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Surprised – curious – confused: epistemic emotions and knowledge exploration

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Surprised – Curious – Confused:

Epistemic Emotions and Knowledge Exploration

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Abstract

Some epistemic emotions, such as surprise and curiosity, have attracted increasing scientific attention, whereas others, such as confusion, have yet to receive the attention they deserve. In addition, little is known about the interrelations of these emotions, their joint antecedents and outcomes, and how they differ from other emotions prompted during learning and knowledge generation (e.g., achievement emotions). In three studies (*N*s = 102, 373, 125) using a trivia task with immediate feedback, we examined within-person interrelations, antecedents, and effects of three epistemic emotions (surprise, curiosity, and confusion). Studies 2 and 3 additionally included two achievement emotions (pride and shame). Using multilevel modeling to disentangle within- and between-person variance, we found that achievement emotions were associated with accuracy (i.e., correctness of the answer), whereas epistemic emotions were related to high-confidence errors (i.e., incorrect answers a person was confident in) generating cognitive incongruity. Furthermore, as compared with achievement emotions, epistemic emotions were more strongly and positively related to subsequent knowledge exploration. Specifically, surprise and curiosity were positive predictors of exploration. Confusion had positive predictive effects on exploration which were significant in Studies 1 and 3 but not Study 2, suggesting that the effects of confusion are less stable and need to be investigated further. Apart from the findings for confusion, the results were fully robust across all three studies. They shed light on the distinct origins and outcomes of epistemic emotions. Directions for future research and practical implications are discussed.

Keywords: epistemic emotion, achievement emotion, cognitive incongruity, knowledge exploration, within-person analysis

Surprise when learning something unexpected, curiosity when a question remains unanswered, and confusion after encountering contradictory information are typical examples of epistemic emotions. Epistemic emotions are major drivers of knowledge acquisition about the self and the world (Brun, Doğuoğlu, & Kuenzle, 2008). These emotions relate to the knowledge-generating qualities of cognitive tasks and activities (Morton, 2010) and are thought to be critically important for learning, conceptual change, and cognitive performance (Pekrun & Stephens, 2012).

Even though there are long-standing traditions of research on a few epistemic emotions, such as surprise and curiosity (Berlyne, 1954; Ekman, 1999), there are notable deficits in the study of these emotions. Empirical evidence for epistemic emotions other than surprise and curiosity, such as confusion, is scarce and inconclusive (e.g., D'Mello, Lehman, Pekrun, & Graesser, 2014). Furthermore, only a few studies (D'Mello & Graesser, 2012; Muis, Pekrun, et al., 2015; Muis, Psaradellis, Lajoie, Di Leo, & Chevrier, 2015) have considered several epistemic emotions simultaneously to explore their common antecedents and outcomes. Finally, research systematically comparing the origins and outcomes of epistemic emotions with the correlates of other emotions is lacking. For example, in addition to feeling surprised, curious, or confused, individuals whose knowledge is challenged may also feel ashamed when something they thought to know turns out to be incorrect, or proud if their knowledge is confirmed. As such, achievement emotions may also be prompted in situations with cognitive incongruity.

It is increasingly recognized that discrete emotions influence cognitive processes in different ways (Angie, Connelly, Waples, & Kligyte, 2011; Lench, Flores, & Bench, 2011). As such, more research is needed to disentangle the antecedents and outcomes of different emotions, including different emotions that have the same object focus (e.g., different epistemic emotions) and emotions that have different object foci (e.g., epistemic and achievement emotions). Gaining

deeper understanding of the circumstances under which different emotions are experienced and how these emotions influence important outcomes may reveal new opportunities for enhancing cognitive processes in various contexts that demand cognitive performance (e.g., school, university, and the work place).

In the present research, we sought to address these gaps in the literature by examining antecedents and interrelations of three prototypical epistemic emotions (surprise, curiosity, and confusion) and two achievement emotions (pride and shame). We also examined the influence of these emotions on knowledge exploration. We used a within-person analytic approach to attain a more precise understanding of functional relations between variables that is not afforded by traditional between-person designs (Molenaar, 2004). To examine the robustness of findings and their generalizability across different measures of exploratory behavior, we investigated these relations in three independent experimental studies.

Epistemic Emotions

The term *epistemic emotions* was originally coined by philosophers referring to affective states that can motivate critical reflection and inquiry (see Brun et al., 2008; Morton, 2010). In line with this notion, Pekrun and Stephens (2012) defined epistemic emotions as emotions that relate to knowledge and the generation of knowledge. These emotions result from the cognitive qualities of knowledge-related tasks and information processing. Specifically, epistemic emotions can be prompted by discrepant, contradictory information generating cognitive incongruity. Cognitive incongruity is produced when task information deviates from prior expectations or beliefs, or when task-related feedback indicates that one's beliefs are incorrect (high-confidence errors; Marshall & Brown, 2006). Other incongruity-inducing scenarios include impasses and obstacles to goal attainment that involve contradictory information (D'Mello & Graesser, 2012). Encountering contradictory information can interrupt the ongoing cognitive process, result in a

reallocation of attention to the unexpected information, and potentially lead to exploration and enhanced processing of this information.

The impact of contradictory information on cognitive processing and behavior may depend upon the emotions that are elicited. Tasks that produce cognitive incongruity can trigger a number of different epistemic emotions. These include surprise and curiosity; confusion when the cognitive incongruity is not resolved; anxiety when the incongruity is extreme and the information deeply disturbs existing beliefs; frustration when resolution of incongruity seems impossible; and enjoyment and delight when the incongruity is resolved (D'Mello & Graesser, 2012; Pekrun & Stephens, 2012; Scheffler, 1991; Silvia, 2013). Although curiosity and confusion are not part of traditional lists of emotions (e.g., Ekman, 1999), several studies indicate that these epistemic states qualify as emotions as defined by multicomponent approaches to emotion (Plutchik, 2001; Russell, 2003; Scherer, 2009), because they involve affective feelings, physiological arousal, specific motivational impulses, and specific facial expressions (Markey & Loewenstein, 2014; Reeve, 1993; Reeve & Nix, 1997; Rozin & Cohen, 2003). These emotions can motivate a broad range of activities with epistemic functions. These activities include epistemic cognition, "which refers to what individuals think knowledge is and how they think that they and others know" (Hofer & Bendixen, 2012, p. 227), as well as actual knowledge-seeking behavior.

In the present research, we focus on surprise, curiosity, and confusion as triggered by high-confidence errors, that is, unexpected feedback on trivia questions that were answered incorrectly although participants had been confident that their answers were correct (i.e., high confidence errors). We also investigated the effect of these emotions on participants' exploration of correct answers. In contrast to emotions such as frustration or delight, these three emotions are

epistemic in nature; they are associated with antecedents (e.g., cognitive incongruity) and outcomes (e.g., knowledge generation) that are particularly important to epistemic emotions.

Surprise is elicited by unexpected or schema-discrepant events (Berlyne, 1954, 1960; Meyer, Reisenzein, & Schützwohl, 1997; Noordewier & Breugelmans, 2013; Noordewier, Topolinski, & Van Dijk, 2016; Scherer, 2009; Stiensmeier-Pelster, Martini, & Reisenzein, 1995). Surprise has been found to fixate individuals' gaze (i.e., visual attention) on the unexpected event (Horstmann, & Herwig, 2015), promote recall of unexpected events (Parzuchowski & Szymkow-Sudziarska, 2008), elicit interest (Renninger & Hidi, 2016), and prompt curiosity (Berlyne, 1954, 1960; Loewenstein, 1994). Based on these findings, we expected surprise to be the initial emotional reaction to high-confidence errors, to trigger curiosity and confusion, and to promote subsequent exploration of knowledge.

Curiosity has been defined as a "drive to know" (Berlyne, 1954, p.187). Curiosity is aroused by unexpected information or events that reveal gaps in one's knowledge (Loewenstein, 1994). Epistemic curiosity is regarded as a means to support learning in educational contexts (von Stumm, Hell, & Chamorro-Premuzic, 2011) and has been found to promote the exploration of new knowledge (Berlyne, 1954, 1960; Litman et al., 2005) and to enhance memory for new information (Gruber, Gelman, & Ranganath, 2014; Kang et al., 2009; Marvin & Shohamy, 2016; Middlebrooks, McGillivray, Murayama, & Castel, 2016). Accordingly, in the present research, we expected curiosity to be triggered by high confidence errors. Furthermore, we expected this effect to be mediated by surprise, and curiosity to relate positively to subsequent knowledge exploration.

Confusion occurs when a person is confronted with novel and complex information that is not easily understood (Silvia, 2013), or when new information is incongruent with previous knowledge and the incongruity cannot be immediately resolved (Pekrun & Stephens, 2012).

Confusion can relate positively to task engagement (D'Mello & Graesser, 2012; Bosch & D'Mello, 2017), and learning outcomes (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello, Lehman, Pekrun, & Graesser, 2014), because impasses (and the associated state of confusion) require active engagement and effortful cognitive processing to be overcome (Brown & VanLehn, 1980; Mandler, 1990). For confusion to be productive, however, it is crucial that incongruity is ultimately resolved (D'Mello & Graesser, 2014; D'Mello et al., 2014). One possibility for resolving incongruity is the exploration of new knowledge (Berlyne,1954, 1960). In the present research, we expected that the effect of high-confidence errors on confusion is mediated by surprise, and that confusion relates positively to subsequent knowledge exploration.

Achievement Emotions

Achievement emotions relate to achievement activities and their success and failure outcomes (Pekrun, 2006). As such, achievement emotions differ from epistemic emotions in terms of their object focus (Brun et al., 2008). As noted, knowledge and the generation of knowledge are the objects of epistemic emotions; in achievement emotions, success and failure are the objects. Some emotions can be either epistemic or achievement-related, depending on the object focus of attention. For example, frustration resulting from an unsolvable problem would be considered epistemic, whereas frustration resulting from personal failure would be considered an achievement emotion (Pekrun, Vogl, Muis, & Sinatra, 2017). In the present research, we considered two prototypical emotions related to success and failure, namely pride and shame. Although situations involving cognitive incongruity are thought to trigger epistemic emotions, they can also induce achievement emotions if they are interpreted in terms of personal success or failure (e.g., being proud if one's knowledge is confirmed, which can be interpreted as success, or feeling ashamed when knowledge turns out to be incorrect, which can be interpreted as failure).

Achievement-related pride is triggered by a specific event (e.g., mastering a skill, getting a good grade; Tangney, 1999; Tracy & Robins, 2004, 2007) and prompted by success that is attributed to internal causes, such as one's own ability or effort (Pekrun, 2006; Weiner, 1985, 2010). Pride in one's success promotes achievement because it is related to task orientation which enhances motivation (Oades-Sese, Matthews, & Lewis, 2014). Experimental studies have shown that pride can lead to greater perseverance even on effortful and unpleasant tasks related to the initial source of pride (Williams & DeSteno, 2008). Similarly, in educational settings, students' pride has been found to promote their interest in the topic, intrinsic and extrinsic motivation, effort, and academic achievement in the subject (e.g., Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017). As such, the experience of pride after success promotes motivation to engage and persevere in ongoing and related tasks and materials. Given that pride is a rewarding experience, the function of such engagement likely is to again be successful and experience pride. In general, feeling proud about a recognized accomplishment is an incentive to pursue further action in the valued domain (e.g., Carver & Johnson, 2010; Williams & DeSteno, 2008). In the present research, we expected pride to result from correctly answering the trivia questions, irrespective of prior confidence. Furthermore, due to its positive effects on motivation we expected pride after correct answers to relate positively to subsequent knowledge exploration.

S*hame* is another self-conscious emotions (Lewis, Sullivan, Stanger, & Weiss, 1989). In achievement contexts, it is triggered by failure that is attributed to internal causes (e.g., lack of ability; Pekrun, 2006; Weiner, 1985, 2010). It is a complex emotion that has been associated with approach (to regain the positive image that one has lost) and avoidance tendencies (to avoid further losses if the positive image cannot be regained; De Hooge, Zeeenberg, and Breugelmans, 2010). In line with this findings, shame can reduce intrinsic motivation, but also strengthen extrinsic motivation to invest effort to avoid failure if a person is confident about their ability

(Turner & Schallert, 2001). As such, we expected shame to occur after incorrect answers, irrespective of prior confidence or level of cognitive incongruity involved, that is, both when participants were confident in their answers (high-confidence errors) and when they were not confident in their answers (low-confidence errors). Due to variable effects of shame on motivation, we did not formulate a directional hypothesis concerning the relationship of shame and knowledge exploration.

