Research Article

Being Snoopy and Smart

The Relationship Between Curiosity, Fluid Intelligence, and Knowledge

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Abstract: Curiosity is a basic driver for learning and development. It has been conceptualized as a desire for new information and knowledge that motivates people to explore their physical and social environment. This raises the question of whether curiosity facilitates the acquisition of knowledge. The present study (N = 100) assessed epistemic curiosity and general knowledge as well as fluid intelligence (i.e., reasoning ability, processing speed, memory) in a student sample. The results indicate that epistemic curiosity is moderately related to knowledge (r = .24) and reasoning ability (r = .30). None of the fluid intelligence measures did moderate the relationship between curiosity and knowledge (interaction terms $\beta < |.08|$). Rather, reasoning ability mediated the relationship between epistemic curiosity and general knowledge (indirect effect: $\beta = .10$, $p < .05$). The findings suggest that epistemic curiosity facilitates the acquisition of knowledge by promoting reasoning. One might speculate that epistemically curious individuals enrich their environment, which in turn enhances their cognitive ability.

Keywords: epistemic curiosity, knowledge, crystallized intelligence, fluid intelligence, reasoning

Curiosity has been considered a driving force in human development and learning (e.g., Baumeister, 2005; Berg & Sternberg, 1985; Kidd & Hayden, 2015; Oudeyer et al., 2016; Schneider & Schmalt, 2009). In psychology, it has been conceptualized as a desire for new information and experience that motivates people to explore their physical and social environment (Berlyne, 1954, 1966; Litman & Spielberger, 2003; Renner, 2006). However, although all humans have a desire for new information and knowledge, people differ in the strength of that desire and the resulting exploratory behavior (e.g., Loewenstein, 1994; Schneider & Schmalt, 2009; Spielberger & Starr, 1994). In addition, intelligence may interplay with curiosity and exploration, leading to learning and accumulating knowledge (Ackerman, 1996). Therefore, the present research focuses on the question of whether interindividual differences in curiosity are related to interindividual differences in general knowledge and how fluid intelligence influences this relationship.

Epistemic Curiosity

The concept of curiosity has been refined by considering the stimuli that elicit curiosity (e.g., Berlyne, 1954, 1966, 1978; Collins et al., 2004; Litman & Pezzo, 2007; Litman & Spielberger, 2003; Renner, 2006). Accordingly, Berlyne (1954, 1966, 1978) drew a distinction between *perceptual* and *epistemic* curiosity. *Perceptual* curiosity refers to a desire for a new perceptual experience evoked by new, complex, or ambiguous patterns of sensory stimulation (e.g., a line drawing depicting a lion with an elephant's head). In contrast, *epistemic* curiosity refers to a desire to acquire new knowledge elicited by new and complex ideas or conceptual ambiguities (e.g., unanswered questions, stories with a surprising end; Berlyne, 1954, 1966; Berlyne & Frommer, 1966).

In addition, Berlyne classified curiosity behavior (i.e., exploratory behavior) according to the curiosity-triggering situation (Berlyne, 1966, 1978). That is, *diversive* curiosity arises in situations that are poor in stimulation. Accordingly, exploratory behavior is directed at satisfying an unspecific desire for stimulation. *Specific* curiosity is triggered by concrete circumstances that are characterized by novelty, complexity, ambiguity, and/or uncertainty; that is, the individual lacks specific information to understand the situation or the issue. Accordingly, exploratory behavior is directed at the acquisition of the missing information (e.g., Schneider & Schmalt, 2009).

Based on Berlyne's distinction, contemporary measures of epistemic curiosity differentiate between *diversive* and *specific* epistemic curiosity (Litman & Spielberger, 2003). *Diversive epistemic curiosity* refers to seeking out situations that have the potential to be interesting; specific epistemic curiosity refers to the extent of exploratory behavior to

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learn more about and understand a situation (Litman & Spielberger, 2003; Mussel 2013a). This classification is related to a more recent one by Litman (2008), defining the interest-type (incl. positive feelings arising from exploration and seeking diverse information) and the deprivation-type of epistemic curiosity (incl. aversive feelings arising from knowledge gaps to be dissolved by specific information).

