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ARTICLE

Are curiosity and situational interest different? Exploring distinct antecedents and consequences

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Abstract

Background: A controversy over the distinction between curiosity and situational interest has recently resurfaced. Nonetheless, empirical research comparing the two is noticeably lacking.

Aims: We attempted to fill this gap and provide much-needed evidence of the distinction between curiosity and situational interest by examining the antecedents and consequences of the two constructs.

Methods: We assessed enjoyment, novelty, uncertainty and surprise as potential antecedents and information seeking, individual interest, career intention and achievement as potential outcomes of curiosity and situational interest among 219 Korean sixth graders in the domain of science.

Results: Of the hypothesized antecedents, enjoyment during science class related most strongly to students' situational interest in science, whereas novelty in science class related most strongly to students' science curiosity. Uncertainty and surprise in science class related to only science curiosity and not situational interest in science. Among the outcomes considered, situational interest in science related to only students' individual interest in science. In comparison, science curiosity related significantly to all science outcomes measured in this study. Science curiosity also significantly mediated the relationships between the antecedents and outcomes in science.

Conclusions: Together, these results support the distinction between curiosity and situational interest and suggest different ways to promote each motivation construct depending on desired outcomes in the science classroom.

KEYWORDS

curiosity, elementary school, science education, situational interest, surprise

INTRODUCTION

Curiosity and situational interest have long been recognized as important motivators for students' learning and engagement. Despite this recognition, whether and how the two constructs differ remains controversial. Some scholars equate curiosity with situational interest (Ainley, 2019; Schmidt & Rotgans, 2020; Silvia, 2017), whereas others distinguish the two (Grossnickle, 2016; Hidi & Renninger, 2019; Markey & Loewenstein, 2014; for a review, see Peterson & Hidi, 2019; Shin & Kim, 2019). This lack of agreement coupled with a paucity of empirical research comparing the two constructs has produced two largely independent bodies of literature, which impedes theoretical and practical advancement. To remedy the situation, we sought to clarify the relationship between curiosity and situational interest by exploring their antecedents and outcomes in elementary school science.

Curiosity and situational interest as distinct psychological experiences

Contemporary discourses on curiosity have primarily adopted the information gap theory (Loewenstein, 1994), while those on situational interest have been based on the four-phase model of interest development (Hidi & Renninger, 2006). According to the information gap theory, curiosity is the deprived state of wanting to obtain missing information that arises from recognizing a gap in one's knowledge and motivates a person to seek the specific missing information to eliminate cognitive deprivation (Loewenstein, 1994; Markey & Loewenstein, 2014). Although this definition is straightforward, the literature points to the potentially multidimensional nature of curiosity. At the broadest level, curiosity can be manifested as either a state of a temporary desire to acquire knowledge when faced with curiosity-evoking stimuli or a trait of persistent inclination to seek new information and experience the state of curiosity (Kashdan et al., 2004; Loewenstein, 1994). State curiosity is further classified into perceptual curiosity (i.e. curiosity for sensory information) and epistemic curiosity (i.e. curiosity for knowledge; Berlyne, 1954, 1960), while trait curiosity can likewise be distinguished into interest-type curiosity (motivated by the enjoyment of learning something new) and deprivation-type curiosity (motivated by a sense of lacking knowledge; Litman, 2010). Some researchers discuss domain-specific curiosity, a tendency to feel curious about a specific academic domain, which displays both the state and trait features (Peterson & Cohen, 2019).

Situational interest, in comparison, is the state of focused attention in response to certain environmental stimuli (Hidi & Renninger, 2006, 2019). Among the four developmental phases of interest, situational interest is the less developed form that can advance into individual interest – the enduring propensity to reengage with the content – with the help of externally acquired value and knowledge of the content. Among the various forms of curiosity discussed above, state epistemic curiosity has most often been conflated with situational interest because of the considerable overlap in their characteristics. Therefore, we focus on state epistemic curiosity in this study and refer to it simply as 'curiosity.'

The recent dispute over the distinction between curiosity and situational interest is due, in part, to the overlap in their triggering factors and consequences (Schmidt & Rotgans, 2020; Shin et al., 2019). Both constructs have been theorized to be elicited by novelty, enjoyment, uncertainty and incongruity in stimuli (Berlyne, 1960; Boykin & Harackiewicz, 1981; Rotgans & Schmidt, 2014). Both are also thought to produce self-directed exploration (Jirout & Klahr, 2012; Rotgans & Schmidt, 2011), deeper engagement (Kang et al., 2009; Linnenbrink-Garcia et al., 2013), positive attitudes (Flowerday et al., 2004; Ruan et al., 2018) and stronger performance (Kashdan & Yuen, 2007; Rotgans & Schmidt, 2011; for a review, see Shin et al., 2019). These similarities have led some researchers to consider the two constructs synonymous (Ainley, 2019; Schmidt & Rotgans, 2020; Silvia, 2017).