Within- versus Between-Person Approaches to Investigate Emotions

Numerous emotion theories proffer explanations about the antecedents and effects of emotions, and many studies have been carried out to test these theories (for an overview see Barrett, Lewis, & Haviland-Jones, 2016). A disparity exists, however, between emotion theory and related research: Emotion theories targeting antecedents and effects generally refer to within-person psychological functioning, while empirical research focused largely on between-person designs (see, e.g., Murayama et al., in press; Voelkle, Brose, Schmiedek, & Lindenberger, 2014). This is problematic because "[t]hese two correlations [i.e., within-person vs. between-person correlations] are statistically independent, and their direction and magnitude can vary widely" (Schmitz and Skinner, 1993, p. 1010; Voelkle et al., 2014).

We argue that within-person approaches are vital for examining the psychological mechanisms underlying epistemic and achievement emotions (see also Fastrich, Kerr, Castel, & Murayama, 2018; Tanaka & Murayama, 2014). For example, we hypothesize that high-confidence errors prompt curiosity, which implies a *positive* relation between these errors and curiosity. While this prediction seems plausible, previous studies based on between-person designs have shown that people who make fewer errors (i.e., high achievers) are more curious (von Stumm et al., 2011), suggesting a *negative* relationship between errors and curiosity. This discrepancy occurs because between-person studies focus on individual differences, ignoring the

variation of curiosity, its antecedents, and its effects within persons. Thus, to adequately investigate how epistemic emotions arise and function, it is imperative to use a within-person approach to examine the relations between variables.

Aims and Hypotheses of the Present Research

In three studies we examined the antecedents, interrelations, and effects of multiple epistemic emotions (surprise, curiosity, and confusion) and achievement emotions (pride and shame, in Studies 2 and 3). The primary focus of our research was on epistemic emotions. As such, we decided to implement a low-stakes experimental setting by introducing the task as a trivia task and refraining from explicitly emphasizing performance outcomes (i.e., success and failure). A high-stakes experimental setting may have been more suited to amplify achievement emotions, but may have reduced the occurrence of epistemic emotions. However, pride and shame may also occur in low-stakes contexts (even if with lower intensity), for example, due to individual propensities to generally value achievement outcomes.

To elicit the target emotions, all three studies provided feedback on participants' responses to trivia questions. We expected the antecedents of epistemic and achievement emotions to differ. Specifically, we expected epistemic emotions to be elicited by high-confidence errors. To prompt high-confidence errors, we included trivia items that explicitly addressed common errors in general knowledge. In contrast, we expected achievement emotions to be elicited by correctly (success) or incorrectly (failure) answering trivia questions, irrespective of the confidence participants had in their answers. Furthermore, we expected all three epistemic emotions to promote knowledge exploration. Specifically, we expected the effects of surprise on exploration to be mediated by curiosity and confusion. We did not expect a direct effect of surprise on exploration (i.e., an effect not mediated by curiosity or confusion). To our knowledge, there is no theory or empirical evidence that would support such a direct effect.

Rather, there is theoretical support for our hypothesized link between surprise and curiosity (Berlyne, 1954, 1960; Loewenstein, 1994), and for surprise and confusion (e.g., D'Mello & Graesser, 2012). Curiosity and confusion, in turn, have been linked to knowledge exploration in previous work (e.g., Berlyne, 1954, 1960; Litman, Hutchings & Russon, 2005). As for the achievement emotions considered, we expected pride experienced after correct responses to also promote exploration. With regard to the relation between shame and knowledge exploration, no specific hypotheses were formulated. The focal hypotheses tested were as follows (see Figure 1):

Hypothesis 1: Antecedents of epistemic emotions. High-confidence errors positively predict surprise, curiosity, and confusion (Figure 1, paths a-c).

Hypothesis 2: Outcomes of epistemic emotions. Surprise positively predicts curiosity and confusion (Figure 1, paths b and c), and curiosity and confusion positively predict exploration (paths d and e). As such, curiosity and confusion are mediators in the surprise-exploration relation (paths b + d and c + e, respectively). We did not expect a direct effect of surprise on exploration.

Hypothesis 3: Epistemic emotions as mediators in the effects of high-confidence errors on exploration. High-confidence errors positively predict knowledge exploration. Epistemic emotions are mediators in the error-exploration relation (Figure 1, paths a + b + d and a + c + e, respectively).

Hypothesis 4: Antecedents of achievement emotions. Correct answers (success) positively predict pride, and incorrect answers (failure) positively predict shame (Figure 1, paths f and g).

Hypothesis 5: Outcomes of achievement emotions. Pride positively predicts knowledge exploration; we leave as an exploratory question whether the relationship between shame and knowledge exploration is positive or negative (Figure 1, paths h and i).

Study 1

Study 1 focused on epistemic emotions. More specifically, this study examined high-confidence errors as an antecedent of surprise, curiosity, and confusion, and subsequent motivation to explore the correct answer as an outcome of these emotions.

Method

Participants. One hundred-two participants (67 females) from a German university completed the study online (age range 19 to 30 years, $M = 23.33$, $SD = 2.55$). Participants were recruited and sent a link to the online questionnaire via the university's mailing list and a university-related Facebook page. Participants were informed that the study would take approximately 12 to 14 minutes and, as an incentive, they were told that after completing the study they would be entered into a lottery to win one of two 20 Euro gift cards for a well-known internet shopping company.

Materials. The trivia task used consisted of 20 single-sentence statements compiled from various sources that tap into general knowledge in several domains (Ebert & Klotzek, 2008, 2010; Nelson & Narens, 1980; Pöppelmann, 2009). To ensure sufficient within-person variance, we selected statements that varied in the degree to which they produced high-confidence errors. Specifically, we included statements that are likely to produce high-confidence errors because they target widespread errors in general knowledge (e.g., "Chameleons match their color to their environment") as well as statements about well-known facts that were not expected to particularly induce high-confidence errors (e.g., "Jupiter is the largest planet of our solar system"; see Supplemental Materials available online for a list of all items, Table S2). One particular advantage of this trivia task is that high-confidence errors - and thus epistemic emotions - can be elicited repeatedly by choosing trivia items from different domains (Reisenzein, 2000).

Procedure and measures. Participants were presented with the 20 trivia statements and instructed to indicate whether the statement was correct or incorrect. After making their decision, participants were asked to indicate how confident they felt about their answer using a 6-point Likert scale (1 = *very uncertain* to 6 = *very certain*). Participants immediately received feedback about the accuracy of their reply (*Your answer is correct"* vs. *"Your answer is incorrect"*). Next, participants were asked to rate how they felt at that very moment. Using short one-item scales of the Epistemic Emotions Scales (Pekrun et al., 2017), participants rated how surprised, curious, and confused they were on a 5-point Likert scale (1 = *not at all* to 5 = *very strong*). After completion of the trivia question trials, participants were presented with a list of those statements they had answered incorrectly. Finally, to measure participants' motivation to explore the correct answers for these statements, they were asked to indicate on a 5-point Likert scale their motivation to explore the correct answer for each of the answers that had been incorrect ("How strong is your desire to receive an explanation for your incorrect answer?"; 1 = *very weak* to 5 = *very strong*). As participants were not provided with information about the correct answers, this measure specifically tapped into motivation to explore rather than actual exploratory behavior. The study has received approval from the research ethics committee of the first author's institution.

Data analysis. The data have a two-level hierarchical structure with trivia statements (Level 1) nested within individuals (Level 2). We used multilevel modeling with Mplus 8 to model within- and between-person relations in these nested data (Muthén & Muthén, 2017). Accuracy (0 = *incorrect*; 1 = *correct*), confidence, and their interaction term were modeled as predictors of emotions at Level 1. Accuracy and confidence were standardized before creating the interaction term. Subsequently, following recommendations for within- and between-person multilevel modeling, the predictors were centered within each individual to avoid confounding

within- and between-person effects (see Enders & Tofighi, 2007; Wang & Maxwell, 2015). The intercepts of the predictors were allowed to vary across individuals (Level 2). To control for possible order- and time-dependent effects, we controlled for trial order by including order as a covariate at Level 1 (Wang & Maxwell, 2015). Our sample included more than 100 participants on L2 with 20 trials on L1. This sample size is in line with Arend and Schäfer's (2018) recommendations for two-level models to ensure sufficient power ($\geq .80$) for detecting small, medium, and large L1 effects (i.e., effects larger than .10, .30, and .50, respectively; see Arend & Schäfer, 2018, Table 5). All data can be downloaded from https://osf.io/vw2cn/.

We estimated two multilevel models to test our directional hypotheses. In Model 1, we explored response accuracy, response confidence, and the accuracy x confidence interaction as antecedents of the emotions to test our hypothesis that high-confidence errors induce epistemic emotions (Hypothesis 1). If high-confidence errors prompt epistemic emotions, the accuracy x confidence interaction should predict these emotions. The model included within-person paths from all three predictors to the three emotions and additionally included the covariances among the predictors and among the residuals of the emotions. Because we aimed to test our hypotheses at Level 1, Level-2 relations between variables were simply estimated as covariances. The model was saturated.

In Model 2, we examined the simple effects of confidence in incorrect answers, thus decomposing the accuracy x interaction term to better understand its effects. This also made it possible to reduce the number of parameters to be estimated. In addition to confidence and emotions, the model included participants' motivation to explore (which had been assessed for incorrect answers only). As such, this model more fully tested the proposed sequence of confidence in incorrect answers, epistemic emotions, and exploration. The emotions were organized sequentially, with surprise predicting curiosity and confusion, which jointly predict

motivation to explore (Hypotheses 2 and 3; see Figure 2). Indirect effects of confidence on exploration as mediated by the emotions were tested using 95% bootstrap confidence intervals. Again, the Level 2 relations between variables were estimated as covariances. In supplemental analyses, we evaluated alternative models testing other sequential orders of the emotions (see Supplemental Materials).

To evaluate the fit of Model 2, we used the comparative fit index (CFI), the Tucker-Lewis index (TLI), the root-mean-square-error of approximation (RMSEA), and the standardized-root-mean residual (SRMR). For CFI and TLI, values greater or equal to .95 for CFI are traditionally interpreted as indicating good fit and values between .90 and .95 as indicating moderate fit (Hu & Bentler, 1999). For RMSEA and SRMR, as recommended by Hu and Bentler (1999), we interpreted values smaller or equal to .06 as indicating good fit and values between .06 and .08 as indicating moderate fit. While these recommended cut-off values provide information for gauging model fit, it is important to bear in mind that one should interpret general cut-off values carefully (Marsh, Hau, & Wen, 2004).

Results

Preliminary analysis. Although there was variation at the between-person level for all emotions (ICCs ranged from .16 to .29), the major part of the variance was at the within-person level, as indicated by the intra-class correlations (ICCs; Table 1). Table 1 also shows the descriptive statistics at the between-person level as well as the between- and within-person correlations for the study variables. At the within-person level, all correlations between confidence and epistemic emotions as well as motivation to explore were significant. Correlations between the observed variables were mostly positive at both levels, with the exception of a negative within-person correlation between participants' confidence in their answers and their curiosity.

Antecedents of epistemic emotions (Model 1). Table 2 displays the within-person path coefficients for accuracy, confidence and the accuracy x confidence interaction as predictors of epistemic emotions. Accuracy negatively predicted all three emotions, suggesting that the emotions were generated by errors (i.e., incorrect answers). Furthermore, supporting Hypothesis 1, the accuracy x confidence interaction was a strong negative predictor of all three emotions indicating that high-confidence errors elicited epistemic emotions (i.e., there were positive effects of confidence in incorrect answers on these emotions).

Effects and interrelations of epistemic emotions (Model 2). Table 4 displays the path coefficients for Model 2. The model (see Figure 2) showed a good fit to the data $\chi^2(1) = 3.832$, $p = .050$; CFI = .997; TLI = .935; RMSEA = .055; $SRMR_{within} = .010$. As expected, high-confidence errors positively predicted surprise, and surprise, in turn, positively predicted curiosity and confusion. In addition, high-confidence errors had a significant direct positive effect on confusion, whereas the direct effect on curiosity was not significant.