Epistemic curiosity may affect the acquisition of knowledge through different pathways. First, epistemically curious individuals might be more likely actively seeking out new environments and situations to satisfy their "thirst of knowledge" (Berlyne, 1966; Loewenstein, 1994). Being in new environments and situations increases the opportunity to learn. Second, once exposed to a situation, curious individuals might be more attentive, apply a higher amount of exploratory behavior and/or apply more comprehensive exploratory behavior (e.g., Reeve & Nix, 1997; Trudewind, 2000). Accordingly, research has shown that more curious individuals display an enhancement of anticipatory gaze (Baranes et al., 2015), tend to ask more questions (Jirout & Klahr, 2020; Peters, 1978), and show more information-seeking behavior (Hardy et al., 2017; Harrison et al., 2011; Jach et al., 2021; Jani & Hwang, 2016; Kang et al., 2009; Litman et al., 2005). Some studies on state curiosity found that individuals are even willing to spend resources (Kang et al., 2009) and undergo electric shocks to explore and consequently satisfy their curiosity (Lau et al., 2020). In the academic context, research shows that students scoring higher on epistemic curiosity tend to use more deep learning approaches (Binu et al., 2020; Richards et al., 2013) as well as more engagement (Vracheva et al., 2020). Taken together, seeking out new environments, being more attentive, and exploring more and more comprehensively might, in turn, also increase the probability of gaining new information. Thus, it is plausible to assume that interindividual differences in epistemic curiosity are related to interindividual differences in general knowledge.

Fluid Intelligence, Investment Traits, and Acquisition of Knowledge

In his *Investment Theory,* Cattell (1963, 1987) suggests that knowledge, as one aspect of crystallized intelligence, depends on the investment of fluid intelligence. He postulated that fluid intelligence (g_f) largely depends on biological functioning, whereas g_c (i.e., the totality of knowledge and skills) accrues from the investment of g_f over time and is influenced by educational experience (Cattell, 1987; Lechner et al., 2019). Accordingly, research consistently shows that measures of fluid intelligence are associated with measures of crystallized intelligence (e.g., Brandt et al., 2020; Lechner et al., 2019; O'Connell, 2018; Von Stumm, Hell, et al., 2011). Although Cattell (1987) held that the level of crystallized intelligence was also affected by personality influences, he did not elaborate on how personality impacts the development of g_c (Lechner et al., 2019). More recent investment theories underline the importance of personality traits (Ackerman, 1996; Gatzka & Hell, 2018; Von Stumm & Ackerman, 2013; Von Stumm, Chamorro-Premuzic, et al., 2011; Ziegler et al., 2012).

Based on Cattells idea's, Ackerman (1996) introduced his *intelligence-as-process, personality, interest, and intelligence-as-knowledge* (PPIK) model. According to the model, not only *intelligence-as-process* (similar to g_f) contributes to the development of *intelligence-as-knowledge* (similar to g_c) but also so-called investment traits (Ackerman, 1996; Von Stumm & Ackerman, 2013). Investment traits are defined as "stable individual differences in the tendency to seek out, engage in, enjoy, and continuously pursue opportunities for effortful cognitive activity" (Von Stumm, Chamorro-Premuzic, et al., 2011, p. 225). Thus, investment traits refer to the proclivity to seize learning opportunities, thereby guiding how, when, and where individuals invest their fluid intelligence (i.e., intelligence-as-process) to develop crystallized intelligence (i.e., intelligence-as-knowledge; Von Stumm & Ackerman, 2013). A recent review and meta-analysis identified 34 investment traits demonstrating that epistemic curiosity is only one of numerous investment traits (Von Stumm & Ackerman, 2013).

In line with the notion of the PPIK model, in the meta-analysis of Von Stumm and Ackerman (2013), investment traits showed positive correlations with different measures of crystallized intelligence (e.g., college entry test, knowledge test, academic performance). Aggregated coefficients ranged from nearly zero to a maximum value of above .55 (Von Stumm & Ackerman, 2013). Looking at specific traits, the coefficients for *Need for Cognition* varied between $\rho = .20$ and $\rho = .33$, for *Typical Intellectual Engagement* (*TIE*) between $\rho = .21$ and $\rho = .38$ (see also Von Stumm, Hell, et al., 2011), and for *Openness to Experience-Ideas* between $\rho = .08$ and $\rho = .55$ (see also Gatzka & Hell, 2018). For *Curiosity/Academic Curiosity* in relation to crystallized intelligence tests, the aggregated coefficient was small ($\rho = .11$), and in relation to academic performance, it was a small to moderate effect ($\rho = .22$; Von Stumm & Ackerman, 2013).

Likewise, studies dealing with the effect of dispositional curiosity in children and adults provide evidence that curiosity is associated with markers of crystallized intelligence. That is, curious children gained more knowledge in learning sessions (Arnone et al., 1994; Van Schijndel et al., 2018) and scored higher on scholastic achievement tests (Alberti & Witryol, 1994; Raine et al., 2002; Shah et al., 2018). Research in the work context shows that dispositional epistemic curiosity is positively related to learning measured by supervisors' ratings (Hassan et al., 2015), self-reported socialization-related learning (Reio & Callahan 2004), training performance (Mussel et al., 2012), vocational school grades (Mussel, 2013a), and intelligence test measuring g_c (Dellenbach & Zimprich, 2008; Mussel, 2013a; Von Stumm & Deary, 2012).

