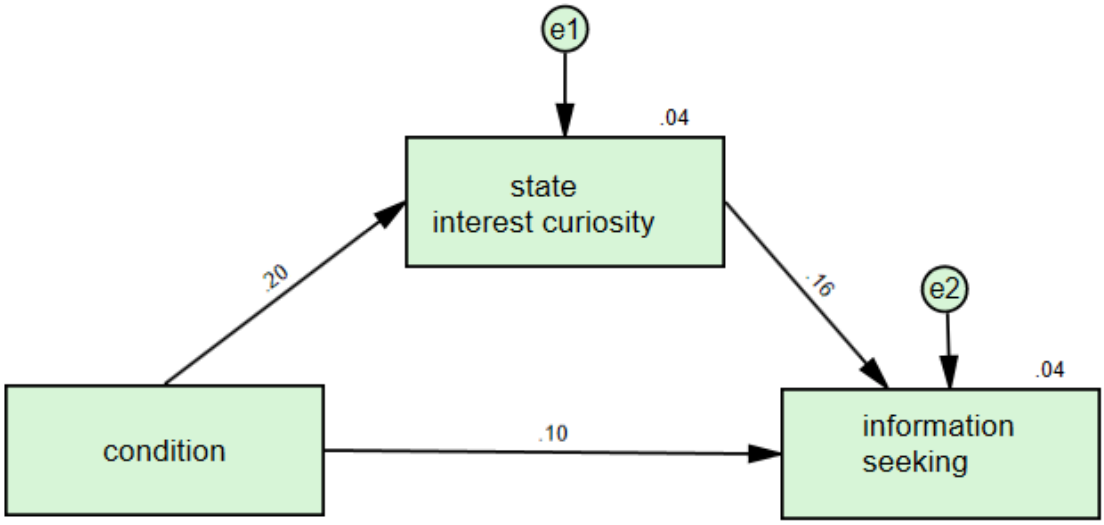


Table 20

Direct and indirect effects of interest curiosity and information seeking mediation model

Direct effect	Standardized estimates (β)	95% CI	Sig.
Condition -> state interest curiosity	.60	[.23, .91]	.005
State interest curiosity -> information seeking	.040	[.009, .078]	.009
Condition -> information seeking	.071	[-.007, .16]	.079

Indirect effect	Standardized estimates (β)	95% CI	Sig.
Condition -> information seeking	.033	[.007, .080]	.006

Note. Estimates are shown as standardized regression weights (betas). Bootstrapped bias-corrected percentile method for assessing significance of indirect effects, 500 bootstrapped samples.

Figure 6

Mediation model demonstrating the full mediation effect of condition on positive mood by states of interest curiosity.

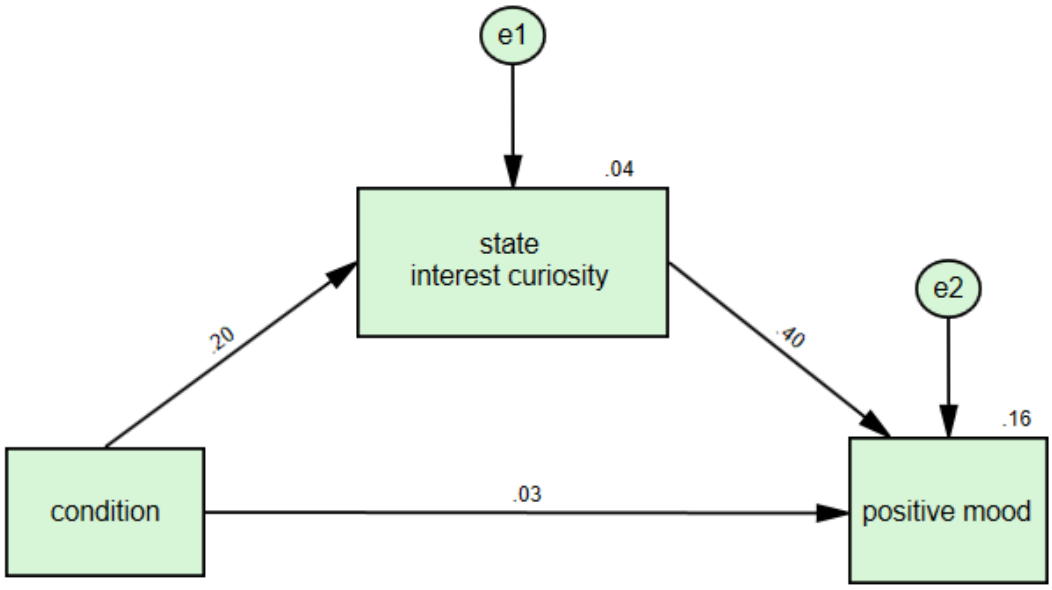


Table 21

Direct and indirect effects of interest curiosity and positive mood mediation model

Direct effect	Standardized estimates (β)	95% CI	Sig.
Condition -> state interest curiosity	.20	[.23, .91]	.005
State interest curiosity -> positive mood	.40	[.21, .36]	.003
Condition -> positive mood	.027	[-.15, .28]	.57
Indirect effect	**Standardized estimates (β)**	**95% CI**	**Sig.**
Condition -> positive mood	.079	[.035, .13]	.003

Note. Estimates are shown as standardized regression weights (betas).

Although a direct effect of condition on learning was not observed, a path model via interest curiosity was explored given the large effects of condition on interest curiosity and the theoretical relevance of interest curiosity on driving the desired outcomes. In particular, as noted in the introduction, it was theorized that interest curiosity may promote learning via attentional mechanisms. In the current study states of interest curiosity were indeed negatively associated with mind wandering during the reading activity. In turn, mind wandering during the activity was negatively associated with learning. Therefore a structural model was examined assessing an indirect effect of condition on learning via states of interest curiosity and reductions in mind wandering, see Figure 7. This indirect effect of condition on learning was significant, β = .056, p=.002, 95% CI [.023, .10], see Table 22 for full statistics.