Supporting Hypothesis 2, curiosity and confusion were positive predictors of motivation to explore. In line with the surprise-exploration relation hypothesis, surprise had a positive indirect effect on motivation mediated by curiosity, and a positive indirect effect on motivation mediated by confusion. In line with the error-exploration relation hypothesis (Hypothesis 3), confidence in incorrect answers positively predicted motivation. Specifically, confidence had both a direct effect on motivation as well as indirect effects mediated by surprise and curiosity and by surprise and confusion.

Discussion

Study 1 examined cognitive incongruity as an antecedent of epistemic emotions and motivation for exploratory behavior as one type of knowledge-generating activity resulting from these emotions. In preliminary correlational analyses, there were differences in the within- versus

between-person relations of emotions with response accuracy, confidence, and knowledge exploration. Clearly, the within-person correlations were more consistent and fully in line with the hypotheses. This highlights the importance of using a within-person approach to investigate these linkages. The results of multilevel modeling indicate that high-confidence errors serve as antecedents of surprise, curiosity, and confusion within persons (e.g., Pekrun & Stephens, 2012; D'Mello & Graesser, 2012). The results further suggest that surprise mediates the effects of high-confidence errors on curiosity and confusion (see also D'Mello & Graesser, 2012; Loewenstein, 1994; Scherer, 2009). Furthermore, as hypothesized, the analyses indicate that both curiosity and confusion can have positive effects on motivation to explore knowledge. High-confidence errors increased the motivation to explore, and this relationship was mediated by epistemic emotions. In sum, our findings were in line with the hypotheses and suggest that cognitively incongruous task information can trigger surprise, which in turn can trigger curiosity and confusion, both of which contribute to the motivation to explore new information.

Study 2

Study 1 included motivation to explore but not actual exploratory behavior as an outcome variable. Furthermore, Study 1 only investigated epistemic emotions. To gain a better understanding of epistemic emotions, it is important to compare their antecedents and outcomes to those of other emotions that may or may not be experienced in the same setting. Therefore, Study 2 aimed to replicate the findings of Study 1 and to extend them by including a measure of actual behavior as well as two achievement emotions, namely pride and shame.

Method

Participants. Three hundred-seventy-three participants (245 females) from a German university completed this study online (age range 18 to 30 years, M = 22.20, SD =2.75). Participants were recruited and sent a link to the online questionnaire via the university's mailing

list and a university-related Facebook page. Participants were informed that the study would take approximately 12 to 14 minutes. As an incentive, they were told that after completing the study they would be entered into a lottery to win one of two 20 Euro gift cards for a well-known internet shopping company.

Materials, procedure, and measures. Study 2 used the same task materials, procedure, and measures of confidence and emotions as Study 1. The trivia statements were presented in a randomized order. Two amendments were made to the design. First, after receiving feedback, participants additionally rated the extent to which they felt proud and ashamed (1 = *not at all* to 5 = *very strong*). Second, instead of asking for participants' motivation to explore after all the trivia question trials, participants were given the opportunity to actually request and read an explanation why their answer was incorrect directly each time after they received negative feedback (*"Would you like to know why your answer was incorrect?"* [0 = *No vs.* 1 = *Yes*]). If requested, the explanation was displayed. We ensured that participants had not participated in Study 1 by asking them if they had participated in a similar study before. Twenty-six individuals reported having done so and were thus excluded from the present study. The study has received approval from the research ethics committee of the first author's institution.

Data analysis. As in Study 1, the data were analyzed using multilevel modeling with trivia statements (Level 1) nested within individuals (Level 2). We used the same method of analysis as in Study 1. Pride and shame were added in Model 2. We included the effects of confidence on pride and shame, and the effects of these emotions on exploratory behavior. Our sample included more than 100 participants on L2 with 20 trials on L1. This sample size is in line with Arend and Schäfer's (2018) recommendations for two-level models to ensure sufficient power ($\geq .80$) for detecting small, medium, and large L1 effects (i.e., effects larger than .10, .30,

and .50, respectively; see Arend & Schäfer, 2018, Table 5). All data can be downloaded from https://osf.io/vw2cn/.

Results

Preliminary findings. Replicating the findings from Study 1, there was variation at the between-person level for all emotions (ICCs ranged from .13 to .31), but the major part of the variance was located at the within-person level. Table 1 shows descriptive statistics at the between-person level as well as between-person and within-person correlations. The findings indicate that there was sufficient score variation for all study variables, although there was some restriction of variance for the exploration scores due to ceiling effects (participants requested information about the correct answer in most cases). Correlations between the observed variables were mostly in line with the findings of Study 1.

Antecedents of epistemic and achievement emotions (Model 1). Table 2 and Table 3 display the standardized within-person path coefficients for accuracy, confidence, and the accuracy x confidence interaction as predictors of the epistemic and achievement emotions, respectively. As in Study 1, the model was saturated. Replicating the findings of Study 1, accuracy negatively predicted all three epistemic emotions. Furthermore, as in Study 1, the accuracy x confidence interaction negatively predicted all three emotions showing that high-confidence errors elicited epistemic emotions (i.e., there were positive effects of confidence in incorrect answers on these emotions).Supporting Hypothesis 1, this finding indicates that high-confidence errors elicited epistemic emotions.

Furthermore, in line with Hypothesis 4, accuracy positively predicted pride and negatively predicted shame. In addition, the accuracy x confidence interaction term positively predicted pride and negatively predicted shame, indicating that pride was more intensely experienced in

case of correct answers the participants were confident in, and shame was more intensely experienced in case of incorrect answers the participants were confident in.

Effects and interrelations of epistemic and achievement emotions (Model 2). Table 4 displays the path coefficients for Model 2. The model (see Figure 2) showed a good fit to the data, $\chi^2(1) = 2.777$, $p = .095$; CFI = 1.000; TLI = .980; RMSEA = .024; $SRMR_{within} = .003$. In line with Hypothesis 1, high-confidence errors positively predicted surprise. Surprise, in turn, positively predicted curiosity and confusion. High-confidence errors were not a direct predictor of curiosity, supporting mediation of the effects on curiosity by surprise. Pride was unrelated to high-confidence errors, likely due to a floor effect in pride after incorrect answers ($M = 1.06$; $SD = 0.20$). However, shame was positively predicted by high-confidence errors.

Replicating the Study 1 findings and supporting Hypothesis 2, curiosity positively predicted exploration. Confusion, however, did not significantly predict exploration. In line with the surprise-exploration relation hypothesis, surprise had a positive indirect effect on exploration mediated by curiosity. The indirect effect of surprise on exploration mediated by confusion was not significant. In contrast to surprise and curiosity, neither pride nor shame predicted exploratory behavior.

Furthermore, in line with the error-exploration relation hypothesis (Hypothesis 3), high-confidence errors had a positive predictive effect on exploration that was mediated by surprise and curiosity. The indirect effect of high-confidence errors on exploration mediated by surprise and confusion was not significant. Supporting the mediating role of surprise and curiosity, the direct effect of high-confidence errors on exploration was not significant.

Discussion

Study 2 aimed to replicate the findings of Study 1 and to extend them by exploring the differences in the antecedents and effects of epistemic versus achievement emotions and by

including actual exploratory behavior as an outcome variable. In support of Hypothesis 1 and replicating Study 1, high-confidence errors served as antecedents of surprise, curiosity and confusion. As for achievement emotions, accuracy promoted pride and inaccuracy promoted shame, in line with Hypothesis 4 and the control-value theory of achievement emotions (Pekrun, 2006). Furthermore, the intensity with which participants experienced pride and shame was also dependent on participants' confidence in their answers: High-confidence errors induced more shame than low-confidence errors, and high-confidence correct answers induced more pride than low-confidence correct answers. However, the findings suggest that the accuracy x confidence interaction more strongly influenced epistemic emotions than achievement emotions (β range -.257 to -.423 for the epistemic emotions in Table 2, and .127 and -.158 for pride and shame in Table 3, respectively).

In line with Hypothesis 3, surprise positively predicted actual exploratory behavior via curiosity. Confusion also had a positive predictive effect on exploration; however, in contrast to Study 1, this effect was not significant due to its small magnitude. One possible explanation for small effect size could be variable effects of confusion. For instance, confusion may lead to increased motivation if a person has positive expectancies to resolve cognitive incongruity but reduced motivation if these expectancies are low (D'Mello et al., 2014; Pekrun & Stephens, 2012). With small effect sizes, coefficients can be non-significant by chance (i.e., due to sampling error). In addition, our results highlight the proposed mediating role of surprise and curiosity in the relationship between high-confidence errors and exploration (Berlyne, 1960; Litman et al., 2005; Loewenstein, 1994).

As for achievement emotions, neither pride nor shame was significantly related to exploration. For pride, one likely reason is that exploration was only offered after *incorrect* answers. It seems plausible that pride does not occur after incorrect answers, implying that it

cannot contribute to explaining subsequent behavior. This explanation is supported by the present data, which showed a floor effect for pride ratings after incorrect answers. The result for shame may indicate that this negative but activating emotion need not have detrimental effects on knowledge generation. This is in line with findings suggesting that shame, in contrast to negative deactivating emotions like boredom (Pekrun, Hall, Goetz, & Perry, 2014; Pekrun et al., 2017; Tze, Daniels, & Klassen, 2015), has variable effects and may not reduce motivation and performance under all circumstances (e.g., Turner & Schallert, 2001).

Study 3

Study 3 aimed to replicate the findings of Study 1 and 2 and to further expand on them in two important ways. First, we included a more extensive measure of exploratory behavior comprising multiple opportunities to request information. Second, we examined exploratory behavior using this measure not only after incorrect answers but also after correct answers to obtain a more complete picture of the relations between performance feedback, emotions, and subsequent exploration. This makes it possible to compare the relations between all of the study variables across instances of correct and incorrect answers.

Method

Participants. One hundred twenty-five participants (90 females) from a German university completed this study online (age range 18 to 30 years, $M = 22.69$, $SD = 2.70$). Participants were recruited and sent a link to the online questionnaire via the university's mailing list and a university-related Facebook page. Participants were informed that the study would take approximately 30 minutes. As an incentive, they were told that after completing the study they would be entered into a lottery to win one of two 20 Euro gift cards for a well-known internet shopping company.

Materials, procedure, and measures. Study 3 used the same materials, procedure, and measures as Study 2. However, participants were provided with the opportunity to request and read an explanation after both correct and incorrect answers (*"Would you like to see the explanation now?"* [*No vs. Yes*]). If requested, the explanation was displayed. In addition to this explanation, participants were able to request up to two more pieces of information for each statement. After the explanation had been displayed, they were asked if they wanted more information (*"Would you like to receive more information concerning this topic?"* [*No vs. Yes*]). An additional piece of information was displayed if the answer was yes. Subsequently, using the same question they were asked one more time if they would like to receive more information. The initial explanations as well as the additional two pieces of information consisted of 16 words each. Based on this design, exploration was defined as the number of participants' requests for information [*0* to *3* for each question]. We ensured that participants had not participated in Study 1 or 2 by asking them if they had participated in a similar study before. Three individuals reported having done so and were thus excluded from the present study. The study has received approval from the research ethics committee of the first author's institution.

Data analysis. As in Studies 1 and 2, the data were analyzed using multilevel modeling with trivia statements (Level 1) nested within individuals (Level 2). We used the same method of analysis as in Study 2. Model 2 assessing simple effects of confidence on emotions and behavior was estimated separately for confidence in incorrect answers (high-confidence errors; Model 2a) and confidence in correct answers (Model 2b). Our sample included more than 100 participants on L2 with 20 trials on L1. This sample size is in line with Arend and Schäfer's (2018) recommendations for two-level models to ensure sufficient power (≥ .80) for detecting small, medium, and large L1 effects (i.e., effects larger than .10, .30, and .50, respectively; see Arend & Schäfer, 2018, Table 5). All data can be downloaded from https://osf.io/vw2cn/.

Results

Preliminary findings. Replicating the findings from Studies 1 and 2, variation of the emotion scores at the within-person level outweighed variation at the between-person level (ICCs ranged from .02 to .56). Table 1 shows descriptive statistics at the between-person level as well as the between-person and within-person correlations. The findings indicate that there was sufficient score variation for all study variables. Correlations between the observed variables were largely in line with the findings of Studies 1 and 2.