Additionally, learning, retention and memory, and thus, the acquisition of knowledge, is related to the momentary state of curiosity (Gruber et al., 2019; Gruber & Ranganath, 2019; Kang et al., 2009). More specifically, these studies have shown that answers to trivia questions that elicited high levels of curiosity were better remembered in an immediate as well as delayed memory test (e.g., Gruber & Ranganath, 2019; Kang et al., 2009; Swirsky et al., 2021). In some studies, also incidental information presented during curiosity states was remembered better (Murphy et al., 2021; Paradowski, 1967; but see Swirsky et al., 2021).

The *Openness-Fluid-Crystallized-Intelligence* (OCFI) model by Ziegler and colleagues (2012) outlined in more detail how investment traits (in the model: Openness) and fluid intelligence co-shape the development of crystallized intelligence. According to the model, from an immediate perspective, *Openness* and *fluid intelligence* interact in their influence on crystallized intelligence. From a developmental perspective, two mediational pathways are suggested: it is proposed that Openness affects crystallized intelligence via fluid intelligence (*Environmental Enrichment Hypothesis*) and, vice versa, that fluid intelligence affects openness (*Environmental Success Hypothesis*).

Research investigating interactional effects between investment traits and fluid intelligence had inconsistent findings (Bergold & Steinmayr, 2018; Heaven & Ciarrochi, 2012; Lechner et al., 2019; Zhang & Ziegler, 2015; Ziegler et al., 2012). Heaven and Ciarrochi found a synergistic effect showing that higher openness/intellect was associated with higher grades but only for those with higher intelligence. Instead, Ziegler and colleagues (Zhang & Ziegler, 2015; Ziegler et al., 2012) found compensatory effects between fluid intelligence and openness. In detail, fluid intelligence was positively associated with measures of crystallized intelligence but only for those low in openness. This relation was diminished for higher openness scores. Bergold and Steinmayr (2018) found no interactional effect of Openness and fluid intelligence on academic achievement; only the facet *Openness-Action* interacted with fluid intelligence. In a longitudinal large-scale study, Lechner and colleagues (2019) found that the interaction between g_f and *Openness* predicted reading competence cross-sectional, however, only when *interest in reading* was not considered. Longitudinally no moderations, including *Openness* were found. For *Need for Cognition*, a study of Strobel and colleagues (2019) could show that *Need for Cognition* interacted with intelligence to predict GPA. More specifically, at higher Need for Cognition scores, the relation between intelligence and GPA was diminished, indicating a compensatory effect between Need for Cognition and intelligence. To the best of our knowledge, no study has so far examined the interactional effect of curiosity and fluid intelligence.

The mediational pathways suggested in the OCFI model have been hardly researched so far (Dellenbach & Zimprich, 2008; Von Stumm & Deary, 2012; Ziegler et al., 2012). A longitudinal study by Ziegler and colleagues (2012) could show that *Openness* positively affects changes in g_f, and changes in g_f were positively associated with changes in g_c; providing evidence for the *Environmental Enrichment Hypothesis*. A study by Dellenbach and Zimperich did not find that fluid intelligence mediated the relationship between Typical Intellectual Engagement (TIE) and crystallized intelligence. The study of Von Stumm and Deary demonstrated that intellectual curiosity (a facet of *TIE*) mediated the relationship between fluid intelligence and crystallized intelligence, providing evidence for the *Environmental Success Hypothesis*. We are not aware of any other study directly investigating one of the mediational pathways (*Environmental Enrichment Hypothesis/Environmental Success Hypothesis*) with regard to epistemic curiosity. However, there is research suggesting that measures of curiosity are related to fluid intelligence (Berg & Sternberg, 1985; Harter & Zigler, 1974; McCall & Carriger, 1993; Muentener et al., 2018; Mussel, 2010, 2013a; Raine et al., 2002; Sakaki et al., 2018; Trudewind, 2000; Von Stumm & Deary, 2012). For instance, for adults, Mussel (2010, 2013a) showed small but positive associations between epistemic curiosity and fluid intelligence. For children, Trudewind (2000) demonstrated that high curious children displayed better problem-solving behavior. Taken together, prior research suggests that epistemic curiosity and fluid intelligence may co-shape the accumulation of knowledge.

The Present Study

The aim of the present study is twofold. The first aim is to clarify whether dispositional curiosity in adults facilitates the acquisition of knowledge. More specifically, we examine whether interindividual differences in epistemic curiosity are related to interindividual differences in general knowledge in adults. We expected that epistemic curiosity is positively related to knowledge. The second aim of the present study is to examine the interplay of epistemic curiosity and fluid intelligence in their effect on crystallized intelligence. Therefore, first, we examined whether the relation between curiosity and knowledge depends on the fluid intelligence of individuals. As we assume that epistemic curiosity leads to knowledge gain only if individuals can deal with the situation, infer and recognize relevant information as well as memorize information, we expected that the relationship between epistemic curiosity and knowledge would be specifically strong for those individuals scoring high on fluid intelligence. That is, fluid intelligence boosts knowledge acquisition for curious individuals. Secondly, we examine whether there is a mediational interplay between epistemic curiosity and fluid intelligence on crystallized intelligence. On the one hand, one could argue that epistemically curious individuals experience an enriched and varying environment and are, therefore, more often confronted with diverse situations in which the rules are unknown. Consequently, these rules must be inferred, which in turn fosters g_f (*Environmental Enrichment Hypothesis*; Raine et al., 2002; Ziegler et al., 2012). On the other hand, one could imagine that individuals with higher g_f are more able to handle and cope with new situations. This experience, in turn, should influence curiosity about new situations (*Environmental Success Hypothesis*; Ziegler et al., 2012). Thus, we will explore both models.