Figure 7

Path model examining the indirect effect of condition on learning, via interest curiosity and mind wandering

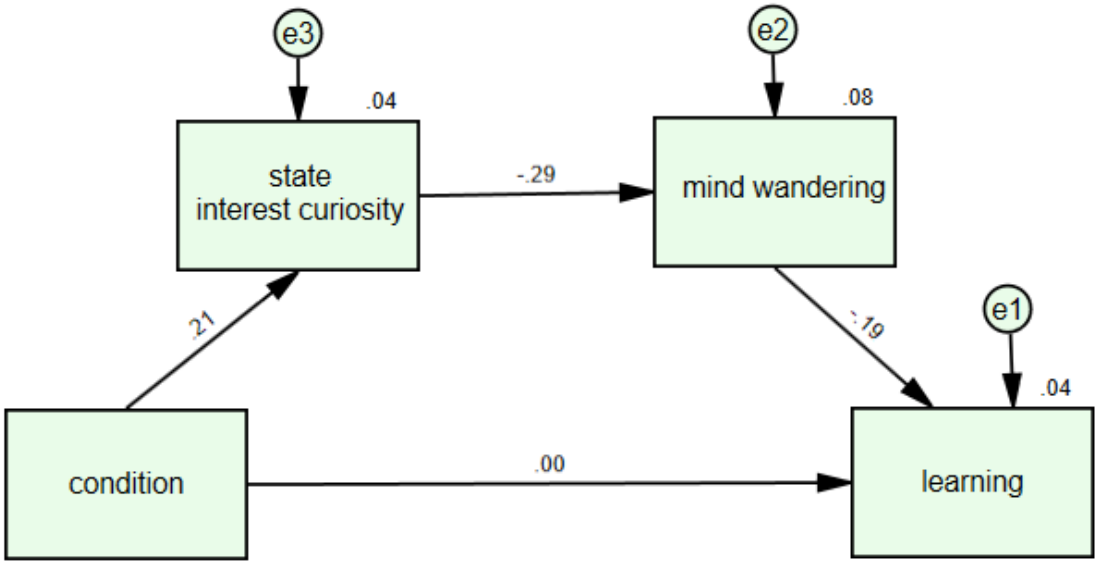


Table 22

Estimates for direct and indirect effects in the path model for condition, interest curiosity, mind wandering, and learning

Direct effect	Standardized estimates (β)	95% CI	Sig.
Condition -> state interest curiosity	.21	[.095, .31]	.004
Interest curiosity -> mind wandering	-.30	[-.41, -.15]	.004
Mind wandering -> learning	-.19	[-.30, -.062]	.006
Condition -> learning	-.002	[-.11, .11]	.95
Indirect effect	**Standardized estimates (β)**	**95% CI**	**Sig.**
Condition -> mind wandering	-.061	[-.112, -.024]	.003
Condition -> learning	.012	[.004, .025]	.002
Interest curiosity -> learning	.056	[.023, .10]	.002

Note. Estimates are shown as standardized regression weights (betas). The significance of the indirect effects was computed using a bootstrapped (500 samples) bias-corrected percentile method.

Next, the relationships between curiosity and the phenomenological qualities of thought was assessed. See Figure 8 for the overall means for each thought dimension across participants.

To determine whether the relationships observed in the previous study (study 4) replicated, partial correlations were run between state interest curiosity and trait interest curiosity. The results indicated that the previously observed effects largely replicated. As

shown in Table 23, trait interest curiosity was associated with fluid, topic shifting, engaging thoughts, while also showing trending for positive emotional valence and meaningful thoughts, as was previously also observed in study 4 (see Table 14, in study 4; note in this study however, meaningful reached statistical significance). Perhaps due to increased power, fluid and bizarre thought dimensions were significantly associated with trait curiosity in this study, whereas they did not reach significance in the previous study.

In the previous study, state curiosity was uniquely associated with engageness of thoughts. This finding was replicated in the current study. Although *engaging* had been the only dimension to predict state curiosity, in the current study state curiosity was additionally associated with *novelty* of thoughts. In the current study, two more dimensions were added due to their similarity with *engaging*, namely *interesting* and *boring*. Both state and trait curiosity were significantly positively associated with *interesting*, but only trait interest curiosity was (negatively) correlated with boring thoughts.

Table 23

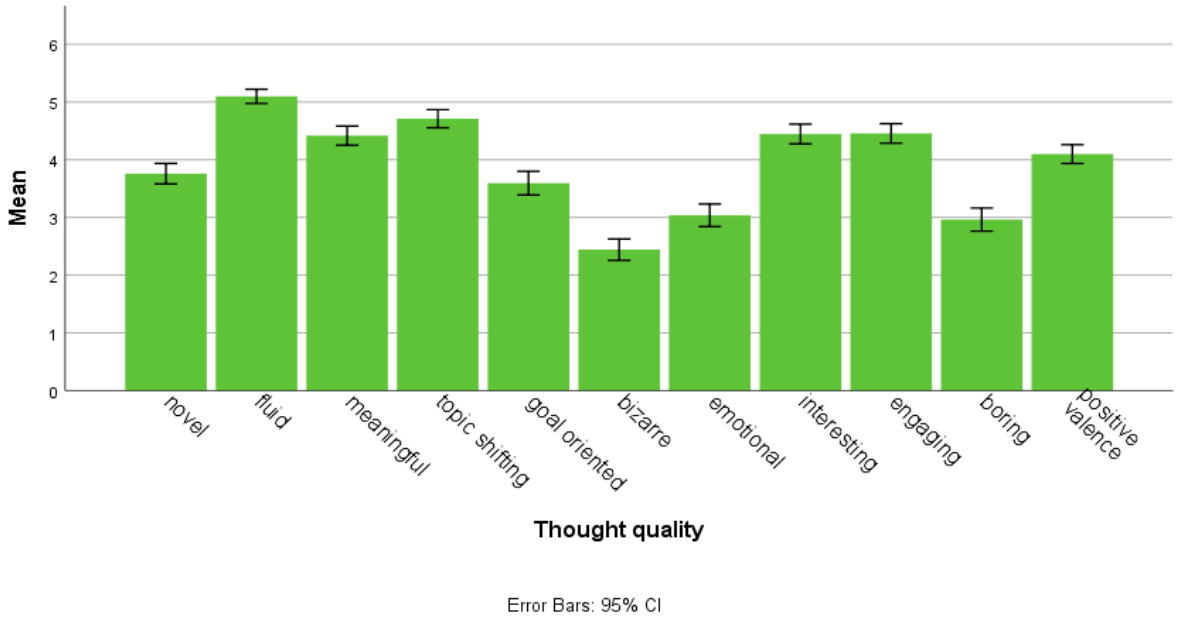
Partial correlations for state interest curiosity and trait interest curiosity