Antecedents of epistemic and achievement emotions (Model 1). Table 2 and Table 3 display the standardized within-person path coefficients for accuracy, confidence, and the accuracy x confidence interaction as predictors of the epistemic and achievement emotions, respectively. As in Studies 1 and 2, the model was saturated. Replicating the Study 1 and 2 findings, accuracy negatively predicted all three epistemic emotions. Furthermore, as in Studies 1 and 2, and supporting Hypothesis 1, the accuracy x confidence interaction was a negative predictor of all three emotions, again confirming that high-confidence errors elicited epistemic emotions (i.e., there were positive effects of confidence in incorrect answers on these emotions).

Furthermore, in line with Hypothesis 4 and the findings of Study 2, accuracy again positively predicted pride and negatively predicted shame. In addition, the accuracy x confidence interaction term positively predicted pride and negatively predicted shame, indicating that pride was more intensely experienced in case of correct answers the participants were very confident in, and shame was more intensely experienced in case of incorrect answers the participants were very confident in.

Effects and interrelations of epistemic and achievement emotions (Model 2). Table 5 displays the path coefficients for Model 2. Both Models 2a and 2b showed a good fit to the data (Model 2a, confidence in incorrect answers: $\chi^2(1) = .951$, $p = .329$; CFI = 1.00; TLI = 1.00;

RMSEA = .000; $SRMR_{within}$ = .003; Model 2b, confidence in correct answers: $\chi^2(1) = .568$, p = .451; CFI = .1.00; TLI = 1.01; RMSEA = .000; $SRMR_{within}$ = .003: Figure 3). In line with Hypothesis 1 and replicating the Study 1 and 2 findings, high-confidence errors positively predicted surprise. In contrast, confidence in correct answers negatively predicted surprise. Surprise, in turn, positively predicted curiosity and confusion in both models. Pride was unrelated to high-confidence errors, likely due to floor effects in the ratings for pride after incorrect answers (M = 1.03, SD = .09). However, pride was positively predicted by confidence in correct answers. Conversely, shame was positively predicted by high-confidence errors but not significantly predicted by confidence in correct answers, likely due to floor effects in the ratings for shame after correct answers (M = 1.05, SD = .11).

Supporting Hypothesis 2 and in line with Studies 1 and 2, curiosity positively predicted exploration, both after incorrect and correct answers. In addition, confusion positively predicted exploration; this effect was significant after incorrect answers but was weak and not significant after correct answers, likely due to floor effects in confusion after correct answers (M = 1.15, SD = .62). Surprise also was a positive predictor of exploration. Specifically, following incorrect answers, surprise had positive indirect effects on exploration that were mediated by curiosity and confusion, supporting the surprise-exploration relation hypothesis. Following correct answers, surprise had a positive indirect effect on exploration mediated by curiosity; the indirect effect mediated by confusion was not significant. Supporting Hypothesis 5, pride positively predicted exploration after correct answers. Shame did not significantly predict exploration.

In line with the error-exploration relation hypothesis (Hypothesis 3), high-confidence errors positively predicted exploratory behavior. Specifically, there were indirect effects of confidence in incorrect answers on exploration that were mediated by surprise and curiosity and by surprise and confusion. Further supporting mediation, the direct effect of confidence in

incorrect answers on exploration was not significant. In contrast, confidence in correct answers negatively predicted exploration. There was a direct negative effect of confidence in correct answers, an indirect negative effect mediated by surprise, and a non-significant indirect negative effect mediated by confusion.

Discussion

Study 3 aimed to replicate the findings of Studies 1 and 2 and to expand on them by using a more extensive measure of exploratory behavior. In addition, exploratory behavior was assessed both after incorrectly *and* correctly answered items. In line with Studies 1 and 2, high-confidence errors positively predicted surprise, curiosity and confusion. As expected, the achievement emotions pride and shame were triggered by positive and negative feedback, respectively (Pekrun, 2006). In addition, pride and shame again depended on participants' confidence in their answers: High-confidence in incorrect answers induced more shame than errors accompanied by low-confidence; conversely, high-confidence in correct answers induced more pride than correct answers accompanied by low-confidence. However, as in Studies 1 and 2, the accuracy x confidence interaction influenced epistemic emotions more strongly than achievement emotions (β range -.349 to -.520 for the epistemic emotions in Table 2, and .130 and -.166 for pride and shame in Table 3, respectively).

As expected, surprise and curiosity positively predicted actual exploratory behavior, both after incorrect and correct answers. Curiosity was a mediator in the effects of surprise. However, the positive effect of confusion on exploration that we found in Study 1 was only partly replicated in Study 3. Confusion promoted exploratory behavior after incorrect answers, but not after correctly answered items. This result is not surprising since confusion is not likely to occur after successful task performance, as documented in the floor effects for the confusion ratings after correct answers. Furthermore, replicating the Study 1 and 2 findings, high-confidence errors

positively predicted exploration. As expected, epistemic emotions were mediators in the effects of errors on exploration. In contrast, confidence in correct answers negatively predicted exploration, suggesting that motivation to explore is undermined when prior beliefs in the accuracy of one's answer are confirmed.

In line with our hypotheses, pride after correct answers positively predicted further exploration. In contrast, replicating the Study 2 findings, incorrect answers did not result in pride, which explains why pride did not contribute to explaining exploration after incorrect answers. Finally, as in Study 2, shame was not significantly related to exploration, supporting the assumption that shame can have variable effects and need not be detrimental for exploration and knowledge generation.

General Discussion

The present research aimed to examine antecedents and functions of epistemic emotions. Our research questions and hypotheses were grounded in theoretical considerations on epistemic emotions (e.g., Pekrun & Stephens, 2012; Loewenstein, 1994; Berlyne, 1960; D'Mello & Graesser, 2012) and achievement emotions (Pekrun, 2006; Pekrun & Perry, 2014; Weiner, 1985, 2010). Specifically, in three independent experimental studies, we used within-person analysis to investigate cognitive incongruity prompted by high-confidence errors during a trivia task as an antecedent of multiple epistemic emotions, namely surprise, curiosity and confusion. Exploration of knowledge was assessed as an outcome of these three emotions. In addition, we compared the epistemic emotions with two achievement emotions, pride and shame, in terms of their antecedents and functions for exploration. Apart from the relation between confusion and exploration, the findings were remarkably consistent across all three studies and fully supported our hypotheses.

Antecedents of Epistemic Emotions

As expected, the results point to distinct patterns of antecedents for epistemic and achievement emotions: The trivia task with immediate achievement feedback induced both epistemic and achievement emotions but under different circumstances. Specifically, as expected, pride was predicted by correct answers (i.e., success), and shame was predicted by incorrect answers (i.e., failure; e.g., Pekrun et al., 2017). The effects of correct versus incorrect answers on pride and shame were quite substantial (range of standardized path coefficients -.352 - .662; Table 3) and fully consistent across Studies 2 and 3 which had assessed these emotions. Similar to shame, the epistemic emotions surprise, curiosity, and confusion were also triggered by inaccuracy. However, supporting our hypotheses, the effects of inaccuracy on these emotions were specified by an interaction with prior confidence in the accuracy of the answer. Surprise, curiosity, and confusion were induced by high-confidence errors; the intensity of these emotions depended on participants' confidence in the answers that turned out to be incorrect, implying incongruity between prior beliefs and the correct answer. The link between high-confidence errors and epistemic emotions was also quite substantial (range of standardized path coefficients for the effects of the accuracy x confidence interaction -.239 to -.520, Table 2), and it was fully robust across all three studies and all three epistemic emotions.

Furthermore, the effects of the accuracy x confidence interaction observed across Studies 2 and 3 indicate that confidence in correct answers was positively linked to pride, and confidence in incorrect answers was positively linked to shame. Importantly, however, these relationships were relatively weak, and notably weaker than those observed for surprise, curiosity, and confusion, suggesting that confidence in one's knowledge is less relevant for the arousal of achievement emotions as compared with epistemic emotions.

Taken together, these findings elucidate potential causes of epistemic emotions and suggest that metacognitive processes play an important role in their occurrence. The results

highlight that cognitive incongruity functions as an antecedent of epistemic emotions that is both common to the three epistemic emotions investigated, and more important to these emotions than to achievement emotions. As such, the findings support propositions that cognitive incongruity is a prime driver of epistemic emotions (Berlyne, 1960; D'Mello & Graesser, 2012; Loewenstein, 1994; Pekrun & Stephens, 2012; Silvia, 2013). More specifically, they highlight the critical role of judgments of confidence in the accuracy of one's knowledge for the experience of surprise, curiosity, and confusion.

With regard to surprise, our results are congruent with empirical evidence on the hypercorrection effect, that is, the phenomenon that individuals are more likely to attempt to rectify high-confidence errors as compared with low-confidence errors (Butterfield & Metcalfe, 2001). The present studies support Metcalfe, Butterfield, Habeck, and Stern's (2012) observation that error correction is in fact not a "cool" (i.e., unemotional) cognitive process as originally proposed by Metcalfe and Mischel (1999). Neurophysiological studies relating the hypercorrection effect to brain regions such as the medial frontal gyrus, which is also involved in the conscious monitoring of emotional states (Phan, Wager, Taylor, & Liberzon, 2002), further support the proposed link between metacognition and epistemic emotions.

The result further shed light on the dynamic interplay of multiple epistemic emotions suggesting that surprise may precede curiosity (Loewenstein, 1994) and confusion (D'Mello & Graesser, 2012). However, in the present research, the data on the temporal ordering of surprise, curiosity, and confusion are correlational; as such, the approach pursued herein needs to be complemented with experimental studies. Similarly, future research will need to examine how curiosity can be fostered without simultaneously promoting confusion. To this end, it may be useful to consider additional antecedents of epistemic emotions such as task-related expectancies of success (Muis, Psaradellis, et al., 2015; Pekrun & Perry, 2014), distal antecedents such as

epistemic beliefs (Muis, Chevrier, & Singh, 2018; Muis, Pekrun, et al., 2015; Trevors, Muis, Pekrun, Sinatra & Muijselaar, 2017), or personality traits that influence how individuals react to unexpected information (e.g., need for structure or openness to experience; Gocłowska, Baas, Crisp, & De Dreu, 2014; Gocłowska, Baas, Elliot, & De Dreu, 2017).

Outcomes of Epistemic Emotions

Our findings further corroborate prior research suggesting positive effects of curiosity on knowledge-generating behavior (e.g., Litman et al., 2005). Specifically, the data demonstrate that both surprise and curiosity related positively to subsequent motivation to explore (Study 1) as well as actual exploratory behavior (Studies 2 and 3). These links were fully robust across all three studies and across correctly as well as incorrectly answered trivia questions. The findings further suggest that cognitive incongruity promotes exploration, and that surprise and curiosity are mediators in this relationship.

For confusion, the findings were somewhat less consistent. Confusion did not relate to exploration after correct answers, which is well explained by floor effects in the occurrence of this emotion after correct answers. Confusion after incorrect answers positively predicted exploration, in line with prior evidence indicating that confusion can promote cognitive performance (D'Mello et al., 2014); however, these effects were relatively weak, and they were significant in Studies 1 and 3 but not in Study 2. These small effect sizes for confusion could be due to variable effects of negative activating emotions, such as confusion, on motivation and behavior (Pekrun & Stephens, 2012). It is possible that confusion strengthens motivation to explore in individuals who expect to successfully resolve their confusion, but undermines motivation and knowledge exploration in persons who expect that the resolution of confusion is less likely. Low expectations could drive these individuals to withdraw from, rather than persist through, the task at hand. Analyzing persons with low and high expectancies simultaneously will

lead to low effect sizes, which can vary in significance due to sampling error. Supporting this interpretation, the confidence intervals for the effects of confusion from the three studies overlap (see Table 4 and Table 5), indicating that the effects were not significantly different across studies and suggesting that the differences in effect size were indeed caused by sampling error. As such, in line with extant theoretical perspectives (Pekrun & Stephens, 2012), the present results suggest that the effects of confusion on motivation can be difficult to anticipate and to predict in any given sample and context. To gain a better understanding of confusion, future research should explore confusion during other cognitive tasks and in relation to various types of motivation to perform these tasks and different types of obstacles encountered during task performance.