Fluid intelligence is often conceptualized narrowly and measured with tests using matrices equating fluid intelligence with reasoning capacity (Carroll, 1993; Danthiir et al., 2005; Flanagan & McGrew, 1997). This is in line with current theoretical models of intelligence (Alfonso et al., 2005; Schneider & McGrew, 2012). However, proponents of investment theories have pointed out that it is necessary to study also other information-processing components such as perceptual speed and memory in relation to knowledge acquisition (e.g., Ackerman, 1996, p. 239), which have been elaborated in more comprehensive and facetted conceptualizations of fluid intelligence (Beauducel et al., 2001; Lindenberger & Baltes, 1997). Therefore, we capture fluid intelligence comprehensively using measures of reasoning ability, processing speed, and memory capacity (Ackerman, 1996). As knowledge acquisition and curiosity are related to anxiousness and conscientiousness (e.g., Kashdan & Roberts, 2004; Von Stumm, Hell, et al., 2011), both traits were considered as control variables.

Method

Procedure

Participants were invited during lectures at a German University to participate in a study about "Curiosity and Knowledge." Prior to the study, participants were informed about the content and the procedure of the study. The study was two-parted. For the first part of the study, participants were handed over a self-report questionnaire on several personality traits (i.e., curiosity, conscientiousness, social anxiety). Approximately 10–20 min were required to fill in the questionnaire. In the second part of the study, the intelligence tests were administered. Administration required approximately 110 min. As compensation for their participation, participants received 2½ hr of course credit.

We strictly followed the German Psychological Society's (Deutsche Gesellschaft für Psychologie) guidelines for conducting psychological studies, similar to those of the American Psychological Association. Since the study conforms with the Declaration of Helsinki and the ethics guidelines of the German Psychological Society, it did not require any additional ethics approval.

Participants

In total, 100 participants (n = 84 female, 84%) with a mean age of 22.24 (SD = 4.79, range = 17–51 years) were recruited for the study. Ninety-eight percent reported to be students.

Measures

Epistemic Curiosity

The Epistemic Curiosity Inventory (EC, Litman & Spielberger, 2003) consists of 10 items asking about one's interest in exploring new ideas and figuring out how things work (e.g., "When I see a complicated piece of machinery, I like to ask someone how it works."). Ratings were provided on a 4-point scale ranging from 1 (= *strongly disagree*), 2 (= *disagree*), 3 (= *agree*), to 4 (= *strongly agree*). The EC scale exhibited good reliability in this study with α = .81, comparable to previous research using the EC scale that ranged between α = .81 and α = .85 (Litman & Spielberger, 2003; Renner, 2006). On average, participants reported an epistemic curiosity of M = 2.96 (SD = 0.45).

Knowledge

General knowledge was measured with the knowledge subscale of the *Intelligenz-Struktur-Test 2000 R* (I-S-T 2000 R; Liepmann et al., 2007). It consists of 84 items capturing knowledge in the realm of geography/history, economics, art/culture, mathematics, natural sciences, and everyday life. Participants had to choose the correct answer out of 5 different answers. The scale exhibited good reliability in this study with α = .75, which is lower than previous research (α = .93; Liepmann et al., 2007). On average, participants answered 44.60 items correctly (SD = 7.75, range = 27–67).

Fluid Intelligence

Fluid intelligence was captured with three different measures. First, the *Wiener Matrizen Test 2* (WMT-2; Formann et al., 2011) was used. The WMT-2 consists of 18 items capturing reasoning. Participants were asked to identify the missing piece in a matrix consisting of nine fields out of eight alternatives. The scale exhibited good reliability in this study with $\alpha = .74$, lower than in previous research, $\alpha = .82$ (Formann et al., 2011). On average, participants identified 12.41 items correctly ($SD = 3.20$, range = 3–18).

In addition, the *Zahlen-Verbindungs-Test* (ZVT) was used to measure mental processing speed (Oswald, 2016). The ZVT comprises four trials. Each trial requires the participants to connect circled numbers from 1 to 90 that are randomly arranged on a sheet of paper. Participants had 30 s to connect the circles in numerical order. Thus, the higher the reached number the higher the processing speed. For each participant, the four trials were averaged. On average participants reached the number 50 ($M = 50.48$, $SD = 7.82$, range = 32–71). The four trials had a high internal consistency ($\alpha = .94$) comparable to previous research ($\alpha = .92$; Oswald, 2016).