	State interest curiosity		Trait interest curiosity	
Thought dimension	Pearson's r	p-value	Pearson's r	p-value
novel	**.14**	**.020**	.079	.19
fluid	-.091	.13	**.15**	**.010**
meaningful	.058	.33	*.099*	*.095*
topic shifting	-.092	.12	**.13**	**.029**
goal oriented	-.018	.77	.059	.32
bizarre	.054	.36	.085	.16

emotional	.14	.022	.028	.64
interesting	**.16**	**.006**	**.12**	**.049**
engaging	**.12**	**.052**	**.14**	**.021**
boring	-.074	.22	**-.12**	**.047**
valence: positive	.097	.10	.085	.15

Figure 8

Descriptive chart demonstrating average ratings of the thought dimensions over the mind wandering session.



Partial correlations were next examined between states of interest and deprivation curiosity. As observed in Table 24, the associations between state interest curiosity and novel, interesting, engaging and (negatively) boring qualities of thought remained significant when partialling out the effects of states of deprivation curiosity. State deprivation curiosity,

on the other hand, was positively associated with meaningful, goal-directed, bizarre, emotional, interesting, and (surprisingly) positively valenced thoughts.

Table 24

Partial correlations for state interest and deprivation curiosity

	State interest curiosity		State deprivation curiosity	
Thought dimension	Pearson's r	p-value	Pearson's r	p-value
novel	**.17**	**.004**	.088	.13
fluid	.003	.95	.018	.76
meaningful	.051	.39	**.16**	**.005**
topic shifting	-.010	.87	.001	.99
goal oriented	-.083	.16	**.22**	**<.001**
bizarre	.044	.45	**.15**	**.010**
emotional	.056	.34	**.26**	**<.001**
interesting	**.20**	**.001**	**.14**	**.021**
engaging	**.16**	**.005**	*.12*	*.050*
boring	**-.17**	**.004**	.001	.98
valence: positive	.086	.14	**.21**	**<.001**

Lastly, partial correlations between the trait versions of interest and deprivation curiosity were examined. For both trait interest and deprivation curiosity, we find a similar pattern of results as observed for the state scales; in particular, interest is once again positively associated with novel, interesting, engaging thoughts while being negatively correlated with boring thoughts. And deprivation curiosity is again associated with

meaningful, goal-directed, and emotional thoughts, see Table 25. Unlike in the state version, the trait version of deprivation curiosity is further correlated with novel thoughts and not significantly associated with positively valenced thoughts. Trait interest curiosity, unlike state interest, is however correlated with positively valenced thoughts while also being marginally associated with fluid thoughts.

Table 25

Partial correlations for trait interest and deprivation curiosity

	Trait interest curiosity		Trait deprivation curiosity	
Thought dimension	Pearson's r	p-value	Pearson's r	p-value
novel	**.13**	**.029**	**.12**	**.037**
fluid	*.11*	*.060*	-.001	.99
meaningful	*.097*	*.10*	**.13**	**.025**
topic shifting	*.093*	*.12*	-.019	.75
goal oriented	.004	.95	**.12**	**.038**
bizarre	*.094*	*.11*	*.092*	*.12*
emotional	.067	.26	**.14**	**.021**
interesting	**.20**	**.001**	.086	.15
engaging	**.20**	**.001**	.086	.15
boring	**-.18**	**.002**	.004	.95
valence: positive	**.14**	**.023**	.063	.29

Next correlations were run to explore associations between the phenomenological qualities of thought and the key outcome variables. As seen in Table 26, the thought dimensions were more closely related to mood than the other outcomes, with positive mood being significantly associated with novel, meaningful, interesting, engaging thoughts, while

being negatively associated with boring thoughts. On the other hand, negative mood was positively associated with goal-oriented, bizarre, emotional, and boring thoughts. Learning was not predicted by any thought dimensions therefore no further analyses probed possible mediating effects of thought qualities on the key outcome of learning.

Table 26

Bivariate correlations between the phenomenological thought qualities and the key outcome variables

Thought dimension	Learning	Information seeking	Positive mood	Negative mood
novel	r=-.050, p=.39	r=.022, p=.70	**r=.17, p=.004**	r=.089, p=.13
fluid	r= .030 p=.61	**r= .15, p=.011**	r= .048. p=.42	r= -.005, p=.93
meaningful	r=-.055, p=.34	r=.060, p=.30	**r=.23, p<.001**	r=.003, p=.96
topic shifting	r=.056, p=.34	r=.061, p=.30	*r=-.10, p=.087*	r=.022, p=.71
goal oriented	r=-.061, p=.30	r=.032, p=.58	r=-.011, p=.85	**r=.19, p=.001**
bizarre	r=-.047, p=.42	r=-.009, p=.87	*r=.10, p=.082*	**r=.16, p=.006**
emotional	r=.015, p=.80	r=.026, p=.65	r=.020, p=.74	**r=.26, p<.001**
interesting	r=-.070, p=.23	r=.083, p=.16	**r=.36, p<.001**	r=-.019, p=.74
engaging	r=-.033, p=.57	*r=.098, p=.095*	**r=.35, p<.001**	r=-.066, p=.26
boring	r=-.094, p=.11	r=-.077, p=.19	**r=-.22, p<.001**	**r=.15, p=.012**

Lastly, independent samples t-tests were used to examine whether the condition led to differences in the phenomenological qualities of thought. In particular, it was examined whether the previously observed effect of condition on engagingness of thoughts was observed. The qualities of thought interesting and boring were also examined as possible DVs, given their similarity with *engaging.* As seen in Table 27, although the finding was not

replicated that the condition led to increased engagingness of thoughts, the related and highly correlated (r=.84, p<.001) thought dimension *interesting* was significantly promoted by the condition such that individuals in the question asking condition experienced their thoughts as on average more interesting, $t(292)=2.04$, $p<.05$.