As for achievement emotions, pride experienced after correctly answered items had positive effects on knowledge exploration, in line with prior findings on positive relations between pride and performance (e.g., Pekrun et al., 2002). In contrast, there were null relations between shame and exploration. Similar to the variable effects of confusion, this finding is consistent with theoretical perspectives and prior evidence that the effects of activating negative emotions can be complex and result in zero correlations with overall measures of performance (Pekrun & Stephens, 2012; Turner & Schallert, 2001).

In sum, the findings are well in line with our study hypotheses and replicated across multiple independent studies (three for epistemic emotions, two for achievement emotions), the only exception being the somewhat variable results for the relation between confusion and exploration that are likely attributable to the weak overall relation between these variables. The results document reliable effects of task feedback and prior confidence on surprise, curiosity, confusion, pride, and shame as well as positive effects of surprise, curiosity, and pride after

correct answers on subsequent knowledge exploration. Clearly, more research is needed to more fully understand the relationship between confusion and epistemic behavior.

Implications for Research and Practice

The results of the present within-person analyses support emotion theories that focus on within-person psychological functioning (e.g., D'Mello & Graesser, 2012; Scherer, 2009; Pekrun, 2006). Our correlational findings point to some discrepancies across the within-person and between-person levels, confirming that it is imperative to decompose within- and between-person covariation when exploring the origins and outcomes of emotions. As epistemic emotions are essentially situation-dependent (i.e., they change over time in response to variations in external situations and internal states), we contend that more research is needed that investigates these emotions using within-person perspectives. This is likely to be true for achievement emotions as well (Pekrun, 2006).

Our experimental approach of using tasks tapping into common misconceptions to induce high-confidence errors reliably elicited both epistemic and achievement emotions. To further probe the robustness of the present findings across different sources of cognitive incongruity, it would be useful to replicate the results using different methods. For example, cognitive incongruity could be induced by confronting persons with information that contradicts their profound personal beliefs (Muis, Pekrun, et al., 2015) or by confronting them with unexpected outcomes in various tasks (e.g., unexpected device malfunctions; D'Mello & Graesser, 2014).

The findings highlight the importance of epistemic emotions in knowledge acquisition (Brun et al., 2008). They suggest that both positive and negative epistemic emotions can promote knowledge exploration, given that both curiosity and confusion had positive effects in our studies. However, it is an important task for future research to examine the impact of other negative emotions. In contrast to confusion, negative emotions such as anxiety and frustration likely have

negative effects on knowledge exploration. Similarly, it will be important to examine the role of arousal. Specifically, future research should investigate the influence of deactivating emotions, such as relaxation and boredom, in addition to the activating emotions surprise, curiosity, and confusion considered here.

Our research demonstrates the impact of epistemic emotions on one specific type of knowledge exploration, namely, seeking access to correct solutions and additional information on the topic. To further understand the role of epistemic emotions in knowledge generation, future research should consider other types of knowledge exploration. For example, it would be interesting to examine whether surprise, curiosity and – possibly – confusion also promote exploration of information that is not just 'one click away' but that requires more complex and continued search for information on the internet or in libraries. In a similar vein, one important step for future research involves replicating the present findings for different types of tasks, including, for instance, physical exploration of space and objects (e.g., exploring a hallway that provides a surprising but illusionary impression that the floor is uneven).

The extended time span required for such types of exploratory behaviors could lead to more complex cognitive and emotional processes including recursive feedback loops of epistemic emotions, their antecedents, and their effects (see also D'Mello & Graesser, 2012). For example, surprise and curiosity prompted by high-confidence errors could lead individuals to search the internet for the correct answer, and this search, in turn, could lead to further surprises, new information gaps, and continued curiosity. Alternatively, continued failure to find the correct answer may result in persistent confusion and promote negative emotions such as frustration and boredom, which can eventually prompt the individual to give up and stop searching.

To more fully understand the role of epistemic emotions in knowledge generation, it would also be important to analyze their impact on other processes underlying knowledge

generation (e.g., cognitive problem solving and memory processes). Expanding the focus of future studies in this way presents a new avenue for interdisciplinary research on epistemic emotions. In fact, recent work in cognitive science, cognitive neuroscience, and computer science has begun to explore curiosity as a factor that is critically important to facilitate knowledge generation (e.g., Gruber et al., 2014; Marvin & Shohamy, 2016; Oudeyer, Gottlieb, & Lopes, in press; Stahl & Feigenson, 2015).

Regarding implications for practice, our research focused on the origins and outcomes of emotional *states*, which might be more amenable to interventions than emotional traits. As such, the present findings provide an important step towards formulating basic guidelines for practical interventions. For example, the findings suggest that teachers should pay close attention to learners' epistemic emotions to foster their self-regulated knowledge generation. According to the findings, including surprising elements in learning situations (e.g., classroom instruction, museum visits) may benefit learning by prompting curiosity and engagement with learning material through exploration (Loewenstein, 1994). Surprise and curiosity could, for example, be triggered by violating expectations (e.g., challenging naïve theories) to induce cognitive incongruity. However, our findings also call for a closer look at confusion. As expected, our findings show that surprising events can not only trigger curiosity but also confusion, which may not always foster knowledge generation. Future research should examine how the present findings translate into antecedents and outcomes of epistemic emotions in real-life settings (e.g., classrooms and occupational contexts), and how they could be used to design settings that promote epistemic emotions and knowledge exploration.

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Table 1

Descriptive Statistics and Within- and Between-Person Correlations

	M_{cor}	SD_{cor}	M_{inc}	SD_{inc}	M_{tot}	SD_{tot}	*ICC*	1	2	3	4	5	6	7	8
Variable								*Study 1*							
1 Accuracy [1]	--	--	--	--	0.54	0.50	.022	--	357*	-.310	-.036	-.200	--	--	--
2 Confidence	3.80	0.85	3.76	0.66	3.79	1.38	.230	.005	--	.016	.089	.172	.327*	--	--
3 Surprise	1.63	0.61	2.65	0.80	2.10	1.17	.224	-.432***	.079**	--	.523***	.828***	.358*	--	--
4 Curiosity	1.93	0.76	3.01	0.91	2.43	1.17	.292	-.455***	-.094**	.531***	--	.531***	.564**	--	--
5 Confusion	1.17	0.30	2.23	0.76	1.67	1.04	.185	-.507***	.221***	.687***	.485***	--	.264	--	--
6 Motivation to explore [2]	--	--	3.76	0.53	--	--	.162	--	.360***	.366***	.317***	.336***	--	--	--
								Study 2							
1 Accuracy [1]	--	--	--	--	0.57	0.50	.020	--	.614***	-.312**	-.147**	-.246***	.016	-.237***	--
2 Confidence	3.81	0.66	3.70	0.50	3.78	0.58	.158	.021	--	-.056	-.020	-.067	.186***	-.164**	.127*
3 Surprise	1.44	0.44	2.67	0.74	1.97	0.52	.178	-.519***	.123***	--	.699***	.797***	.497***	.548***	.152**
4 Curiosity	1.92	0.79	3.13	0.91	2.43	0.77	.310	-.518***	-.054**	.585***	--	.643***	.510***	.393***	.357***
5 Confusion	1.17	0.21	2.33	0.71	1.67	0.39	.136	-.554***	.229***	.749***	.558***	--	.493***	.674***	.216***
6 Pride	2.41	0.97	1.06	0.20	1.83	0.59	.251	.661***	.130***	-.409***	-.385***	-.461***	--	.310***	-.190***
7 Shame	1.04	0.16	1.66	0.73	1.31	0.38	.234	-.450***	.113***	.413***	.304***	.455***	-.400***	--	.097*
8 Exploration [2, 3]	--	--	0.96	0.11	--	--	.181	--	.088***	.131***	.191***	.119***	-.012***	.010	--

Table 1 *(continued)*

								Study 3							
1 Accuracy [1]	--	--	--	--	0.52	0.50	.028	--	.779***	.026	.134	.357	.366*	.130	-.038
2 Confidence	3.65	0.59	3.80	0.51	3.73	1.42	.141	-.075***	--	.044	.029	.114	.244*	.146	.070
3 Surprise	1.66	0.42	2.76	0.59	2.18	1.30	.100	-.447***	.204***	--	.655***	.821***	.414**	.560***	.318**
4 Curiosity	2.25	0.78	3.15	0.83	2.68	1.35	.325	-.404***	.014	.607***	--	.606***	.301**	.380***	.720***
5 Confusion	1.15	0.62	2.09	0.54	1.60	1.05	.099	-.473***	.305***	.676***	.462***	--	.514***	.734***	.307**
6 Pride	2.17	0.86	1.03	0.09	1.63	1.06	.222	.601***	.070**	-.321***	-.252***	-.355***	--	.41**	.068
7 Shame	1.05	0.11	1.52	0.54	1.27	0.71	.153	-.362***	.148***	.352***	.295***	.378***	-.312***	--	.285**
8 Exploration[4]	1.47	0.93	1.80	0.83	1.63	1.17	.568	-.213***	-.015	.310***	.447***	.253***	-.100***	.119***	--

Note. Means and *SD*s are estimated sample statistics on the between-person level. ICC = Intraclass correlation coefficient. Within-person correlations appear below the diagonal; between-person correlations appear above the diagonal. [1] Proportion of correct answers per person (range = .15-.75, .25-.90, and .20-.80 in Studies 1, 2, and 3, respectively). [2] Coefficients for exploration after incorrect answers (no assessment of exploration after correct answers in Studies 1 and 2). [3] Proportion of requests for information after incorrect answers relative to the number of incorrect answers (range 0-1). On average, participants answered 8.57 (SD = 2.59) out of 20 questions incorrectly. Out of these incorrectly answered questions, they explored 8.23 (SD = 2.62) on average questions (i.e., 96% of the incorrectly answered items). [4] Mean of the sum score of explorations (range 0-3). On average, participants answered 9.66 (SD = 2.50) out of 20 questions incorrectly. For these incorrectly answered items, they explored 1.63 (SD = 1.17) pieces of information on average.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2

Path Coefficients for Epistemic Emotions in Model 1

	Surprise				Curiosity				Confusion			
Predictor	b	ß	*p*	95% CI	b	ß	*p*	95% CI	b	ß	*p*	95% CI
						Study 1						
Accuracy	-.472	-.399	.000	[-.442, -.356]	-.508	-.428	.000	[-.473, -.384]	-.508	-.483	.000	[-.517, -.448]
Confidence	.104	.078	.000	[.042, .114]	-.125	-.094	.001	[-.138, -.049]	.262	.221	.000	[.188, .254]
Accuracy x Confidence	-.494	-.420	.000	[-.463, -.377]	-.282	-.239	.000	[-.280, -.198]	-.332	-.317	.000	[-.355, -.280]
Confidence in incorrect answers	.425	.503	.000	[.448, .557]	.106	.145	.000	[.073, .217]	.406	.030	.000	[.451, .550]
Confidence in correct answers	-.289	-.479	.000	[-.338, -.241]	-.256	-.365	.000	[-.306, -.207]	-.077	-.234	.000	[-.106, -.047]
Order	.031	.152	.000	[.125, .180]	.023	.113	.000	[.079, .146]	.021	.115	.000	[.090, .140]
						Study 2						
Accuracy	-.625	-.535	.000	[-.555, -.515]	-.605	-.524	.000	[-.547, -.502]	-.596	-.570	.000	[-.587, -.553]
Confidence	.165	.132	.000	[.114, .149]	-.055	-.044	.001	[-.067, -.022]	.268	.239	.000	[.222, .256]
Accuracy x Confidence	-.495	-.423	.000	[-.441, -.406]	-.296	-.257	.000	[-.276, -.238]	-.385	-.368	.000	[-.386, -.351]
Confidence in incorrect answers	.504	.588	.000	[.563, .613]	.182	.270	.000	[.235, .305]	.475	.601	.000	[.575, .626]
Confidence in correct answers	-.204	-.417	.000	[-.444, -.390]	-.208	-.333	.000	[-.362, -.304]	-.069	-.217	.000	[-.247, -.186]
Order	.000	.002	.870	[-.014, .017]	.000	-.002	.863	[-.017, .014]	.002	.013	.098	[.000, .026]

Table 2 *(continued)*

	Study 3										
Accuracy	-.538	-.432	.000	[-.470, -.394]	-.455	-.404	.000	[-.438, -.369]	-.459	-.451	.000	[-.481, -.421]
Confidence	.227	.171	.000	[.142, .171]	-.021	-.017	.384	[-.049, .015]	.294	.271	.000	[.242, .299]
Accuracy x Confidence	-.646	-.520	.000	[-.551, -.489]	-.426	-.379	.000	[-.411, -.346]	-.354	-.349	.000	[-.376, -.322]
Confidence in incorrect answers	.647	.667	.000	[.633, .701]	.308	.399	.000	[.350, .449]	.484	.565	.000	[.530, .600]
Confidence in correct answers	-.322	-.517	.000	[-.559, -.475]	-.328	-.431	.000	[-.476, -.387]	-.058	-.153	.000	[-.200, -.107]
Order	-.002	-.009	.532	[-.032; .014]	.002	.009	.630	[-.021, .038]	-.007	-.041	.004	[-.064, -.018]

Note. b = unstandardized path coefficient. ß = standardized coefficient, *p* = p-value, CI = confidence interval.