On the other side of this dispute are scholars who are keen on the distinction between the two (Grossnickle, 2016; Hidi & Renninger, 2019; Markey & Loewenstein, 2014). Shin and Kim (2019) contend that curiosity represents an uncomfortable deficit state, unlike situational interest which represents a positive emotional experience. Uncertainty and incongruity (which accompanies surprise) are proposed as the two most direct and unique sources of curiosity (Berlyne, 1962; Hidi & Renninger, 2019; Jirout & Klahr, 2012; Loewenstein, 1994). Compared to situational interest, curiosity is, thus, believed to result in a more intense and specific information search out of the desire to terminate the state of discomfort (Grossnickle, 2016; Hidi & Renninger, 2019; Markey & Loewenstein, 2014).

Importance of distinguishing curiosity and situational interest in elementary school science

Investigating differences between curiosity and situational interest is also meaningful for practice. The early curiosity and situational interest of young students in science are vital for them to attain important learning outcomes in science, such as engagement (Ainley & Ainley, 2011; Alexander et al., 2019; Jirout, 2020; Simpkins et al., 2006), performance (Denissen et al., 2007; Wu et al., 2018) and motivation to pursue careers in science (Alexander et al., 2019; Gottfried et al., 2016; Maltese & Tai, 2010; Wang & Degol, 2013). Leading organizations and initiatives such as the American Association for the Advancement of Science (2008), European Commission (2007) and Next Generation Science Standards Lead States (2013) have, thus, advocated that stimulating curiosity and interest should be the goal of science education for young children. However, without deliberate planning and design to achieve this mission, students' curiosity and interest in science diminish with age and schooling, making the elementary school period particularly critical to stopping this unfortunate trend (Jirout & Klahr, 2012; Potvin & Hasni, 2014). Devising optimal science curricula, educational programs and strategies to activate each construct and evaluate their benefits requires a clear understanding of their antecedents and consequences.

Strategies to improve curiosity or situational interest may not produce their intended effects when the two constructs are not carefully distinguished. Shin and Kim (2019) illustrated how a strategy to stimulate one construct may end up harming the other. For example, highlighting uncertainty in the information to pique students' curiosity could undermine their situational interest because of the negative affect generated by the lack of understanding. Having students engage in the science content that they have already mastered could promote their situational interest but not their curiosity because hardly anything remains unknown. The findings of this study can offer significant implications in this regard by suggesting effective ways to foster curiosity or situational interest.

Distinct antecedents of curiosity and situational interest

Curiosity is thought to arise from the states where desired information is absent. Uncertainty is representative of such a state where individuals lack essential information to comprehend an event or content (Bar-Anan et al., 2009; Shin & Kim, 2019). Uncertainty accompanies negative affect such as confusion and frustration, which turns positive with its resolution (Bar-Anan et al., 2009; D'Mello et al., 2014; Lamnina & Chase, 2019). Encountering uncertainty instils greater curiosity about the information currently deprived in the environment (Berlyne, 1962; Boykin & Harackiewicz, 1981; Lamnina & Chase, 2019; Ruan et al., 2018).

Surprise is another primary antecedent of curiosity. It is an immediate emotional reaction to incongruity where individuals stumble upon information or an event that contradicts their expectations (Bruner & Postman, 1949; Shin & Kim, 2019). According to the early incongruity theories, curiosity is a natural human tendency to make sense of the world when one's expectation is violated (for reviews, see Jirout & Klahr, 2012; Loewenstein, 1994). Surprise stemming from incongruity has indeed proven to be a powerful precursor of curiosity (Brod et al., 2018; Piaget, 1952; Vogl et al., 2019), even among young children (Stahl & Feigenson, 2015).

On the contrary, positive affective experiences may be the driving force of situational interest. Enjoyment is a positive emotion brought on by the desired event or activity (Pekrun et al., 2011;

Reeve, 2009). Prior studies that explored the sources of situational interest have identified enjoyment as its primary determinant. For instance, Chen et al. (2001) observed that enjoyment emerged as the strongest predictor of situational interest, which also mediated the relationships of novelty, challenge, attention demand and exploration intention with situational interest.

Unlike uncertainty, surprise and enjoyment discussed earlier, novelty has been regarded as a source of both curiosity and situational interest. It refers to the state where individuals appraise the given event as unusual, new or unfamiliar (Barto et al., 2013; Berlyne, 1960; Noordewier & van Dijk, 2016). Turner Jr. and Silvia (2006), for example, showed that individuals' feeling of interest in a painting was significantly predicted by how novel they appraised the painting. However, Smock and Holt (1962) found that young children demonstrated an increased frequency of curiosity-driven behaviours (e.g. exploration) when given novel, rather than familiar toys. We made no hypothesis about the role of novelty in generating curiosity and situational interest.