Table 27

Independent samples t test examining the effect of condition on engagingness of thought and related thought dimensions

Key thought dimensions	t	Sig.	mean difference
Engaging	1.19	.24	.12
Interesting	**2.04**	**.042**	**.21**
Boring	-.97	.33	.098

Discussion.

Using the newly developed induction for promoting states of interest curiosity, this study experimentally examined the impact of appetitive interest on curiosity-related outcomes for the first time. States of interest curiosity were found to be linked to changes to attentional, phenomenological, and affective processes; these processes may have important implications for driving positive outcomes that have previously been associated with curiosity. In this study downstream consequences on information seeking and learning were examined and found to be related directly and indirectly, respectively, to interest based states of curiosity.

Attentional processes were assessed retrospectively directly following the curiosity induction. States of interest curiosity were found to predict reduced mind wandering, i.e.

increased attentional engagement, during the reading activity. Given the detrimental effects of mind wandering on reading comprehension (McVay & Kane, 2021), this finding suggests that interest curiosity may promote attentional processes important for deep processing, informational engagement, and learning. In line with this, the present study revealed that mind wandering was negatively associated with learning in a surprise recall and comprehension test delivered later in the study. An exploratory path model further revealed that the interest curiosity induction, involving question generation in response to interesting articles, may enhance learning indirectly by promoting states of interest curiosity and reducing mind wandering. Given that existing learning models for curiosity focus almost entirely on uncertainty reduction, this finding has important implications for existing theory in curiosity and may have potentially important pedagogical implications.

It was further found that interest curiosity promotes behavioral manifestations of curiosity, namely, information seeking. In the current study, interest curiosity was effective in driving information seeking behavior, whereas states of deprivation curiosity were negatively correlated with information seeking behavior. In line with this, there is existing evidence that merely lacking information is insufficient to instigate information seeking behaviors in children (Busch & Legare, 2019). These recent findings draw into question existing theory of curiosity which suggests that the drive associated with information seeking behaviors is reinforced via the reward elicited following uncertainty reduction, or the relief of an information gap (Gottlieb et al., 2013). Instead, we find evidence that the positive affective state of interest curiosity may promote information seeking. This suggests that in addition to the need to pacify an aversive sense of uncertainty, information can also be driven by the pleasure of information gain (van Lieshout et al., 2020).

Recent findings support the idea that information seeking can be driven by diverse motives (Kobayashi et al., 2019a). For instance, research suggests that individuals prefer positively valenced over negatively valenced information (Marvin & Shahomy, 2016) while even at times avoiding negative information (Sharot & Sunstein, 2020). Indeed, in opposition to the uncertainty reduction view, individuals have even been found to choose to *prolong* their state of uncertainty by choosing to receive hints to desired answers rather than the answer itself (Metcalfe et al., 2021). Such findings suggest that the rewarding aspects of curiosity may go beyond uncertainty reduction; indeed, individuals appear not simply driven to gain information in general, but rather driven to maximize the pleasurable process of information gain. Such findings go in opposition to some prominent theorists who define curiosity as inherently aversive (e.g. Loewenstein, 1994).

Given the differences between deprivation and interest based states of curiosity, it is likely that the mechanisms that underlie their relationships to learning and information seeking also differ. The motivational processes that underpin interest based information seeking warrant further examination. Further, other processes beyond expectation driven prediction errors likely facilitate learning in the context of interest curiosity. The present research offers an initial exploratory path through reductions in mind wandering, however this initial research warrants follow up research to understand the exact mechanisms and processes that may give rise to these findings.

The previously observed phenomenological correlates of state and trait curiosity were largely replicated in the current study. This study further allowed for the teasing apart and comparison of both state and trait versions of interest and deprivation curiosity. Here it was observed that both the state and trait versions of interest curiosity appear to be associated

with novel, engaging, and interesting thoughts, while the state and trait versions of deprivation curiosity predict meaningful, goal-directed, and emotional thoughts. Contrary to prediction, we did not find any relationship between these phenomenological qualities of thought and learning, however mood seemed to be associated with many qualities of thought. This may suggest that the phenomenological qualities of thought have important affective consequences; conversely it is possible that positive mood may drive more productive qualities and content of thought. Further research should experimentally investigate these possibilities. Furthermore, although we did not observe any practical benefits to the qualities of thought (e.g. for learning), it is nevertheless possible that the phenomenological dimensions of curiosity play an important role in driving other curiosity related outcomes.

Lastly, as in the initial studies using the induction (study 1 in chapter II and study 4 in chapter IV), the interest curiosity induction was found to robustly and uniquely promote states of general interest curiosity. This study included a novel measure of state deprivation curiosity allowing us to rule out the possibility that the experimental condition promoted this state. No effect on deprivation curiosity was observed, therefore any effects on information seeking are unlikely to have been caused by this state.

The current study made several key findings that warrant further examination. Interest curiosity was reliably promoted through the combination of inquiring strategies (i.e. question asking) and the use of interesting materials. This state was observed to drive the positive outcomes associated with the manipulation including positive affect, information seeking, and reductions in mind wandering, which in turn were associated with increased learning. We further find that the state of deprivation curiosity predicts neither learning nor information seeking; indeed state deprivation curiosity was negatively associated with the

latter. These results are surprising given that most existing theory in curiosity emphasizes the need for an aversive sense of uncertainty and the creation of salient information gaps to drive learning and information seeking behaviors. Future research is necessary to understand under what conditions deprivation curiosity is beneficial or detrimental, and to further untangle the mechanisms and processes that underlie the positive effects of interest curiosity. Given the far reaching impacts curiosity has on academic, professional, and personal development, this area of research is bound to have consequential impacts for both science and society.