Finally, two *memory tasks* were used to capture interindividual differences in the ability to memorize verbal and figural material (Liepmann et al., 2007). In the first task, participants had one minute to memorize five different higher-order categories (e.g., sports, food) with 2–3 related terms (e.g., golf, motorsports, cauliflower, pasta). Subsequently, the first letters of the terms were presented (e.g., M), and participants were asked which higher-order category the term belongs to. Ten different first letters were presented to the participants ($\alpha = .71$). Similarly, in the second task, participants had to memorize 13 pairs of shapes. Subsequently, one of the shapes was presented, and the participants had to choose the corresponding shape out of 5 different shapes ($\alpha = .70$). Memory tasks were moderately correlated ($r = .34$, $p < .001$) and summed up for further analysis. On average participants remembered 18 items ($M = 18.26$, $SD = 3.61$, range = 9–23).

Conscientiousness and Anxiety

To capture conscientiousness and anxiety, participants were asked to rate themselves on the personality traits of conscientiousness ("In general I am motivated to perform") and anxiety ("In general I am anxious"). Answers for absolute ratings were given on a 4-point scale ranging from 1 (= *strongly disagree*), 2 (= *disagree*), 3 (= *agree*), to 4 (= *strongly agree*). In addition, participants were asked to judge themselves on the two personality traits compared to an average peer of the same gender. Answers for comparative ratings were given on a 7-point rating scale ranging from 1 (= *much below average*), 2 (= *below average*), 3 (= *somewhat below average*), 4 (= *average*), 5 (= *somewhat above average*), 6 (= *above average*), to 7 (= *much above average*). Bivariate correlations between the items were $r = .73$ and $r = .78$ for conscientiousness (achievement motivation) and anxiety, respectively. Therefore, both items for the respective trait were z-standardized and averaged.

Bivariate correlations between all variables are displayed in Table 1.

Analytical Procedure

Eight participants had missing values varying between 0.4 and 12.8%. According to standard procedures, missing values were imputed prior to forming scales using the EM method in SPSS 24 (Schafer & Graham, 2002).

For examining the combined impact of individual differences in epistemic curiosity and fluid intelligence on knowledge, moderated regression analyses were conducted with *knowledge* as the dependent variable. *Epistemic curiosity,* as well as different measures of *fluid intelligence* (i.e., *reasoning, processing speed, memory*), and their respective interaction terms were entered as independent variables. Thus, three different moderated regression analyses were conducted. All independent variables were centered, and the interaction terms were based on centered variables (Aiken & West, 1991).

To conduct the mediation analysis, the PROCESS macro, a path analysis modeling tool for SPSS provided by Hayes (2018), was used. Therein, bias-corrected bootstrap confidence intervals were estimated based on 5,000 bootstrap samples (Hayes & Scharkow, 2013). As neither anxiety nor conscientiousness showed a substantial bivariate correlation with epistemic curiosity, knowledge, or fluid intelligence, they were not included in the analyses.

Results

Curiosity, Fluid Intelligence, and Knowledge

All three regression analyses were significant (see Table 2). The analyses revealed significant main effects on reasoning and memory. The main effect of epistemic curiosity did not reach significance when considered simultaneously with the fluid intelligence measures reasoning or memory. In contrast, the main effect for epistemic curiosity did reach significance when considered simultaneously with processing speed. Processing speed, however, did not relate significantly to knowledge. None of the analyses revealed a significant interaction between epistemic curiosity and fluid intelligence (all β's < |.08|).

Looking at the bivariate correlations shows that epistemic curiosity is related to both knowledge ($r = .24$) and reasoning ($r = .32$). However, it is not related to mental processing speed and memory, making mediation analyses unnecessary. The regression analysis shows that the relation between epistemic curiosity and knowledge is reduced

Table 1. Bivariate correlations (N = 100) between epistemic curiosity, knowledge, and different measures of fluid intelligence

		Fluid intelligence				
	Knowledge	Reasoning	Processing speed	Memory	Conscientiousness	Anxiety
Epistemic curiosity	.24*	.32***	.11	.13	.03	.19
Knowledge		.37***	.19	.29**	.00	−.04
Fluid intelligence						
Reasoning			.38***	.16	.11	−.04
Processing speed				.19*	−.03	−.12
Memory					−.15	−.17
Conscientiousness						.15

Notes. ****p* < .001; ***p* < .01; **p* < .05.