Distinct outcomes of curiosity and situational interest

Active information seeking and better achievement are well-known consequences of experiencing curiosity. The effect of curiosity in initiating exploratory behaviours has been documented in many previous studies (for a review, see Jirout & Klahr, 2012). For instance, Vogl et al. (2019) found that participants' curiosity about trivia answers led to their exploration of further explanations about the answer. Litman et al. (2005) showed that students opened a greater number of sealed envelopes that contained the correct answers to the questions they were curious about. The state of curiosity is also found to accompany heightened memory for the sought-after information (Kang et al., 2009) and recruitment of the hippocampal activity, the brain region associated with memory consolidation (Gruber et al., 2014). Given the impact of curiosity on the active exploration of information and memory, it is no surprise that curiosity leads to superior achievement (Kashdan & Yuen, 2007; Marvin & Shohamy, 2016). A meta-analysis by Von Stumm et al. (2011) concluded that the tendency to feel curious is an influential predictor of academic achievement.

Curiosity can also be linked to stronger career intention. When Venville et al. (2013) surveyed scientists, curiosity was identified as one of the most significant factors that led scientists to pursue occupations in science. A 10-year longitudinal investigation that examined the relationship among parental stimulation of curiosity, science curiosity, science achievement and science career interest demonstrated that students' curiosity during early adolescence bore a positive relationship to their science career interest measured during the last year of high school (Gottfried et al., 2016).

Both curiosity and situational interest may promote individual interest in the topic area. The notion that situational interest deepens and shifts to individual interest with increasing knowledge of and value for the content is well established in the literature (Crouch et al., 2018; Hidi & Renninger, 2006; Linnenbrink-Garcia et al., 2013). Curiosity resolution also fosters the acquisition of knowledge, value and positive affect (e.g. enjoyment) towards the content, which are the three key elements of individual interest (Shin & Kim, 2019). Rotgans and Schmidt (2017) found that repeated arousal of young students' curiosity (wanting to know more) and situational interest (focused attention) in science class both significantly contributed to the growth of their individual interest in science. It remains still unclear which of the two constructs is a better predictor of individual interest (Shin & Kim, 2019), but existing evidence point to both curiosity and situational interest as equally viable predictors of individual interest.

It is possible that situational interest also predicts information seeking, career intention and achievement as curiosity does. Evidence shows that situational interest in science contributes to the intention to explore or actual exploration of science (Ainley & Ainley, 2011; Rotgans & Schmidt, 2011), better science achievement (Crouch et al., 2018; Denissen et al., 2007) and career aspiration in science (Alexander et al., 2019; Maltese & Tai, 2010). Nonetheless, curiosity is expected to be a stronger predictor of these outcomes because wanting to know, actively searching for an answer, learning new knowledge and perceiving high value in the area of attained knowledge are inherent elements of curiosity experiences.

Present study

Although recent proposals on the conceptual distinctions between curiosity and situational interest have illuminated the initial step in exploring the differences between the two constructs, the empirical validation of these suggestions remains largely scarce. The present study aimed to test the postulation that the two constructs would be associated with different antecedents and outcomes by surveying the variables in elementary school science.

We examined four presumed antecedents (i.e. enjoyment, novelty, uncertainty and surprise) and four probable outcomes (i.e. information seeking, individual interest, career intention and achievement) of curiosity and situational interest in the context of elementary school science. We hypothesized that uncertainty and surprise in science class would be stronger predictors of curiosity than interest, whereas enjoyment in science class would be a stronger predictor of situational interest. We further hypothesized that curiosity in science class would relate to information seeking, career intention and achievement in science more strongly than situational interest.

METHOD

Participants and procedure

Two hundred and nineteen 6th graders (115 boys, 104 girls) at a public elementary school in Seoul, Korea, who provided written consent of themselves and their parents, participated in the study. The study was approved by the university's Institutional Review Board.

The researchers administered the science exam and survey during designated class hours towards the end of the school year. The exam and survey took place on two consecutive days. An entire class hour (40 min) was devoted to the science exam. The survey took about 15 min to complete. Homeroom teachers stayed in the classroom to help administer both the science exam and the survey.

Measures

The items of all self-report measures and their reliability are presented in Table S1 and Table 1 respectively. We adopted the items from prior studies by translating them into Korean and then back-translating them into English by two bilingual researchers. Three content experts made sure that the translated items had the same meaning as the original items. All items referred to either students' experience in their current science class or a science domain in general.

Antecedents

Students indicated how frequently they experienced each of the four antecedents (i.e. enjoyment, novelty, uncertainty and surprise) in their science class this semester using a 5-point Likert scale (1 = *never*, 5 = *all the time*). Enjoyment was assessed using a three-item measure from Pekrun et al. (2011) (e.g. “I enjoyed science class this semester”). Novelty was also measured using three items, two of which were adapted from Turner Jr. and Silvia (2006) (e.g. “I felt that the contents covered in science class this semester were unfamiliar”), and one was developed by the researchers (e.g. “The contents covered in science class this semester were novel”). We used five items to assess the feeling

TABLE 1 Descriptive statistics and intercorrelations among the variables.