V. Conclusion

1. Empirical contributions

Epistemic curiosity—the tendency to pursue novel, diverse, complex, and challenging experiences—has been linked to academic and professional success, creativity, happiness, health, satisfying relationships, and increased meaning in life (Von Stumm et al., 2011; Richman et al., 2005; Kashdan & Steger, 2007; Kashdan & Fincham, 2004; Marvin & Shohamy, 2016). To date, these associations are almost entirely correlational which makes it difficult to understand the nature of the role that curiosity plays in these outcomes. An additional complexity has recently been uncovered in that interest, but not deprivation, curiosity tends to drive correlations with these positive outcomes. Indeed, deprivation curiosity has even recently been found to negatively correlate with such positive outcomes as intellectual humility, learning, creativity, and well-being. This is particularly noteworthy given that experimental research to date has almost entirely relied on the induction of deprivation curiosity. Through the development of an interest based curiosity induction, biological indicators of trait and state curiosity, and measures of *state* interest and deprivation curiosity, the current thesis strove to clarify and deepen our existing understanding of the nature of curiosity, its subfacets, and its role in promoting positive outcomes.

Chapter II began by discussing the development of a novel method for inducing states of interest based curiosity. This chapter describes an easily implementable induction that harnesses a natural behavior that has long been theorized to characterize human curiosity, namely, question-asking. Asking questions was found to markedly promote states of interest curiosity, in other words, a general drive to learn and engage in novel experiences. Experimental research on interest curiosity is entirely lacking, however this induction method

paves the way for a new line of psychological and neuroscientific research into this valuable characteristic. Furthermore, question asking had directionally larger effects on interest curiosity than the interestingness of articles and reflects a strategy that individuals can apply to *any* materials, whether they are interesting or not. This may allow individuals to self-generate a sense of interest in situations in which they might not naturally be intrinsically engaged, such as in the context of required readings for class.

Chapters III and IV discussed the development of objective indicators of curiosity grounded in neurobiological theory. Chapter III described how eye movement behavior and visual saliency differ depending on individual differences in curiosity. Here it was observed that curiosity predicts the systematic prioritization of certain visual features, which may be relevant to information gain. This research represents some of the first in-depth examinations of personality driven natural eye movement behavior with important implications. A long history of research has observed robust and systematic individual differences in eye movement (e.g. De Haas et al., 2019), however existing research has yet to explain from where these differences derive and the degree to which they may implicate higher order characteristics. Future research should strive to explore the implications of these visual differences on perception, phenomenology, and behavior.

Chapter IV expanded upon the incentive salience framework to consider impacts on the phenomenology of everyday thought, both as a function of state and trait curiosity. In the first study in this chapter (study 3), it was observed that trait curiosity is a robust predictor of several key features, including novel, meaningful, and goal oriented aspects of everyday thought. The second study in this chapter (study 4) compared trait curiosity to the states of curiosity promoted following the novel curiosity induction. Here it was observed that state

curiosity was uniquely associated with engaging thoughts, but the features that were observed for trait curiosity were not observed under states of curiosity. These findings elaborate on existing findings which suggest certain aspects of mind wandering, such as the control of mind wandering (Diaz et al., 2014; Kane et al., 2017; Carciofo & Jiang, 2021), may differ between people as a function of personality. The content and valence of mind wandering has also been found to change during different states, such as meditative states (Kok & Singer, 2017; Williams, 2017), as well as across the lifespan (Maillet et al., 2018). However, to date, few studies have included an extensive range of thought qualities as included in the present studies. Studies 3, 4, and 5 aim to provide a richer picture of the stream of consciousness and how its features may differentiate on the basis of personality.

In sum, by grounding the study of curiosity within a modern neurobiological framework, two fundamental features of the human mind– perception and phenomenology– were explored in the context of the incentive salience theory of dopamine function. These chapters contribute to our understanding of how the processes that give rise to individual differences in curiosity may have a profound impact on the way that we perceive and think about our world.

Chapter V brings together several threads from this thesis, using the novel induction method to examine how interest curiosity driven changes to attentional, phenomenological, and affective processes may drive downstream effects on information seeking and learning. Here it was found that by reducing mind wandering, interest curiosity may facilitate learning and comprehension in the context of a reading paradigm. This study further provided the first explicit evidence of interest curiosity driven information seeking. This chapter further reports on the development of a novel measure of state deprivation curiosity. By teasing apart the

contribution of state interest and deprivation curiosity, it was observed that states of deprivation curiosity are negatively associated with information seeking and are positively associated with negative affect. These findings have important theoretical implications for understanding the causes and consequences of curiosity driven outcomes.

These studies strove to lead the way in understanding appetitive states of interest curiosity. Despite a long standing understanding that organisms are driven towards non-instrumental information, existing research has emphasized the aversive quality of uncertainty that motivates this behavior but has largely neglected the positive, appetitive states which may also play an important role in driving exploratory behaviors, learning, and a broad range of other positive outcomes. By gaining a better understanding of interest curiosity, we can better understand how to harness its benefits in scientific, workplace, and educational settings.

2. Theoretical Implications

This work contributes to existing theories on curiosity in several ways. First of all, it brings to question existing strict definitions of curiosity as requiring a knowledge gap (e.g. Pekrun, 2019). Both activity-based curiosity and general interest curiosity were promoted by the generation of broad scope questions and by reading interesting articles. Given that participants generated questions for several minutes and there was no indication that answers would be revealed, this paradigm was unlikely to have promoted the sensation of a *specific*, defined knowledge gap. This possibility was further ruled out in the final study in which a newly developed state deprivation measure was included. Here it was confirmed that the induction did not promote the aversive, uncertainty-laden qualities characteristic of a state of information deprivation. This suggests that the definition of curiosity as the recognition of a

knowledge gap is not broad enough to capture the various ways in which this characteristic can be experienced. Theoretical approaches that focus away from strict definitions and more towards the processes (e.g. Murayama et al., 2019) and motivational drives (e.g. Kidd & Hayden, 2015) underlying curious behaviors may be more beneficial going forward.