Table 3

Path Coefficients for Achievement Emotions in Model 1

	Pride				Shame			
Predictor	b	ß	*p*	95% CI	b	ß	*p*	95% CI
				Study 2				
Accuracy	.676	.662	.000	[.643, .682]	-.316	-.457	.000	[-.480, -.434]
Confidence	.128	.117	.000	[.096, .138]	.090	.122	.000	[.101, .143]
Accuracy x Confidence	.129	.127	.000	[.103, .150]	-.109	-.158	.000	[-.183, -.132]
Confidence in incorrect answers	.002	.010	.679	[-.029, .048]	.159	.301	.000	[.269, .333]
Confidence in correct answers	.159	.285	.000	[.244, .326]	-.017	-.126	.000	[-.159, -.092]
Order	.002	.000	.204	[-.003, .026]	.000	-.001	.902	[-.017, .015]
				Study 3				
Accuracy	.571	.609	.000	[.573, .645]	-.234	-.352	.000	[-.389, .314]
Confidence	.116	.116	.000	[.086, .147]	.086	.122	.000	[.089, .154]
Accuracy x Confidence	.121	.130	.000	[.088, .172]	-.110	-.166	.000	[-.208, .124]
Confidence in incorrect answers	.007	.046	.149	[-.006, .099]	.142	.249	.000	[.205, .293]
Confidence in correct answers	.178	.276	.000	[.222, .330]	-.011	-.054	.057	[-.100, .007]
Order	.004	.023	.137	[-.002, .049]	-.003	-.029	.059	[-.053, -.004]

Note. b = unstandardized path coefficient. ß = standardized coefficient, *p* = p-value, CI = confidence interval.

Table 4

Path Coefficients for Model 2 in Studies 1 and 2

Path	b	ß	*p*	95% CI
		Study 1		
Conf-Sur (a)	.429	.506	.000	[.452, .560]
Conf-Cur	-.046	-.063	.194	[-.142, .017]
Conf-Con	.196	.240	.000	[.175, .306]
Conf-Mot	.200	.249	.000	[.177, .321]
Sur-Cur (b)	.358	.416	.000	[.344, .487]
Sur-Con (c)	.499	.520	.000	[.455, .584]
Cur-Mot (d)	.247	.225	.000	[.151, .298]
Con-Mot (e)	.104	.106	.008	[.040, .172]
Sur-Cur-Mot (b + d)	.088	---	.000	[.056, .121]
Sur-Con-Mot (c + e)	.052	---	.010	[.019, .085]
Conf-Sur-Cur-Mot (a + b + d)	.038	---	.000	[.023, .053]
Conf-Sur-Con-Mot (a + c + e)	.022	---	.017	[.007, .038]
		Study 2		
Conf-Sur (a)	.504	.588	.000	[.563, .613]
Conf-Cur	.005	.008	.752	[-.032, .048]
Conf-Con	.222	.280	.000	[.249, .311]
Conf-Pri	.002	.010	.680	[-.029, .048]
Conf-Sha	.159	.301	.000	[.269, .333]
Conf-Expl	.004	.030	.320	[-.020, .081]
Sur-Cur (b)	.350	.446	.000	[.403, .488]
Sur-Con (c)	.503	.545	.000	[.513, .577]
Cur-Expl (d)	.032	.171	.000	[.126, .217]
Con-Expl (e)	.005	.034	.154	[-.005, .073]
Pri-Expl (h)	-.008	-.011	.756	[-.069, .047]
Sha-Expl (i)	-.007	-.029	.114	[-.060, .001]
Sur-Cur-Expl (b + d)	.011	---	.000	[.007, .015]
Sur-Con-Expl (c + e)	.003	---	.156	[.000, .006]
Conf-Sur-Cur-Expl (a + b + d)	.006	---	.000	[.004, .007]
Conf-Sur-Con-Expl (a + c + e)	.001	---	.154	[.000, .003]

Note. Conf = confidence; Sur = surprise; Cur = curiosity; Con = confusion; Pri = pride; Sha = shame; Mot = motivation to explore; Expl = exploration. Letters in parentheses denote paths predicted by the main hypotheses (see Figure 1). b = unstandardized path coefficient. ß = standardized coefficient. CI = confidence interval.

Table 5

Path Coefficients for Model 2 in Study 3

	Incorrect answers				Correct answers			
Path	b	ß	*p*	Path	b	ß	*p*	Path
				Study 3				
Conf-Sur (a)	.647	.667	.000	[.633, .701]	-.322	-.517	.000	[-.559, -.475]
Conf-Cur	.014	.018	.609	[-.041, .078]	-.206	-.271	.000	[-.324, -.217]
Conf-Con	.179	.210	.000	[.161, .258]	.014	.038	.343	[-.028, .103]
Conf-Pri	.007	.046	.149	[-.006, .099]	.178	.276	.000	[.222, .330]
Conf-Sha	.141	.249	.000	[.205, .292]	-.011	-.054	.056	[-.100, -.007]
Conf-Expl	.010	.020	.575	[-.038, .078]	-.049	-.081	.027	[-.141, -.021]
Sur-Cur (b)	.455	.571	.000	[.503, .638]	.378	.310	.000	[.257, .364]
Sur-Con (c)	.470	.532	.000	[.479, .586]	.224	.370	.000	[.280, .460]
Cur-Expl (d)	.215	.316	.000	[.258, .373]	.304	.383	.000	[.323, .444]
Con-Expl (e)	.061	.100	.008	[.038, .162]	.081	.051	.054	[.007, .094]
Pri-Expl (h)	-.109	-.032	.377	[-.092, .028]	.080	.085	.004	[.036, .134]
Sha-Expl (i)	-.007	-.008	.820	[-.064, .049]	-.165	-.058	.176	[-.128, .012]
Sur-Cur-Expl (b + d)	.098	---	.000	[.075, .120]	.115	---	.000	[.087, .143]
Sur-Con-Expl (c + e)	.029	---	.010	[.010, .047]	.018	---	.058	[.002, .034]
Conf-Sur-Cur-Expl (a + b + d)	.063	---	.000	[.048, .078]	-.037	---	.000	[-.047, -.027]
Conf-Sur-Con-Expl (a + c + e)	.019	---	.010	[.007, .031]	-.006	---	.058	[-.011, -.001]

Note. Conf = confidence; Sur = surprise; Cur = curiosity; Con = confusion; Pri = pride; Sha = shame; Mot = motivation to explore; Expl = exploration. Letters in parentheses denote paths predicted by the main hypotheses (see Figure 1). b = unstandardized path coefficient. ß = standardized coefficient. CI = confidence interval.

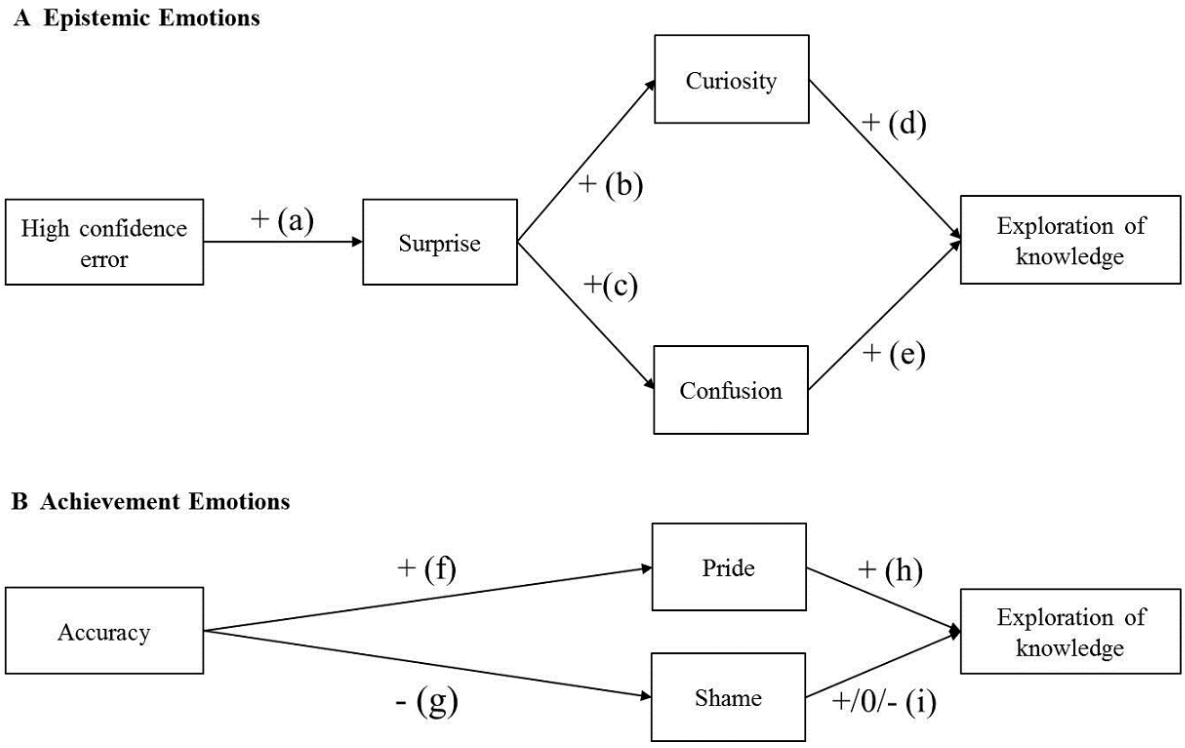

Figure 1. Main hypotheses. Pride is expected to occur after correct answers and to promote exploration after these answers. Shame is expected to occur after incorrect answers; no prediction is made for the direction of effects of shame on exploration.