Table 2. Regression analysis with knowledge as dependent variable and epistemic curiosity and different measures of fluid intelligence as independent variables (N = 100)

	Fluid intelligence: Reasoning					Fluid intelligence: Processing speed					Fluid intelligence: Memory test				
		CI (95%)					CI (95%)					CI (95%)			
	B (*SE*)	LL	UL	β	*t*-value	*B* (*SE*)	LL	UL	β	*t*-value	*B* (*SE*)	LL	UL	β	*t*-value
Intercept	44.76 (0.76)	43.27	46.26		59.30***	44.60 (0.76)	43.10	46.10		58.90***	44.65 (0.74)	43.18	46.12		60.34***
Epistemic curiosity	2.16 (1.72)	−1.26	5.57	0.12	1.25	3.77 (1.75)	0.30	7.23	0.22	2.16*	3.13 (1.77)	−0.38	6.63	0.18	1.77
Fluid intelligence	0.75 (0.25)	0.26	1.24	0.31	3.03**	0.17 (0.10)	−0.03	0.36	0.17	1.70	0.57 (0.21)	0.16	0.98	0.26	2.75**
Interaction term	−0.38 (0.50)	−1.36	0.61	−0.08	−0.75	−0.01 (0.21)	−0.42	0.40	0.00	−0.04	−0.27 (0.41)	−1.07	0.54	−0.07	−0.65
Model	*R* = 0.40; *F*(3, 96) = 6.04***					*R* = 0.29; *F*(3, 96) = 2.90*					*R* = 0.36; *F*(3, 96) = 4.65**				

Notes. ****p* < .001; ***p* < .01; **p* < .05.

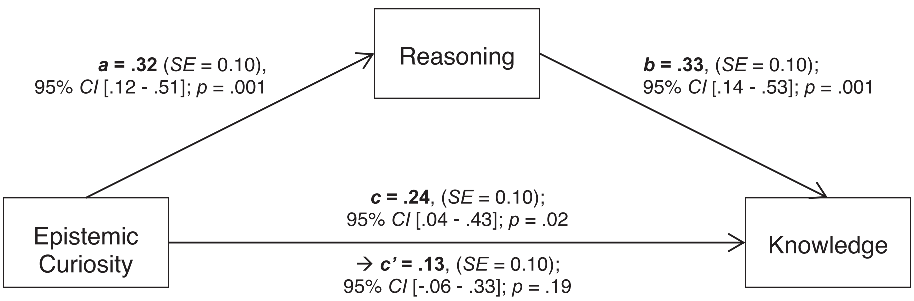

Figure 1. Relationship between epistemic curiosity, reasoning, and knowledge (N = 100).

when taking reasoning into account (see Figure 1). This pattern of results suggests that the relationship between epistemic curiosity and knowledge might be mediated by reasoning. In contrast, it speaks against a mediation by epistemic curiosity. Therefore, a mediation analysis was conducted with knowledge as the dependent variable, epistemic curiosity as the independent variable, and reasoning as the mediator variable.

In total, 15% of the variation in knowledge was explained by the model (R = .39, R^2 = .15). The indirect effect reached significance with $a \times b$ = .10, 95% CI [.03, .22]. Thus, reasoning mediates the relationship between epistemic curiosity and knowledge (see Figure 1).

Discussion

In the present study, the relationship between epistemic curiosity, general knowledge, and fluid intelligence was examined. Fluid intelligence was comprehensively captured by taking reasoning, processing speed, and memory capacity into account. The bivariate correlations indicate that epistemic curiosity is moderately related to knowledge. Thus, the more epistemically curious an individual is, the greater the general knowledge he or she has. However, simultaneously considering epistemic curiosity and fluid intelligence (i.e., reasoning or memory), the relationship between curiosity and knowledge vanished. In addition, none of the fluid intelligence measures did moderate the relationship between curiosity and knowledge. Rather, reasoning ability mediates the relationship between epistemic curiosity and knowledge. The findings suggest that epistemic curiosity facilitates the acquisition of knowledge by promoting reasoning. Thus, the findings of the present study shed light on the mechanisms connecting curiosity and knowledge.

Mediation by Fluid Intelligence

The finding that the effect of epistemic curiosity on knowledge is mediated by reasoning ability is in line with the *Environmental Enrichment Hypothesis* (Raine et al., 2002; Ziegler et al., 2012): Accordingly, curious individuals select and create for themselves an enriched environment which in turn results in an enhanced cognitive ability (Raine et al., 2002). More specifically, one might speculate that epistemically curious individuals, in their search for new information and answers, seek out new and varying situations and environments (e.g., lectures, libraries, museums) or create their environment to be intellectually stimulating (e.g., containing books, newspapers, films; Buss, 1987; Raine et al., 2002). Dealing repeatedly with new information and issues, in turn, stimulates and trains the ability to identify and infer relations and rules, thus, enhancing reasoning ability. This is in accordance with meta-analytical findings showing that the relation between investigative interests and intelligence is more pronounced in older age. That is, the longer individuals indulge their investigative interest, the higher their intelligence (e.g., reasoning; Päßler et al., 2015).