	Variable	*M*	*SD*	*α*	1	2	3	4	5	6	7	8	9
1.	Enjoyment	3.32	1.01	.88	–								
2.	Novelty	3.20	.91	.88	.67**	–							
3.	Uncertainty	2.69	.76	.86	−.16*	.02	–						
4.	Surprise	2.25	.82	.87	.08	.25**	.48**	–					
5.	Curiosity	2.88	.90	.89	.63**	.70**	−.09	.21**	–				
6.	Situational interest	3.35	1.02	.94	.73**	.66**	−.19**	.02	.69**	–			
7.	Information seeking	2.14	.91	.87	.44**	.46**	.07	.22**	.57**	.38**	–		
8.	Individual interest	3.07	.95	.89	.60**	.57**	−.22**	.07	.75**	.78**	.48**	–	
9.	Career intention	2.67	1.10	.92	.28**	.35**	.04	.12	.48**	.31**	.38**	.47**	–
10.	Achievement	15.16	3.85	.77	.18**	.12	−.18**	−.05	.24**	.22**	.15*	.20**	.20**

Note: All variables except for achievement were measured using a 5-point Likert scale. The possible range for achievement scores was 0–25. *$p < .05$. **$p < .01$.

of uncertainty, of which two were adapted from Lamnina and Chase (2019) (e.g. “In science class this semester, I felt uncertain whether the concept or principle I had in mind was correct”) and three were created (e.g. “I was confused with the contents covered in science class this semester”). Finally, surprise was assessed with three items that we developed (e.g. “In science class this semester, I was surprised to learn that what I used to know was incorrect”).

Curiosity and situational interest

To measure curiosity and situational interest in science, we asked students to indicate the degree to which they concurred with each curiosity and situational interest item about their current science class using a Likert scale ranging from 1 (*not at all true*) to 5 (*very true*). Curiosity was assessed with four items adapted from Naylor (1981) (e.g. “I wanted to know more about the contents covered in science class this semester”), and situational interest was assessed using a modified version of the three-item scale from Durik et al. (2015) (e.g. “I found the contents covered in science class this semester interesting”).

Outcomes

We operationalized information seeking as an active search for specific information and assessed it with three items that we developed (e.g. “I have searched on the internet to learn about the contents and principles from science class that I wanted to know more about”). Students indicated the frequency with which they engaged in information-seeking behaviour on a Likert scale ranging from 1 (*never*) to 5 (*all the time*). Four items from Durik et al. (2015) were adopted to measure individual interest (e.g. “I like learning new science concepts”), and two items from Hulleman and Harackiewicz (2009) were adapted to assess career intention (e.g. “I want to have a job that involves science someday”). Students responded on a Likert scale ranging from 1 (*not at all true*) to 5 (*very true*). Finally, science achievement was assessed with 25 multiple-choice and short-answer questions. The researchers developed the questions and had them reviewed by school teachers for content and grade-level appropriateness.

RESULTS

Preliminary analyses

Table 1 shows descriptive statistics and zero-order correlations among the measured variables. Curiosity and situational interest correlated strongly with each other ($r = .69$). Although the correlational patterns for curiosity and situational interest were generally similar, a few relations were noticeably different. For example, uncertainty correlated negatively and significantly with only situational interest ($r = -.19$), while surprise correlated positively and significantly with only curiosity ($r = .21$).

Because of the conceptual similarities and strong correlations observed between several variables, we performed two sets of confirmatory factor analyses (Brown, 2006), one with curiosity and situational interest and the other with enjoyment, situational interest and individual interest. Table 2 presents the results. For the curiosity and situational interest model, a two-factor solution fit the data significantly better than a single-factor solution, $\Delta\chi^2(1) = 76.35$, $p < .001$, suggesting that curiosity and situational interest are sufficiently distinct. For the enjoyment, situational interest and individual interest model, a three-factor model yielded the best and a significantly better fit than that of the best-fitting two-factor solution, $\Delta\chi^2(2) = 76.22$, $p < .001$, thus providing support that the three constructs should be treated separately.

TABLE 2 Comparisons of model fit among the factor models.

Model	χ^2	*df*	CFI	TLI	RMSEA (90% CI)	$\Delta\chi^2$
Curiosity and situational interest						
One latent factor	96.22	14	.84	.76	.17 (.14, .20)	
Two latent factors	19.87	13	.99	.98	.05 (.00, .09)	76.35***
Enjoyment, situational interest, individual interest						
One latent factor	209.75	35	.84	.79	.15 (.13, .17)	
Two latent factors (ENJ + II vs. SI)	188.58	34	.85	.81	.15 (.13, .17)	21.17***
Two latent factors (ENJ vs. SI + II)	135.22	34	.90	.87	.12 (.10, .14)	53.36***
Two latent factors (ENJ + SI vs. II)	134.04	34	.91	.88	.12 (.10, .14)	1.18
Three latent factors	57.82	32	.98	.87	.06 (.04, .09)	76.22***

Note: ***$p < .001$.