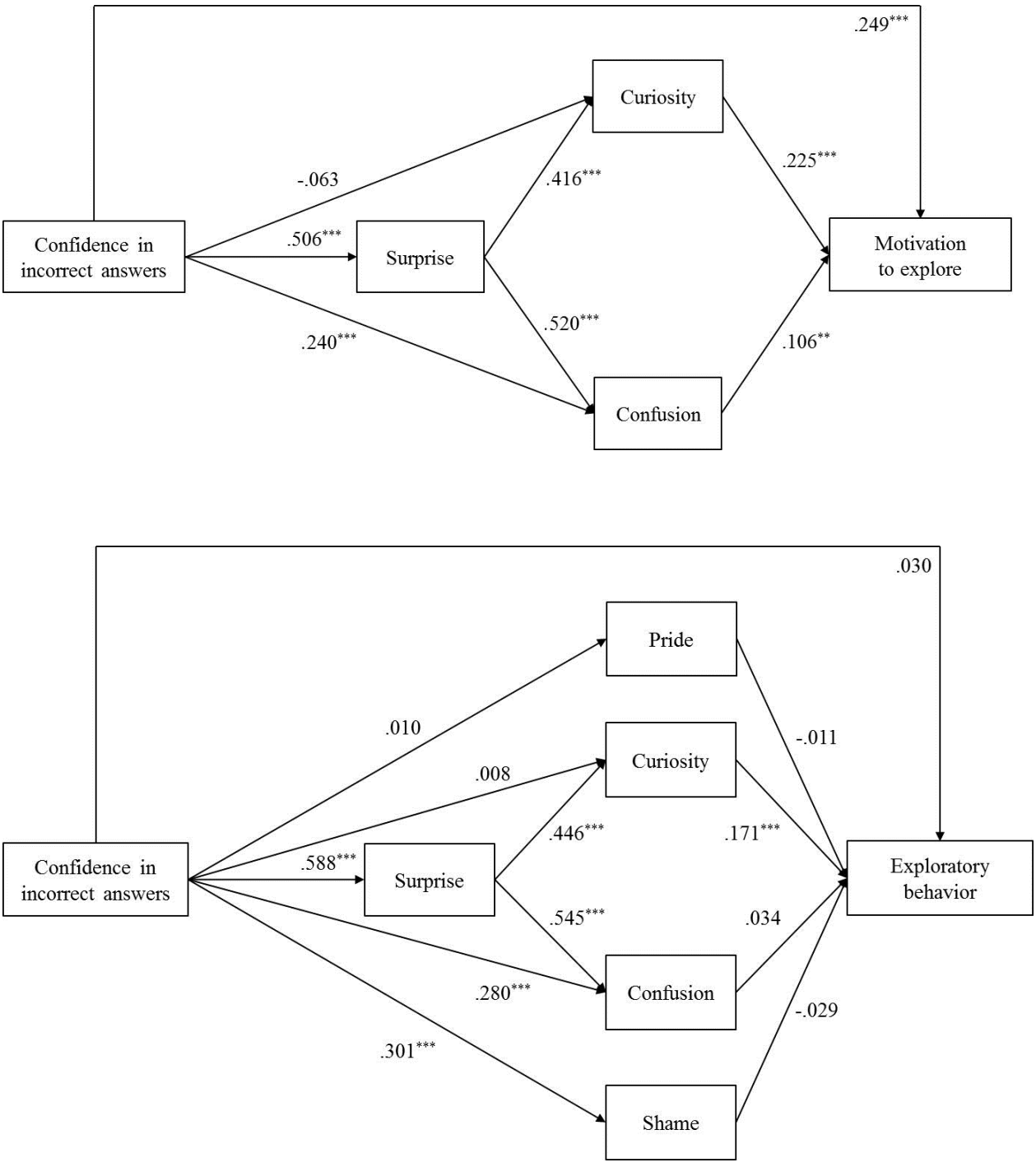

Figure 2. Relations between confidence in incorrect answers, epistemic emotions, and exploration at the within-person level (Model 2) in Studies 1 (upper panel) and 2 (lower panel). Residuals and correlations between emotions are not depicted. * $p < .05$. ** $p < .01$. *** $p < .001$.

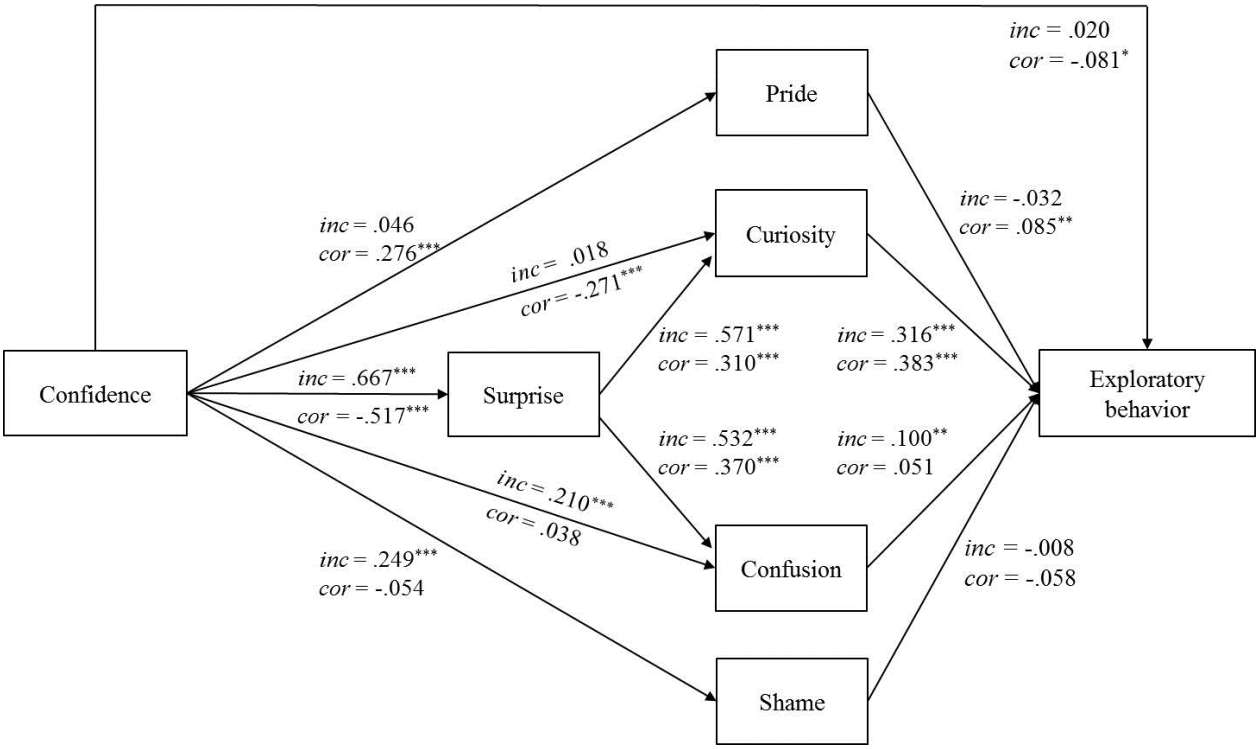

Figure 3. Relations between confidence in incorrect answers, epistemic emotions, and exploration at the within-person level in Study 3. *inc* = path coefficients for incorrect answers (Model 2a). *cor* = path coefficients for correct answers (Model 2b). Residuals and correlations between emotions are not depicted. * $p < .05$. ** $p < .01$. *** $p < .001$.

Supplemental Materials for

Surprised – Curious - Confused:

Epistemic Emotions and Knowledge Exploration

This file includes:

Test of alternative models

Table S1: Fit indexes of alternative models

Table S2: Trivia task items with English translation

Test of Alternative Models

To further investigate the robustness of findings concerning the interplay of surprise, curiosity, and confusion, we additionally estimated two alternative models for each study. Specifically, in Model 2 depicted in the main text, surprise predicted curiosity and confusion, and curiosity and confusion, in turn, predicted exploration. In Models 3 and 4 described here, we changed this sequence. In Model 3, curiosity predicted surprise and confusion, and these two emotions predicted exploration. In Model 4, confusion predicted surprise and curiosity, and these two emotions predicted exploration. Other than that, Models 3 and 4 had the same structure as Model 2 (see Figure 1, main text). To estimate Models 3 and 4, we used the same data analytic procedures as for Model 2 (see the Method sections of Studies 1-3, main text).

For Studies 1 and 2, the three models were estimated for confidence, emotions, and exploration after incorrect answers; exploration had not been examined after correct answers in these studies, For Study 3, the models were estimated both for incorrect and correct answers.

As reported in the main text and summarized in Table S1, Model 2 (surprise first) had a very good fit across all four analyses. In contrast, Model 3 (curiosity first) did not fit the data. Model 4 (confusion) first had a good fit in Studies 1 and 2 but had a substantially worse fit than Model 2 in the analyses for Study 3, both in the analysis for incorrect and correct answers. Given that Model 2 was the only one that showed an excellent fit across all analyses, we decided to keep this model and report it in the main text.

Table S1. *Fit Indexes of Alternative Models*

Model	CFI	TLI	RMSEA	$SRMR_{within}$
		Study 1		
2 – Surprise first	.997	.935	.055	.010
3 – Curiosity first	.987	.673	.123	.037
4 – Confusion first	.999	.970	.037	.007
		Study 2		
2 – Surprise first	1.00	.980	.024	.003
3 – Curiosity first	.990	.526	.114	.021
4 – Confusion first	1.00	1.00	.000	.001
		Study 3 – Incorrect answers		
2 – Surprise first	1.00	1.00	.000	.003
3 – Curiosity first	.965	-.694	.233	.032
4 – Confusion first	.998	.920	.051	.007
		Study 3 – Correct answers		
2 – Surprise first	1.00	1.00	.000	.003
3 – Curiosity first	.957	-1.10	.192	.046
4 – Confusion first	.996	.804	.051	.006

Table S2. *Trivia Task Items with English Translation*

Item	Question	Correct Answer	Additional information 1	Additional information 2
1	Jupiter ist der größte Planet unseres Sonnensystems. [richtig]	Der Gasriese Jupiter ist mit einem Äquatordurchmesser von 142.800 Kilometern der größte Planet des Sonnensystems.	Als eines der hellsten Objekte des Nachthimmels ist er nach dem römischen Hauptgott Jupiter benannt.	Für einen Umlauf um die Sonne benötigt Jupiter 11 Jahre, 315 Tage und 3 Stunden.
	Jupiter is the largest planet in our solar system. [correct]	With an equatorial diameter of 142,800 kilometers, gas giant Jupiter is the largest planet in the solar system.	As one of the brightest objects in the night sky, Jupiter is named after the chief deity of Roman religion.	It takes Jupiter 11 years, 315 days and three hours to orbit the Sun.
2	Die legendären einäugigen Riesen aus der griechischen Mythologie werden nicht Zyklopen genannt. [richtig]	Zyklopen sind Gestalten der griechischen Mythologie mit kreisrunden Augen oder einem Einzelauge auf der Stirn.	Die bekannteren Zyklopen, denen Odysseus auf seiner Irrfahrt (Odyssee) begegnete, waren die Söhne des Poseidon.	Der Fund von Elefantenschädeln deren Nasenöffnungen als Augenhöhlen interpretiert wurden, begründete die Legende der Zyklopen.
	The legendary one-eyed giants in Greek mythology are not called cyclopes. [correct]	In Greek mythology, cyclopes are creatures with round eyes, or with a single eye on their forehead.	The more famous cyclopes were the sons of Poseidon and those which Odysseus encountered on his Odyssey.	The cyclopes myth was inspired by the discovery of elephant skulls that had large nasal cavities interpreted as eye sockets.
3	Der Rio Grande ist nicht der längste Fluss Südamerikas. [richtig]	Der aus den Anden nach Osten fließende Amazonas ist mit 6.448 km der längste Fluss Südamerikas.	Der Amazonas ist mit einer mittleren Wasserführung von 209.000 m^3/s der wasserreichste Fluss der ganzen Welt...	Der Rio Grande entspringt in den Rocky Mountains und fließt durch New Mexico Richtung Süden.
	The Rio Grande is not the longest river in South America. [correct]	Flowing eastwards from the Andes Mountains, the Amazon is the longest river in South America (4,007 miles).	With an average discharge volume of 209,000 m^3/s, the Amazon is the largest river by discharge volume of water in the world.	From its sources in the Rocky Mountains, the Rio Grande flows through New Mexico and towards the South.
4	Da Vinci bemalte die Decke der sixtinischen Kapelle. [falsch]	Die Deckenmalereien malte Michelangelo Buonarroti zwischen 1508 und 1512 im Auftrag von Papst Julius II.	Besonders der Ausschnitt, in dem Gott mit ausgestrecktem Finger Adam zum Leben erweckt, ist berühmt.	Mona Lisa (original La Gioconda) ist der deutsche Titel des berühmten Gemäldes von da Vinci.