In contrast, neither processing speed nor memory mediates the relationship between epistemic curiosity and knowledge. Although prior research has shown that the experiences of momentary states of curiosity facilitate the storage and recall of information (Gruber & Ranganath, 2019; Kang et al., 2009), in the present study, dispositional epistemic curiosity was not related to memory capacity. Expecting individuals scoring high on dispositional curiosity to experience more information as curiosity-evoking, one would also expect them to memorize more information. The studies on momentary states of curiosity studies have shown that the answers to curiosity-evoking questions (Gruber & Ranganath, 2019; Kang et al., 2009) or information presented during curiosity states were remembered better (Murphy et al., 2021; Paradowski, 1967; but see Swirsky et al., 2021). However, the design of the present study deviates considerably from the *trivia paradigm* usually used when studying the effect of curiosity states on memory (Gruber & Ranganath, 2019). In the *trivia paradigm*, questions are presented to the participants. For each question, the participants rate their level of curiosity and confidence about knowing the answer to the question. Afterwards the correct answer to the question is usually shown. Then either immediately or delayed, a memory task must be solved (Gruber & Ranganath, 2019). It is reasonable to assume that epistemic curiosity may only be related to learning and memory if the information has a rewarding value to dissolve uncertainty (Gruber & Ranganath, 2019), however, this cannot be tested with the present design. The information to be remembered in the present study neither had curiosity-evoking qualities nor did it close any knowledge gap (Berlyne, 1966; Kang et al., 2009) and was therefore not better memorized. In addition, the above-cited studies did not include trait curiosity to examine the effect on state curiosity and the memorized information (Gruber et al., 2019; Kang et al., 2009). One might speculate that dispositional epistemic curiosity might indirectly affect memory capacity mediated through knowledge. Specifically, the acquired knowledge structures may enhance the possibility to integrate newly learned information into existing knowledge structures (Brod et al., 2013; Shing & Brod, 2016), thereby making it more easily stored and retrieved. As in the present study, memory capacity was assessed only with abstract information, this cannot be tested with the present data. How the interplay between trait and states curiosity as well as existing knowledge structure facilitates learning is still an open question to further research.

Also, processing speed as a measure of fluid intelligence did not mediate the relationship between epistemic curiosity and knowledge. In addition, it did not have any predictive value for knowledge. Processing speed is defined as the ability to fluently perform easy elementary cognitive tasks (McGrew, 2009, p. 6). It is strongly related to white matter maturation in childhood and young adulthood as well as to white matter integrity in general (Ferrer et al., 2013; Turken et al., 2008). It has been shown that processing speed mediates the relationship between white matter organization and reasoning ability (Ferrer et al., 2013). Thus, processing speed may be viewed as a basic cognitive ability that subserves more complex cognitive abilities like reasoning (Ferrer et al., 2013) or memory, therefore not directly related to knowledge.

Taken together, it appears that the ability to reason can be stimulated or maxed out by curiosity, whereas processing speed and memory capacity remain untouched by curiosity-motivated information-seeking behavior.

The Interplay of Curiosity and Fluid Intelligence

This study's positive relation between epistemic curiosity and knowledge supports theoretical notions that curiosity is a basic force for development and knowledge acquisition.

Thus, individuals with a higher epistemic curiosity accumulate more knowledge than individuals with lower "thirst of knowledge". As Kang and colleagues (2009) could show, individuals were more attentive towards the information they were curious about, more willing to spend resources (e.g., time) to acquire the respective information, and learned the respective information more readily in contrast to information they were not curious about. Thus, one might speculate that individuals with a high dispositional curiosity experience more information as curiosity-evoking and, therefore, are more attentive toward that information, more willing to spend resources to acquire missing information, and learn that information more readily. In this sense, curiosity manifests itself as a higher investment of cognitive resources to search for and process information.

We neither found incremental validity of epistemic curiosity above fluid intelligence nor did we find a significant interaction between epistemic curiosity and fluid intelligence. These findings contrast with the PPIK- and OFCI-model. Accordingly, both investment traits and fluid intelligence should simultaneously influence crystallized intelligence. Consistently, some studies have found an additive effect of investment traits and fluid intelligence (i.e., two main effects). For instance, a meta-analysis (Von Stumm, Hell, et al., 2011) has shown that *Typical Intellectual Engagement* and fluid intelligence independently predict crystallized intelligence. Also, studies on *Need for cognition* (e.g., Strobel et al., 2019) and *Openness* (e.g., Bergold & Steinmayr, 2018; Furnham & Chamorro-Premuzic, 2006; Studies 1 and 3; Lechner et al., 2019) did show incremental validity of the investment traits above fluid intelligence measures. However, there are also studies that did not find additive effects (e.g., Furnham & Chamorro-Premuzic, 2006, Study 2; Lechner et al., 2019; Chamorro-Premuzic et al., 2006). The few studies investigating interactional effects between investment traits and fluid intelligence have found either a synergistic interaction (Heaven & Ciarrochi, 2012) or a compensatory interaction (Strobel et al., 2019; Zhang & Ziegler, 2015; Ziegler et al., 2012). Taken together, research on the interplay of fluid intelligence and investment traits, specifically epistemic curiosity, is still scarce and yields inconsistent results.