Abbreviations: ENJ, enjoyment; II, individual interest; SI, situational interest.

Analytic approach

We performed multiple mediation analyses using the PROCESS macro (Preacher & Hayes, 2008) to examine direct and indirect relationships that curiosity and situational interest maintain with the four potential antecedents and the four potential outcomes. We adopted Hayes's PROCESS approach because it has several methodological advantages. First, it enables a bootstrapping procedure, which provides power advantages to small-sample data like the present one (Hayes, 2017). Second, the PROCESS macro utilizes separate ordinary least squares (OLS) regression equations. Again, this approach requires considerably smaller samples than simultaneous estimation using maximum likelihood (ML) in structural equation modelling (SEM),[1] known as a large-sample technique (Hayes et al., 2017). Third, it allows comparisons of multiple mediators using bootstrapping. The indirect effect of any particular mediator can be calculated while controlling for the effects of the other mediators, and the estimated indirect effects can be contrasted with one another.

Four models were tested for each of the four outcomes. Each of these four models included one of the four antecedents as an independent variable, curiosity and situational interest as two mediators, and one of the four outcomes as a dependent variable. The three remaining antecedents were entered as covariates in each model, and the bootstrapping procedure was employed with 10,000 random resamples. We computed the standardized estimates from the results. The statistical significance of indirect effects as well as the difference between the indirect effects via curiosity and those via situational interest were attained when the bias-corrected 95% confidence intervals (CIs) did not contain zero (MacKinnon et al., 2004).

Antecedents and outcomes of curiosity and situational interest

Figure 1 presents the standardized coefficients of statistically significant direct paths. All antecedents except for uncertainty related positively to curiosity (enjoyment: $\beta = .27, p < .001$; novelty: $\beta = .49, p < .001$; surprise: $\beta = .12, p = .03$). Unexpectedly, uncertainty negatively related to curiosity ($\beta = -.11, p = .05$). Both enjoyment ($\beta = .49, p < .001$) and novelty ($\beta = .35, p < .001$) significantly and positively related to situational

[1]We nonetheless examined our model using SEM and checked if the results differed from those obtained using the PROCESS macro. The SEM model demonstrated a satisfactory model fit, $\chi^2(391) = 775.56, p < .001$ (CFI = .92, TLI = .91, RMSEA = .07). All paths were comparable except for the two paths linking the antecedents and individual interest. In the SEM model, the path from uncertainty to individual interest was not significant (SEM: $\beta = -.09, p = .12$; PROCESS: $\beta = -.10, p = .03$). Instead, novelty was significantly and negatively related to individual interest (SEM: $\beta = -.21, p = .03$; PROCESS: $\beta = -.06, p = .32$). Given the positive bivariate association between novelty and individual interest, this result likely represents a suppression effect. The overall consistency in results between the two sets of analyses adds to the validity of our findings.

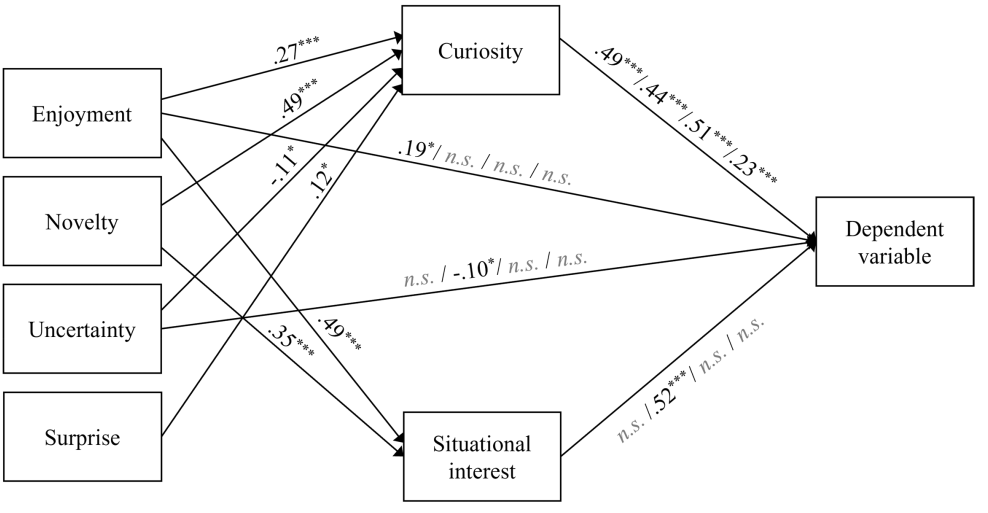

FIGURE 1 Antecedents and outcomes of curiosity and situational interest.
Note: *n.s.* = statistically non-significant path. Values represent standardized parameter estimates. Values predicting the dependent variable are from, respectively, information seeking/individual interest/career intention/achievement models. *$p < .05$; ***$p < .001$.

interest. Of the antecedents, novelty was linked to curiosity most strongly, as enjoyment was to situational interest. Surprise significantly predicted only curiosity, supporting our hypothesis.