The interest curiosity induction paradigm was also found to promote information seeking. Once again, existing theories of curiosity-driven information seeking emphasize the drive for *uncertainty reduction*, i.e. the reduction of a knowledge gap, in explaining the curiosity driven motivation to pursue information (e.g. Bromberg-Martin & Monosov, 2020; Gottlieb et al., 2019; Holm et al., 2019). Some modern theorists have proposed that the desire for information can instead be driven by the expectation of rewarding sensations of interest (Litman, 2008; van Lieshout et al., 2020; Kobayashi et al., 2019a). While the present studies show some of the first experimental evidence for this, we additionally find that an interest based desire for information can translate into information seeking behaviors. This finding does not naturally fit with some existing theories of curiosity. For instance, recent theorists have described interest as a state of high *liking* but low *wanting* (Litman, 2008). Given that interest curiosity appears to *motivate* information seeking behavior, it is difficult to imagine this state as reflecting low *wanting.* Rather it seems more likely that interest curiosity and deprivation curiosity both represent *liking* and *wanting* but with different motives and goals. Deprivation curiosity may represent an aversion motivated desire (wanting) for information with the goal of experiencing the pleasurable state of uncertainty reduction (liking*).* While interest curiosity may represent an approach motivated desire (wanting) for information with the goal of experiencing the pleasures of information gain (liking).

Existing theories of curiosity-driven learning are also largely specific to deprivation based accounts of learning. As previously described, learning is thought to occur as a result of the error associated with the closing of a knowledge gap (Marvin & Shohamy, 2016). The error arises when individuals generate predictions about missing information with varying levels of accuracy. When information is revealed the prediction error represents the difference between the expected and actual information. Since interest curiosity is a drive to discover *new* information, rather than reduce uncertainty regarding existing knowledge, this state is likely not associated with defined predictions about to-be-learned information. Instead the mechanisms underlying interest based learning are likely better explained by associated affective, attentional, or phenomenological processes. In the final study in this thesis, evidence is presented that curiosity potentially affects attentional processes, by reducing mind wandering. This in turn may contribute to deeper processing and learning, however direct relationships between interest curiosity and learning were not observed, which may be due to the learning task that was used. Given existing correlations suggesting an association between interest curiosity and learning (e.g. Zedelius et al., 2022) this relationship deserves further experimental attention. Such research will help to clarify and expand existing theories regarding curiosity-driven learning mechanisms.

Chapter III offers some of the first experimental evidence for the incentive salience theory of curiosity. It has previously been suggested that curiosity may reflect a tendency for attributing motivational salience to information, or a sensitivity to the reward value of information. If this is the case we should expect curious individuals to differentially prioritize visual information that offers maximal information gain. We find evidence that curious individuals do indeed show consistency in gaze patterns towards such information rich

semantic features as text. This study offers a crossover between the fields of personality psychology, cognitive neuroscience, and vision science, while contributing insights that may help further bridge the dynamics of dopamine function, reward sensitivity, higher order characteristics and low level visual behavior.

Chapter IV contributes additional evidence that spontaneous thoughts may act as an indicator of incentive salience. In line with initial theorizing in this area (Rice & Fredrickson, 2017), it is proposed that spontaneous thoughts may reflect incentive salience processes. The contents of thought likely reflect prioritized or valued information while also driving goal oriented behavior towards similar valued information. Our observed findings are in line with this account, suggesting that individuals high in interest curiosity not only consume novel and diverse information, but that their stream of consciousness reflects these qualities. The novel and topic shifting qualities associated with interest curiosity may reflect their appetitive stance towards information gain. On the other hand, trait deprivation curiosity was associated with goal-oriented and less positively valenced thoughts. This again may reflect incentive salience processes, particularly the negative motivational quality driving these individuals to pursue information and to close knowledge gaps. These sections have taken initial steps to extending modern theory of dopamine function to the study of curiosity, in particular the incentive salience theory.

3. Methodological contributions

This work demonstrated the use of several novel methodological tools and paradigms. First, the development of state deprivation and interest curiosity scales will allow researchers to determine which facets of curiosity were elicited under different conditions. Until now, researchers have relied upon 1-item likert questions that simply ask people “How curious do

you currently feel?" or "How interested are you to see the answer?". Self-reporting one's state of curiosity is limited for several reasons. These measures rely on individuals' accurate self-assessment of their own state, they assume a similar definition or interpretation of curiosity across lay people, and they are prone to known methodological limitations, such as demand characteristics and expectation effects. Furthermore, such questions are limited in that they do not differentiate between interest and deprivation-based experiences of curiosity. For instance, it is possible that being presented with interesting trivia questions– a standard paradigm for inducing deprivation curiosity– may drive some degree of *interest curiosity*, in other words, a general, appetitive desire to learn *more* interesting facts. However, due to the fact that states of interest and deprivation curiosity are never measured in these studies it is impossible to determine this. Future research should make use of these state scales in order to understand which circumstances promote one, or both, of these facets of curiosity.

This thesis additionally uncovered two strategies for promoting states of interest curiosity. Both question asking and reading interesting materials promoted states of general interest curiosity. The question asking procedure, in particular, has great promise as a general strategy for promoting interest curiosity in applied settings, such as workplace or educational contexts. The easily implementable and scalable induction method paves the way for the first laboratory investigations of interest curiosity. In particular, this induction method makes possible much needed research examining the affective, phenomenological, behavioral, and neural consequences of states of interest curiosity, as well determining its potential causal role in positive downstream outcomes, such as learning, humility, and well-being.