Differentiating Investment Traits

One reason for this might be down to the different investment traits. In contrast to that notion are empirical findings showing a lack of discriminant validity between epistemic curiosity, Need for Cognition and Typical Intellectual Engagement. However, on a conceptual level, differences between these traits have been pointed out. In their review, Von Stumm and Ackerman (2013) categorized the 34 investment traits. *Need for Cognition* and *Typical Intellectual Engagement* formed one category reflecting the core of investment: "the tendency to seek out, engage in, enjoy, and continuously pursue opportunities for effortful cognitive activity" (Von Stumm, Chamorro-Premuzic, et al., 2011, p. 225), i.e., the need to engage cognitively with and understand the environment (Von Stumm & Ackerman, 2013). Another category was labelled *Intellectual Curiosity* and contained, amongst others, *epistemic curiosity* and the Openness facet *ideas*, in sum reflecting "the hunger for knowledge and engagement in cognitively stimulating activities." (Von Stumm & Ackerman, 2013, p. 848). According to Von Stumm and Ackerman (2013) these categories differ in that *intellectual curiosity* refers to a preference for seeking out new information. Whereas the core investment traits refer to a general desire to understand one's environment (Von Stumm & Ackerman, 2013). Mussel (2013b) aims to systemize personality traits related to intellectual achievement within a 2-dimensional model. He differentiates between two processes (*Seek* and *Conquer*) crossed by three operations (*Think*, *Learn*, and *Create*). *Need for Cognition* and *Typical Intellectual Engagement* are related to *think/seek* as they both emphasize interest in thinking for its own sake, pleasure from deliberative thinking, processing complex information and abstract thinking (Mussel, 2013b). Depending on the curiosity type, epistemic curiosity is linked either to *learn/seek* or to *learn/conquer*. Whereas the interest-type curiosity is linked to the process *seek* (i.e., approaching situations that are intellectually challenging), deprivations-type curiosity is linked to the process *conquer* (i.e., motivational tendencies once such situations have been encountered such as working hard to resolve incongruities; Mussel, 2013b). Thus, on a conceptual level, epistemic curiosity is directed at seeking out new situations and information as well as maintaining exploratory behaviors until new information is understood. Whereas *Typical Intellectual Engagement* and *Need for cognition* are more directed at thinking about complex issues and deliberate complex situations (Mussel, 2013b).

By using the Epistemic Curiosity Scale (Litman & Spielberger, 2003) in the present study, only interest-type curiosity was considered. According to Mussel (2013b), interest- and deprivation-type curiosity relate to different stages in the course of action, namely to *seek* (i.e., approaching situations that are intellectually challenging) and to *conquer* (i.e., motivational tendencies once such situations have been encountered; Mussel, 2013b), respectively. As *Conquer* concerns the persistence to explore until the information is understood, one might speculate that deprivation-type combined with the ability to understand and comprehend (i.e., fluid intelligence) should boost the effect of fluid intelligence on crystallized intelligence, thus, leading to an interaction. On the other hand, and rather comparable with our results, to *seek* information may rather lead to new and broad information or enriched situations which may train the cognitive mechanic (i.e., reasoning ability), therewith mediating to increase knowledge.

Limitations

The strength of the present study is clearly that it extends previous research through the comprehensive assessment of fluid intelligence uncovering differential relations between investment traits, fluid intelligence and knowledge. Given this strength, some limitations need to be considered. First, the mediational models in the present paper tested concurrent associations. However, to test whether epistemic curiosity is causal in stimulating reasoning and consequently leads to greater general knowledge, a developmental perspective has to be taken, and a cross-lagged design realized (Ziegler et al., 2012). In addition, future research needs to validate whether individuals with higher curiosity show more investment behaviors, such as going to the museum or reading books (e.g., Strobel et al., 2018). Second, effects have been shown in a young, educated, and predominantly female sample. Future research needs to investigate whether the results can be replicated in other samples differing in age, gender, education status, and social environment (e.g., different work contexts or senior citizen centers). Third, to comprehensively understand the simultaneous impact of investment traits and fluid intelligence on knowledge acquisition, additional investment traits such as *Typical Intellectual Engagement, Openness,* or *Need for Cognition* need to be considered. Likewise, studying alternative aspects of crystallized intelligence will broaden the understanding of the complex interplay.

Conclusion

Curiosity is a basic driver for learning and development. It has been conceptualized as a desire for new information and knowledge that motivates people to explore actively their physical and social environment. The present study advocates that epistemic curiosity not only fosters the search for new information in the environment and/or the creation of enriched environments but also that it stimulates and trains the ability to identify and infer relations, thus, enhance reasoning ability.

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