Curiosity predicted all four outcomes significantly (information seeking: $\beta = .49$, $p < .001$; individual interest: $\beta = .44$, $p < .001$; career intention: $\beta = .51$, $p < .001$; science achievement: $\beta = .23$, $p = .03$). In contrast, situational interest related only to individual interest ($\beta = .52$, $p < .001$). In addition, enjoyment displayed a positive direct path to information seeking ($\beta = .19$, $p = .03$), while uncertainty exhibited a negative direct path to individual interest ($\beta = -.10$, $p = .03$).

Mediating roles of curiosity and situational interest

Tests of indirect effects demonstrated that curiosity and situational interest mediated the links between antecedents and outcomes differently. Table 3 presents the standardized estimates of indirect effects. Curiosity acted as an intervening variable between all antecedents, except for uncertainty, and outcomes. In contrast, situational interest significantly mediated the indirect paths from enjoyment and novelty to individual interest. Surprise was linked to the outcomes only indirectly via curiosity, suggesting an indirect-only mediation (Zhao et al., 2010). As indicated in Table 3, the indirect path from novelty to information seeking through curiosity was significantly stronger than the indirect path from novelty to information seeking through situational interest. Curiosity also mediated the path from novelty to career intention more strongly than did situational interest.

DISCUSSION

With the pressing need to attain conceptual clarity of curiosity and situational interest, we sought to examine the distinct antecedents and outcomes of the two constructs in elementary school science. As presented in Table 4, our findings suggest that curiosity and situational interest are distinguished by different affective antecedents and outcomes in science as well as by their unique mediating role in these relationships. Most of the results map onto the theoretical distinctions between curiosity and situational interest and thus provide novel and much-needed empirical support for the theory.

TABLE 3 Indirect effects of antecedents on science outcomes through curiosity and situational interest.

	Dependent variable (DV)											
	Information seeking			Individual interest			Career intention			Achievement		
Tested effect	*β*	*SE*	95% CI	*β*	*SE*	95% CI	*β*	*SE*	95% CI	*β*	*SE*	95% CI
Enjoyment → Curiosity → DV	**.13**	.04	**[.06, .22]**	**.12**	.03	**[.06, .19]**	**.14**	.05	**[.06, .24]**	**.06**	.12	**[.00, .13]**
Enjoyment → SI → DV	−.07	.05	[−.16, .04]	**.26**	.05	**[.15, .36]**	−.02	.05	[−.11, .08]	.04	.23	[−.06, .17]
Novelty → Curiosity → DV	**.24**[a]	.05	**[.14, .34]**	**.21**	.05	**[.13, .31]**	**.25**[a]	.07	**[.14, .37]**	**.11**	.25	**[.00, .23]**
Novelty → SI → DV	−.04[b]	.04	[−.13, .03]	**.18**	.05	**[.10, .28]**	−.01[b]	.04	[−.07, .06]	.03	.19	[−.05, .13]
Uncertainty → Curiosity → DV	−.05	.04	[−.13, .01]	−.05	.04	[−.11, .01]	−.06	.05	[−.14, .01]	−.02	.11	[−.07, .01]
Uncertainty → SI → DV	.01	.02	[−.01, .04]	−.05	.03	[−.10, .00]	.00	.02	[−.01, .03]	−.01	.07	[−.04, .01]
Surprise → Curiosity → DV	**.06**	.03	**[.00, .12]**	**.05**	.03	**[.00, .11]**	**.06**	.05	**[.00, .14]**	.03	.09	[−.01, .07]
Surprise → SI → DV	.01	.01	[−.01, .04]	−.03	.03	[−.09, .02]	.00	.01	[−.01, .02]	−.01	.05	[−.03, .01]

Note: The boldfaced indicates significant indirect effects. Coefficients with the different superscripts ([a, b]) indicate indirect effects that are significantly different from each other for each dependent variable. Values represent standardized parameter estimates.

Abbreviations: DV, dependent variable; SI, situational interest.

TABLE 4 Distinct antecedents and outcomes of curiosity and situational interest in science.