Curiosity was also found to predict distinct gaze patterns and phenomenological markers. These studies suggest that eye movement and thought qualities may be plausible

avenues for assessing objective markers of personality, both in observational and experimental research. Further research should continue to index the eye movement signatures and thought qualities associated with different personality patterns. In time, these indicators may become well-defined and specific enough to act as objective, proxy measures of personality. The vast majority of existing personality research instead uses self-report questionnaires. Although the field has progressed using these methods, the validity of self-report assessments is tentative given that questionnaires often associate weakly with behavioral measures. Further, experimental findings do not always line up with the findings that would be anticipated based on correlational research. For instance, as described in Chapter V, deprivation curiosity has been found to promote learning in previous experimental research (i.e. in which a state of deprivation is induced; Marvin & Shohamy, 2016) while studies using trait questionnaires suggests that deprivation curiosity is negatively associated with learning (Zedelius et al., 2022). It is possible that such discrepancies are the cause of differences in methods used in experimental and correlational research, particularly the reliance on self-report questionnaires in the latter. The development of objective measures of curiosity, and other personality facets, may help to clear up such contradictory findings. Furthermore, the development of biologically based indicators of personality is critical to understanding the way in which these characteristics manifest in the real world.

Studies 4 and 5 demonstrated the effectiveness of an online paradigm for capturing the phenomenology of thought. Using a Simple Reaction Time task during the thinking session effectively ensured individuals stayed engaged in the task even in an online format. Indeed, both studies largely replicated the results that were observed in the extensive experience sampling procedure. This crossover between daily life and laboratory findings is

often hard to achieve (e.g. Kane et al., 2017). However, our results indicate that it is possible to capture naturalistic thought content in a cost effective and time efficient online paradigm, opening up possibilities for running much larger samples with less intensive involvement from participants.

Finally, study 5 demonstrated the effectiveness of a novel information seeking paradigm for capturing behavioral manifestations of curiosity. Until now, there have been very few easily implementable methods for demonstrating the effects of curiosity on information seeking behavior. The *information foraging task* was inspired by recent research suggesting that individuals exhibit different information foraging styles depending on trait levels of curiosity (Lydon-Staley et al., 2021). In Lydon-Staley and colleagues (2021) study, participants viewing behavior was quantified after free exploration of Wikipedia pages. These findings revealed distinct natural exploration behaviors; namely tighter networks of information explored (i.e. more similar information) and a greater likelihood of returning to previously explored topics as a function of deprivation curiosity. These findings, though interesting, had a couple limitations for the current application. First of all, mainly the deprivation facet of curiosity was found to reliably predict the information seeking metrics quantified by the researchers, thereby making it less useful for understanding the interest based subfacet of curiosity. Secondly, while the paradigm was useful in understanding individual differences, it has not yet been applied under *states* of curiosity, therefore it is unclear whether the metrics quantified in this study are sensitive for capturing fluctuating changes in curiosity. And finally, the study used a total of 5 hours of Wikipedia surfing across 21 days, making the use of this paradigm in simple laboratory experiments less feasible.

The *information foraging task* presented in study 5 is easily implementable for experimental contexts as well as in-person or online research. The measure can be used as a measure of states of interest, replacing self-report methods, which makes it particularly useful for experiments with transparent goals, in other words, in contexts which are vulnerable to demand characteristics. The task can also be used as a dependent variable to test the effects of other possible induction methods. Finally, the task is sensitive for capturing states of curiosity and appears to be particularly predictive of curious information seeking behavior driven by appetitive states of interest.

4. Limitations and future directions

The current thesis endeavored to contribute empirical, theoretical, and methodological advances to the study of curiosity. The present studies were however not without their limitations. In this section, various limitations will be discussed along with potential avenues for future research that may clarify and extend the present findings. It is the intention of this work to inspire and pave the way for new, exciting lines of research on this valuable characteristic.

While the interest curiosity induction reported represents a novel method for enhancing curiosity in the lab, the reported studies favored a combination method for the induction: compounding the separate effects of reading strategy (question asking) and features of the materials (interesting articles) to gain a more powerful induction effect. This decision was made given that the present studies were primarily concerned with understanding the effects of *interest curiosity* rather than fine tuning the induction method itself. Indeed, the a priori goal was to establish mediating effects of the induction via interest curiosity; thus, the direct effects of the induction were of less importance. However, in future

research the direct effects may be of more importance or value, such as when considering the use of the induction method in applied contexts (e.g. workplace and educational settings). For this research, it may be more important to examine the active variables separately, otherwise any direct effects of the induction may be difficult to interpret.

Future research should also continue to fine tune the induction method. Although the question-asking instructions were effective in promoting interest curiosity, it is possible that refinements could produce a more powerful induction. For instance, the current instructions attempted to lift rules, guidelines, and constraints on the types of questions that could be asked. This was done in an effort to streamline existing question asking approaches and to produce a more divergent, free flowing state of open curiosity. However, it is possible that there are certain *types* of questions that are particularly effective in promoting curiosity. For instance, questions that are more open-ended, or less concrete, may be more effective in promoting a state of open interest. Observational and qualitative research should first strive to quantify the types of questions individuals spontaneously ask and determine whether some types of questions are rated as more or less curiosity-promoting. Experimental research could follow up on these findings by testing the effects of different question-asking instructions (i.e. instructions to generate only *open-ended vs close-ended* questions) on interest based curiosity. An intriguing possibility is that curiosity-eliciting question-asking can be scaffolded such that it is maximally captivating, while being personalized to different individual's intrinsic interests, experiences, and concerns.

Reading *interesting* articles was also found to promote interest curiosity. Future research should explore interesting qualities in various other modalities, materials, and mediums. Interesting content delivered in modalities that are more immersive, such as audio-

visual modalities, may promote interest curiosity to a greater degree. For instance, it is quite common in awe research to use videos with sensational views of nature, generally also accompanied by uplifting music, to powerfully induce a sense of awe (van Elk et al., 2016). Educational videos, podcasts, or videos that visually demonstrate interesting phenomena may be more effective in promoting a state of interest. A further concern will be to determine the degree to which curiosity stimulated through one modality (e.g. watching an interesting ted talk) translates into information seeking behavior in another modality (e.g. reading interesting articles). Finally, future research could combine the question-asking method with these other modalities as well, such as question-generation in response to interesting films, visual art pieces, or podcasts.