	The ceiling of the Sistine Chapel was painted by Da Vinci. [iIncorrect]	Michelangelo Buonarroti painted the ceiling between 1508 and 1512 commissioned by Pope Julius II.	The part depicting God stretching his finger to endow Adam with life is especially famous.	The German title of Da Vinci's famous portrait is Mona Lisa (original title: La Gioconda).
5	In Australien läuft das Badewasser gleichherum ab wie in Europa. [richtig] In Australia, water swirls down the plughole in the same direction as in Europe. [correct]	Die Badewannenstrudel in Australien sind viel zu schnell, um durch die Erdrotation beeinflusst zu werden. In Australia, the water swirls down the plughole much too fast to be affected by Earth's rotation.	Durch die Erdrotation werden unter anderem die Winde aus ihrer ursprünglichen Richtung abgelenkt (Coriolis-Kraft). One of the effects of Earth's rotation is that it causes the direction of winds to be deflected from their original direction (Coriolis force).	Die Corioliskraft führt dazu, dass auf der Nordhalbkugel Flussufer in Fließrichtung rechts stärker erodiert werden. Due to the Coriolis force, rivers in the northern hemisphere erode more strongly along their right bank in the direction of flow.
6	Zündhölzer sind nicht moderner als Feuerzeuge. [falsch] Matches were not invented before lighters. [incorrect]	Während das erste Feuerzeug 1823 gefertigt wurde, entstanden die ersten Sicherheitszündhölzer erst im Jahr 1848. While the first lighter was devised in 1823, the first matches were only manufactured in 1848.	Die Urform des Feuerzeuges (Döbereiner-Feuerzeug) erfand der Döbereiner, der an der Universität Jena lehrte. The prototype of all lighters, the "Döbereiner lamp", was invented by Döbereiner, who taught at the University of Jena.	Zündhölzer haben gegenüber Gasfeuerzeugen generell den großen Vorteil, dass sie auch bei strengem Frost funktionieren. One of the general advantages of matches over butane lighters is that they also work in freezing temperatures.
7	Die Berliner Gedächtniskirche hat ihren Namen bekommen, weil sie an den Krieg erinnern soll. [falsch] The Kaiser Wilhelm Memorial Church (Berliner Gedächtniskirche) received its name as an anti-war memorial. [incorrect]	Die Berliner Gedächtniskirche, wie die Kaiser-Wilhelm-Gedächtniskirche umgangssprachlich genannt wird, ist Gedenkstätte für Wilhelm I. The "Berliner Gedächtniskirche", as the Kaiser Wilhelm Memorial Church is often referred to colloquially, is a memorial for Wilhelm I.	Der Grundstein für die Gedächtniskirche wurde gelegt, um an den Geburtstag des Namensgebers zu erinnern. The cornerstone of the Memorial Church was laid in memory of its namesake's birthday.	Die Ruine des im zweiten Weltkrieg komplett zerstörten Hauptturmes der Gedächtniskirche wurde als Mahnmal erhalten. The original west tower of the Memorial Church has remained standing as a ruin and anti-war memorial.

8	Ketchup ist eine amerikanische Erfindung. [falsch]	Der Ursprung von Ketchup ist eine chinesische Sauce aus eingelegten Schalentieren, ihr Name war „Kê-tsiap“.	Erstmals tauchte der Begriff im englischen Sprachraum in einem Wörterbuch Ende des 17. Jahrhunderts auf.	In Deutschland wurde Ketchup nach 1945 durch die britischen und auch amerikanischen Besatzungssoldaten breiter bekannt.
	Ketchup is an American invention. [incorrect]	Ketchup was originally developed from „kê-tsiap“, a Chinese sauce derived from fermented shellfish	In the English-speaking world, the word first appeared in dictionaries towards the end of the 17th century.	In Germany, Ketchup became more widely known after 1945 due to the British and American occupation.
9	Das Sternbild, das wie ein fliegendes Pferd aussieht, heißt Zentaurus. [falsch]	Pegasus ist ein Sternbild am Herbsthimmel, das ein auf dem Kopf stehendes fliegendes Pferd darstellt.	Das Sternbild Pegasus fällt vor allem dadurch auf, das seine Hauptsterne ein Quadrat bilden.	Der Zentaur ist ein Sternbild am Südhimmel, das ein Mischwesen aus Pferd und Mensch darstellt.
	The constellation resembling a winged horse is called Centaurus. [incorrect]	Pegasus is a constellation in the northern sky which depicts an upside-down winged horse.	Most notable about the Pegasus constellation is the square formed by its four main stars,	The Centaurus is a constellation in the southern sky depicting a creature that is part human, part horse.
10	Sokrates wurde mit Hilfe des Schierlingsbechers hingerichtet. [richtig]	Schierlingsbecher ist eine Vergiftung, bei der einem Getränk der Saft des Gefleckten Schierlings beigemischt wird.	Der Schierling gehört zu den giftigsten einheimischen Pflanzenarten, dessen Wirkstoff (das Alkaloid Coniin) tödlich ist.	Sokrates war ein für das abendländische Denken sehr grundlegender griechischer Philosoph, der in Athen lebte.
	Socrates was sentenced to die by drinking the hemlock cup. [correct]	Hemlock cup poisoning involves mixing a drink with poisonous spotted hemlock.	Containing the deadly toxin Coniine (an alkaloid), the hemlock is one of the most poisonous deadly plants.	Socrates was a very influential Greek philosopher in terms of impacting Western thinking, and lived in Athens.
11	In Indien wird nicht mit Kopeken bezahlt. [richtig]	In Indien wird von der Regierung und der Zentralbank die indische Rupie als Währung ausgegeben.	Die Einführung der indischen Rupie geht auf den damaligen Herrscher Afghan Sher Shah Suri zurück.	Kopeke ist der Name einer seit dem 16. Jahrhundert ausgegebenen Kleinmünze des ehemaligen Russischen Reichs.
	The copeck is not the official currency of India. [correct]	The official currency issued by the Indian government and central bank is the Indian rupee.	The Indian rupee was introduced by the medieval ruler Afghan Sher Shah Suri.	Copeck is the name of a coin that was introduced in the 16th century and formed part of the currency of the former Russian Empire.

12	Versailles wurde nicht von König Louis XIV erbaut. [falsch]	Der Bau des Schlosses von Versailles war Teil von Louis Strategie zur Zentralisierung der Macht.	Versailles ist einer der größten Paläste Europas und gilt als einer der Höhepunkte europäischer Schlossbaukunst.	Seit 1979 ist das Schloss Teil des UNESCO-Weltkulturerbes,welches durchschnittlich drei Millionen Besucher hat.
	Versailles was not built by King Louis XIV. [incorrect]	Building the Palace of Versailles was part of Louis' strategy for centralizing power.	Versailles is one of the largest Palaces in Europe and is considered one of the highlights of European castle architecture.	In 1979, the Palace was inscribed into the list of UNESCO World Heritage Sites and has an average of three million visitors.
13	Chamäleons passen Ihre Farbe der Umgebung an. [falsch]	Chamäleons passen ihre Farbe normalerweise nicht der Umgebung an, sondern wechseln sie entsprechend ihrer Stimmung.	Durch unterschiedliche Färbungen können sich Chamäleons ihren Artgenossen mitteilen, so signalisieren sie zum Beispiel Paarungsbereitschaft.	Der Farbwechsel der Chamäleons kann auch der Tarnung dienen, ist aber nicht die eigentliche Funktion.
	Chameleons can adapt their skin coloring to their environmental surroundings. . [incorrect]	Chameleons usually do not adapt their skin coloring to their environmental surroundings, but change their coloring according to their mood.	Chameleons can communicate with other members of their species by changing their coloring, for instance, to signal their readiness to mate.	Color change in chameleons can serve as camouflage, but this is not its actual main function.
14	Die Ägypter schrieben im Alltag nicht in Hieroglyphen. . [richtig]	Die Ägypter schrieben im Alltag nicht in Hieroglyphen, sondern benutzten eine so genannte „hieratische" Schrift.	Hieroglyphen sind Zeichen des ältesten bekannten ägyptischen Schriftsystems, das den Charakter einer reinen Bilderschrift hatte.	Die hieratische Schrift ist ebenso alt wie die Hieroglyphenschrift und eine eher kursive Variante davon.
	Egyptians did not use hieroglyphs in everyday writing. [correct]	Egyptians did not use hieroglyphs in everyday writing, but relied on so-called "hieratic" script.	The oldest Egyptian writing system known today is made up of hieroglyphic symbols and resembles purely pictographic script.	Hieratic script is as old as hieroglyphic writing, and presents a cursive variant of the latter.
15	Mozart hieß mit Vornamen Joannes Chrysostomus Wolfgangus Theophilus. [richtig]	Mozart nannte sich Wolfgang Amade, ist aber eigentlich auf den Namen Johannes Chrysostomus Wolfgangus getauft.	Schon als Mozart fünf Jahre alt war, zeichnete Vater Leopold Musikstücke als "Wolfgangerls Compositiones" auf.	Der Komponist starb am 5. Dezember 1791 im Alter von fast 36 Jahren in Wien.

	Mozart's first name was Joannes Chrysostomus Wolfgangus Theophilus. [correct]	Mozart called himself Wolfgang Amade, but he was actually christened Johannes Chrysostomus Wolfgangus.	When Mozart was five years old, his father Leopold already recorded his musical pieces under the name "Wolfgangerls Compositiones".	The composer died in Vienna on December 5, 1791 at almost 36 years of age.
16	Der Ursprung des Wortes "Hängematte" kommt nicht von "hängende Matte. [richtig]	"Hängematte" kommt von "hamaca", wie sie von den Erfindern, den südamerikanischen Indiandern, gemeinhin genannt wurde.	An Land bot die Hängematte Schutz vor Feuchtigkeit und in der Schifffahrt eine platzsparende Schlafgelegenheit.	Alle Hängematten lassen sich nach Art der Liegefläche entweder in Tuchhängematten oderin Netzhängematten untergliedern.
	The origin of the German word "Hängematte" (Engl. hammock) is not "hanging matt". [correct]	"Hängematte" (Engl. hammock) strems from "hamaca", which was the word for hammock commonly used by indigenous peoples of South America.	Hammocks offered protection against dampness ashore, and space-saving sleeping accommodation at sea.	Different types of hammocks can be differentiated based on the material they are made up of, including rope netting or cloth.
17	Nur männliche Löwen können Mähnen haben. [falsch]	Nicht nur männliche Löwen, sondern auch alte, nicht mehr fruchtbare Weibchen können eine Mähne haben.	Löwen sind eine Art der Katzen, die im Unterschied zu anderen Katzen in Rudeln leben.	Löwen sind zwar anpassungsfähig, was ihren Lebensraum angeht, ihr bevorzugter Lebensraum ist jedoch die Savanne.
	Only male lions can grow manes. [incorrect]	Manes can be grown not only by male lions, but also by older, barren lionesses.	Lions belong to the family of big cats, but in contrast to other cats, they live in prides.	When it comes to their natural habitat, lions are adaptable, but their preferred habitat is the savannah.
18	Päpste können keine legitimen Kinder haben. [falsch]	Päpste können Kinder haben, denn es steht jedem Witwer mit Kindern frei, die Priesterlaufbahn einzuschlagen.	Für das Amt vom Papst kann nach dem Kirchenrecht jeder gläubige männliche Katholik gewählt werden.	Der Petersdom ist die größte der Papstbasiliken Roms und eine der bedeutendsten Kirchen der Welt.
	Popes cannot have children legitimately. [incorrect]	Popes can legitimately have children since every widower is free to enter priesthood.	According to ecclesiastical law, any devout male Catholic can be elected pope.	The St. Peter's Basilica is the largest of the papal basilicas and one of the most important churches in the world.

19	Unsere Ziffern sind ursprünglich indisch. [richtig] Our numerals are of Indian origin. [correct]	Die Europäer übernahmen die Ziffern der Araber, welche diese aber wiederum aus Indien übernommen hatten. The Europeans adopted the Arabic numerals which, in turn, were adopted from Indian culture.	Ziffer wird von dem arabischen Wort aṣ-ṣifr abgeleitet, das aus dem Sanskrit śūnyā) übersetzt wurde. The German word "Ziffer" (numeral, digit) is derived from Arabic aṣ-ṣifr, which is a translation of the Sanskrit word śūnyā.	In Europa gibt es vor allem zwei Darstellungsweisen von Ziffern: die Versalziffern und die Mediävalziffern. In Europe, two main typefaces are distinguished: so-called versal numerals and medieval numerals.
20	Englisch ist die gesetzliche Amtssprache der USA. [falsch] English is the official language of the United States of America. [incorrect]	Englisch ist nicht die gesetzliche Amtsprache der USA, denn dort gibt es keine offizielle Amtssprache. English is not the official language of the United States seeing as the US does not have an official language.	In den USA werden 337 Sprachen gesprochen oder geschrieben, von denen 176 uramerikanischen Ursprungs sind. In the US, 337 languages are spoken or written, 176 of which are of Native American origin.	Die größte Sprechergemeinschaft der USA spricht englisch, die zweitgrößte spanisch und die drittgrößte chinesisch (kantonesisch). The most common language spoken in the US is English, the second most common is Spanish, and the third most common is Chinese (Cantonese).