Antecedents	Curiosity vs. situational interest	Outcomes
Common mechanism		
Enjoyment (+)	Curiosity Situational interest	Individual interest
Novelty (+)		
Distinct mechanism		
Uncertainty (−)	Curiosity	Information seeking
Surprise (+)		Career intention
		Achievement

Note: All outcomes were positively predicted by curiosity and situational interest. All possible indirect effects from both the common and distinct mechanisms, except for Surprise → Curiosity → Achievement, were statistically significant.

Abbreviations: +, positive predictor; −, negative predictor.

Surprise as a unique antecedent of curiosity

While all four cognitive and emotional experiences (i.e. enjoyment, novelty, uncertainty and surprise) in science class predicted students' curiosity, only enjoyment and novelty in science class significantly predicted their situational interest. The novelty students experienced in their science class most strongly predicted their science curiosity, and their enjoyment of science class most strongly explained their situational interest in science class. The surprise students felt during science class promoted students' science curiosity but not their situational interest, thus serving as a unique determinant of curiosity. The results are generally in line with the theoretical argument that curiosity is triggered by stimuli inducing an information gap, while situational interest is spurred by emotional satisfaction (Markey & Loewenstein, 2014; Shin & Kim, 2019).

The negative association between uncertainty and curiosity warrants an explanation because uncertainty has been suggested as a strong predictor of curiosity (Lamnina & Chase, 2019; Ruan et al., 2018). We cautiously attribute this finding to the characteristics of the present context. In a typical Asian classroom where getting the right answer is emphasized (Shin et al., 2018), feeling confused and uncertain may adversely influence student motivation (Jirout, 2020). The state of uncertainty can cue students' incompetence and serve as a threat to achieving the goals salient in the environment. Future studies should examine whether uncertainty is indeed evaluated differently depending on the classroom culture.

These findings bear important implications for promoting students' curiosity and situational interest in science class. Using novel and enjoyable science materials and activities (e.g. novel prompts, demonstrations and group activities) will be effective in fostering both curiosity and situational interest. However, surprise and uncertainty may have limited effects. Providing surprising materials that deviate from students' expectations (e.g. myth-debunking information) can be a powerful tool to spark students' curiosity, but not necessarily their situational interest. When incorporating uncertainty (e.g. quizzes and fill-in-the-blank questions), teachers may first need to establish a mastery-oriented classroom where the process is emphasized over the end product, which alleviates students' anxiety and helps them view the uncertainty as beneficial rather than as a threat to their learning.

Curiosity as a positive predictor of science outcomes

The curiosity generated during science class was positively linked to all science outcomes considered in this study. When students frequently became curious about what they were learning in their science class, they were more prone to explore unknown information, be interested in science and science careers and perform better in science. In contrast, situational interest in science class led only to individual interest in science.

Compared to situational interest, curiosity has received relatively scant attention in motivation research. However, our results shed light on the role of curiosity as a principal motivator of learning outcomes in science. That curiosity was strongly associated with not only information seeking but also career intention and achievement in science demonstrates the benefit of piquing students' curiosity during science class. Several distinctive properties of curiosity may undergird these findings. Unlike situational interest which entails positive emotion, curiosity represents an adverse state of not having the desired information. When experiencing this negative state, people naturally want to alleviate it and restore cognitive balance by actively seeking the missing information (Loewenstein, 1994; Piaget, 1952). In addition, the successful resolution of curiosity accompanies satisfaction and the perception of greater value towards the target information (Loewenstein, 1994). Satisfying curiosity is associated with increased post-answer interest (Fastrich et al., 2018; McGillivray et al., 2015), a stronger inclination to reengage with the materials (Ruan et al., 2018), and enhanced memory of the answer (Kang et al., 2009). These properties might have collectively contributed to the power of curiosity observed in this study.

Although situational interest in science class led only to individual interest in science, their tight association is nonetheless consistent with the theory of interest development (Hidi & Renninger, 2006, 2019; Renninger & Hidi, 2011). Situational interest in science class demonstrated a stronger relationship with individual interest in science than did curiosity, further supporting the four-phase model of interest development. Still, Ainley (2019), as well as Hidi and Renninger (2019), contend that the relationship between curiosity, situational interest and individual interest could be more complex than previously argued. Curiosity-driven information seeking may be what maintains interest, and the resolution of curiosity may further support the deepening of interest in the topic. While it was not possible to test this conjecture in the present study, it will be an interesting agenda for future research.

Curiosity as a mediating mechanism between emotions and science outcomes

The tests of indirect effects showed that curiosity and situational interest in science class played non-identical mediating roles in the relationship between the cognitive and affective antecedents and outcomes in science. The curiosity students experienced during science class significantly mediated the relationship between their enjoyment, novelty and surprise in science class and their information seeking, individual interest, choice intention and achievement in science. On the contrary, situational interest students felt in science class was a significant mediator only for the paths linking students' enjoyment and novelty during science class to their individual interest in science.