Further research has also demonstrated the effects of music on cognitive, affective and phenomenological processes. For instance, "heroic" music has been recently found to promote empowered (positive, constructive, exciting, motivating) thoughts during mind wandering (Koelsch et al., 2019). Given the relatedness of curiosity to sensation seeking (Byman, 2005), it is possible that exposure to novel, or epistemically captivating, sounds or visuals may similarly be conducive to motivating explorative behavior or interesting thought content.

The research presented here endeavored to address not only interest and deprivation curiosity, but also their state and trait dimensions. This ambitious goal was only partially met, as some studies included traits but not states (e.g. the eye movement study reported in Chapter III) while other studies focused more on interest over deprivation (e.g. studies using the interest curiosity induction). A great deal of further research is necessary to understand the degree to which these facets share underlying cognitive and neural mechanisms, and the

circumstances under which they are beneficial, or potentially, even detrimental. The hope is that the methodological contributions provided in this thesis will pave the way for further research to continue to flesh out the similarities and differences, along with the causes and consequences, of state and trait interest and deprivation based facets of epistemic curiosity.

Finally, future research should strive to drive forward experimental research to better understand the nature of the relationship between interest curiosity and the desirable outcomes it has been associated with. Past theory and correlational research suggests that curiosity is associated with intellectual humility (Zedelius et al., 2022), creativity (Gross et al., 2020), and growth mindsets (Gross et al., unpublished), along with many other valuable characteristics. However, no studies have tested these relationships experimentally in order to determine whether interest curiosity promotes these outcomes. With the interest curiosity induction measure in hand this research can now be undertaken.

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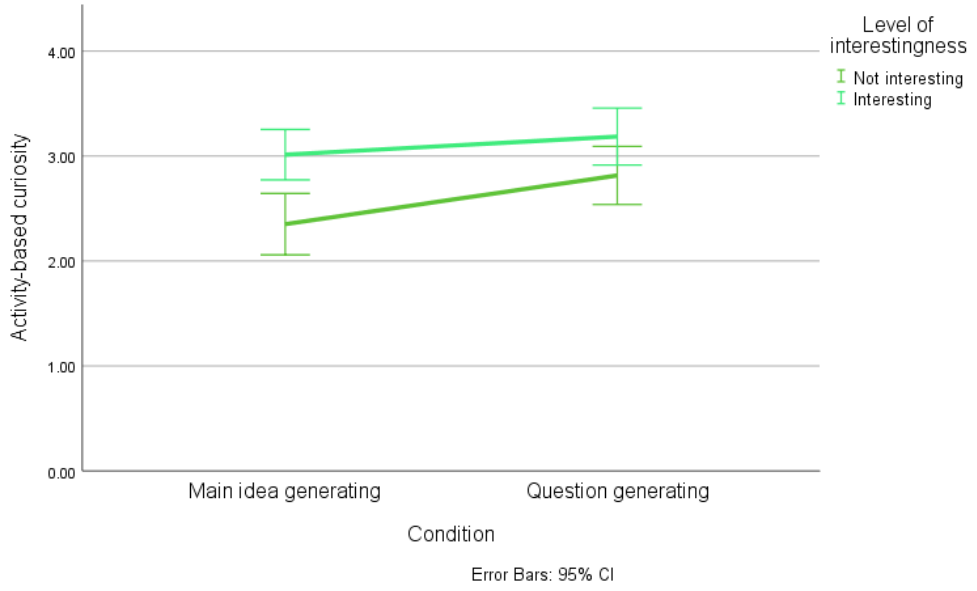
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Supplemental materials

Study 1.

Supplemental Figure S1

Interaction between question-asking condition and interest level of articles on activity-based curiosity.



Supplemental Table S1

Means for curiosity variables across interacting conditions

Experimental condition (Question asking vs control)	Reading materials (Interesting vs neutral)	Mean state curiosity	Mean activity based curiosity
Control	Neutral	3.95	2.35
Question asking	Neutral	4.71	2.82
Control	Interesting	4.64	3.01
Question asking	Interesting	4.95	3.18

Study 6.

Supplementary Table S2

Partial correlations exploring emotional and temporal dimensions of thought in association with trait, state, interest, and deprivation curiosity

A. State vs trait curiosity

Thought quality	State curiosity	Trait curiosity
Emotion: neutral	*r*= -.038, *p* = .52	*r*= -.090, *p* = .13
Emotion: negative	*r* = .009, *p* = .89	*r* =.050, *p* =.402
Temporal orientation: past	*r* =.058, *p* =.331	*r* =-.057, *p* =.342
Temporal orientation: present	*r* =.027, *p* =.645	*r* =-.094, *p* =.115
Temporal orientation: future	*r* =.044, *p* =.463	*r* =.075, *p* =.208
Temporal orientation: atemporal	*r* = -.033, *p* =.584	*r* =*.115*, *p* =*.053*

B. Trait interest vs trait deprivation curiosity.

Thought quality	Trait interest curiosity	Trait deprivation curiosity
Emotion: neutral	*r* = -.017, *p* =.78	*r* = -**.13, *p* =.030**
Emotion: negative	*r* = -.059, *p* =.32	*r* =.13, *p* =.026
Temporal orientation: past	*r* = -.004, *p* =.95	*r* = -.028, *p* =.63
Temporal orientation: present	*r* = -.089, *p* =.13	*r* = -.012, *p* =.84
Temporal orientation: future	*r* = .034, *p* =.57	***r* = .095, *p* =.11**
Temporal orientation: atemporal	*r* = .098, *p* =.10	*r* = .028, *p* =.65

C. State interest versus state deprivation.

Thought quality	State interest curiosity	State deprivation curiosity
Emotion: neutral	*r* = -.005, *p* =.93	*r* = -**.23, *p* <.001**
Emotion: negative	*r* = -.022, *p* =.71	*r* = .12, *p* =.049
Temporal orientation: past	*r* = .00, *p* = .10	*r* = .068, *p* =.24
Temporal orientation: present	*r* = -.025, *p* =.67	*r* = .006, *p* =.92

Temporal orientation: future	r = -.014, p =.81	**r = .22, p <.001**
Temporal orientation: atemporal	r = .063, p =.29	r = -.059, p =.32