These indirect effects of curiosity and situational interest are in line with previous findings. For example, after analysing the Program for International Student Assessment (PISA) data, Ainley and Ainley (2011) concluded that students' interest in science mediated the link between their enjoyment of science and more developed forms of interest. Anderson et al. (2019) reported that dispositional awe, similar to the surprise assessed in the current research, led to positive academic outcomes such as behavioural engagement, attitudes and academic self-efficacy via trait curiosity. Likewise, Vogl et al. (2019) argued that curiosity is the binding process that leads the experience of a surprise to adaptive behavioural and cognitive outcomes such as information seeking, interest and choice intention. Consistent with the prior reports, students' curiosity in science class in this study fully mediated the relationship between their feelings of surprise during science class and their science outcomes.

Limitations and future directions

Several limitations of this study need to be addressed in future investigations. First, we relied on a single time-point survey to examine the relationship between antecedents and outcomes. Therefore, we could not draw causal conclusions about which precedes which. Assessing the variables at multiple time points would allow tests of the potential temporal ordering among them and hence possible causal inferences. For example, information seeking may be shorter lasting than the other more enduring science outcomes such as science interest, science career aspiration and science achievement. If so, it could serve as a mediating behaviour through which students' science curiosity is linked with these outcomes. The plausibility of such a conjecture can be tested only in studies with a longitudinal design.

Second, we measured students' cognitive and emotional experiences during their science class, including enjoyment, novelty, uncertainty and surprise, as well as the frequency of curiosity and situational interest towards specific stimuli, in a retrospective manner. We intentionally chose this option to deal with the fleeting nature of these experiences and to capture students' subjective and general approximation of a particular state in their science class relative to others (Linnenbrink-Garcia et al., 2010; Loewenstein, 1994). We are reasonably confident that we successfully measured the target experiences because the pattern of the bivariate correlations was highly consistent with the existing literature. Still, this practice runs the risk of producing biased recollections and possible conflation with more trait-like constructs, such as domain-specific curiosity and topic interest. While the latter issue would not change our conclusion, as curiosity and interest are distinguishable even at the trait level (Peterson & Cohen, 2019), using real-time analyses such as the experience sampling method can be an appealing alternative to consider in future studies.

Third, the assessments of uncertainty and information seeking can improve in subsequent research. Unlike other experiences, uncertainty may be ill-suited to be measured by self-report items (D'Mello et al., 2014). Various factors could jeopardize the accurate assessment of uncertainty, including students' imprecise introspection of their momentary experiences or their unwillingness to report negative emotions. The inclusion of aversive emotions that commonly coincide with uncertainty in the items, such as confusion and frustration (D'Mello et al., 2014), could have worsened the unpleasant connotations associated with the uncertainty measure. To overcome this shortcoming, future works should include objective measures of uncertainty (e.g. facial expression) to investigate its relationship with other variables. Information seeking was operationalized as an active search for specific information in the current research. This definition aligns closely with the characteristics of information-seeking behaviours when curiosity arises. It is not surprising, therefore, that curiosity was linked strongly to information seeking, while situational interest was not, in this study. If information seeking had been defined as a casual search for more broad knowledge; however, the results might have been different.

Lastly, the correlations among the motivation variables such as curiosity, situational interest and individual interest were quite high. This was somewhat predicted considering the conceptual and phenomenological overlap among the variables. We were relieved that factor analyses supported the distinct factor structure despite the high intercorrelations. Nonetheless, the possibility of collinearity affecting the results cannot be completely ruled out.

CONCLUSION

The discourse on the possible distinction between curiosity and situational interest has recently become intense. However, there exists insufficient empirical evidence in the literature to systematically examine this question. To help address the issue, we assessed a set of presumed antecedents and consequences of curiosity and situational interest in the context of elementary school science and analysed their relationships. Our results illustrate the distinct relationships that curiosity and situational interest maintain with enjoyment, novelty, uncertainty and surprise as their antecedents and with information seeking, individual interest, career intention and achievement in science as their outcomes. Our findings also depict the unique mediating role played by curiosity and situational interest between the antecedents and consequences. We believe that the present results add valuable insights into the theory of curiosity and interest as well as the practice of supporting students' curiosity and interest in the science classroom.

AUTHOR CONTRIBUTIONS

Dajung Diane Shin: Conceptualization; formal analysis; investigation; methodology; writing – original draft. **Yoonah Park:** Conceptualization; formal analysis; investigation; writing – original draft. **Minhye**

Lee: Conceptualization; formal analysis; investigation; methodology. **Sung-il Kim:** Conceptualization; methodology; supervision. **Mimi Bong:** Conceptualization; funding acquisition; methodology; project administration; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

All authors declare that there is no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the first or the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICAL APPROVAL

We certify that our research received approval from the Institutional Review Board (approval no. KUIRB-2019-0160-01), and all procedures were performed in compliance with the relevant laws and institutional guidelines in operation at the time of this research.

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SUPPORTING INFORMATION

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