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Shared and Unique Features of Epistemic Emotions: Awe, Surprise, Curiosity, Interest, Confusion, and Boredom

Marret K. Noordewier[1] and Małgorzata A. Gocłowska[2]

[1] Social, Economic and Organisational Psychology; Faculty of Social and Behavioural Sciences; Leiden University; Leiden, The Netherlands.

[2] Department of Psychology; Faculty of Humanities and Social Sciences; University of Bath, United Kingdom

Author Note

Marret K. Noordewier https://orcid.org/0000-0001-9084-2882

Małgorzata A. Gocłowska https://orcid.org/0000-0002-1504-5557

Correspondence concerning this article should be addressed to Marret K. Noordewier; Faculty of Social and Behavioural Sciences, Leiden University, PO Box 9555, 2300 RB Leiden, The Netherlands. Email: m.k.noordewier@fsw.leidenuniv.nl

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Abstract

Epistemic emotions are hardly ever studied together, making it difficult to predict what features are shared versus unique to each emotion. To address this, we conducted two autobiographical recall experiments. We compared awe, surprise, curiosity, interest, confusion, and boredom in terms of elicitors, subjective experience components, and actions tendencies. Ratings were analyzed using network analyses, to describe the central features for the whole group of epistemic emotions. In addition, ratings were compared per emotion, to identify key features for each individual emotion. Results showed that valence, arousal, coping potential, and avoidance are central features of all epistemic emotions. Awe, surprise, and interest were relatively positive emotions, which together with curiosity, were associated with arousal, high coping potential, and approach. Confusion and boredom were relatively negative emotions, which were associated with low arousal, low coping potential, and avoidance. Further analyses revealed unique features of (groups of) emotions. For example, awe was associated with exceeded expectancies, while surprise was associated with both exceeded and disconfirmed expectancies. Moreover, curiosity and confusion were associated with having (too) little information, while awe and interest were associated with having sufficient information. All emotions except boredom were associated with exploration, but this was particularly high for curiosity and interest.

Keywords. Epistemic emotions, autobiographical recall, network analyses.

Shared and Unique Features of Epistemic Emotions: Awe, Surprise, Curiosity, Interest, Confusion, and Boredom

Epistemic (or knowledge) emotions such as surprise, confusion, interest, or boredom are responsible for people's willingness to explore and update existing information (Keltner & Shiota, 2003; Silvia, 2010; Vogl et al., 2021). They can affect a range of important outcomes, such as complex learning (D'Mello et al., 2014), science interest (McPhetres, 2019), and openness towards individuals who challenge social proscriptions (Gocłowska et al., 2017; Prati et al., 2015). For example, complex problems or unusual art can result in withdrawal tendencies when people cannot resolve their confusion about those objects (D'Mello & Graesser, 2012; Fayn et al., 2019; Silvia, 2010). Contrary, information-gaps can result in a powerful motivation to explore when people anticipate their resolution (Gocłowska et al., 2017; Loewenstein, 1994; Noordewier & Van Dijk, 2020).

Epistemic emotions arise as a function of the various properties of the information provided. When a situation is novel, complex, unexpected, or in another way not understood, people can experience surprise, awe, curiosity, interest, or confusion (D'Mello & Graesser, 2012; Keltner & Haidt, 2003; Litman, 2005; Loewenstein, 1994; Noordewier & Van Dijk, 2019; Silvia, 2010). Conversely, when a situation lacks stimulation, meaning, or challenge, people can experience boredom (Bench & Lench, 2013; Tam et al., 2021; Van Tilburg & Igou, 2012). Epistemic emotions can thus arise in a number of situations as the product of all sorts of epistemically-based triggers. This can range from intellectual challenges and thought-provoking art to complex innovations, trivia questions, or the complete lack of any of this in the case of boredom (Fayn et al., 2019; Gocłowska et al., 2017; Gruber et al., 2014; Noordewier et al., 2016; Pekrun et al., 2017).

A growing body of research studies the predictors and consequences of epistemic emotions. Most epistemic emotions research to-date focuses on discrete emotions and their

consequences. Studies have for example focused on elicitors of awe (Gocłowska et al., 2021) or the subjective experience of surprise (Noordewier & Van Dijk, 2019). However, focusing on single discrete emotions has limitations, as this approach is not sufficient for understanding what various epistemic emotions have in common (shared features) and how they differ from one another (unique features).

Some recent work studied multiple epistemic emotions together—for example, in the context of complex information and problem solving (e.g., Di Leo et al., 2019; Fayn et al., 2019; Muis et al., 2015ab), or in response to high-confidence errors in trivia knowledge (e.g., learning that Chameleons do not match their color to their environment; Vogl et al., 2020). Results from these studies suggest that epistemic emotions can co-occur (e.g., interest and confusion, in those who are open-minded to complexity; Fayn et al., 2019) or that they may occur sequentially (e.g., surprise about a high-confidence error may precede curiosity or confusion; Vogl et al., 2020; see also D'Mello & Graesser, 2012). These studies highlight the potential dynamic nature of epistemic emotions, but they do not provide a test of shared vs. unique features of different epistemic emotions.

To address this, the current autobiographical recall studies directly compared epistemic emotions in terms of elicitors, subjective experience components, and action tendencies (Lazarus, 1991; following Campos et al., 2013). We focused on awe, surprise, curiosity, interest, confusion, and boredom, as they frequently occur in the literature on epistemic emotions[1]. Our aim was to create a framework of shared and unique features of this group of emotions (for a similar approach regarding positive emotions, see Campos et al., 2013; see also Desmet et al., 2021). Specifically, we aimed to identify 1) central features to

[1] We did not include frustration, anxiety, or enjoyment, which are sometimes also included in work on epistemic emotions (e.g., Chevrier et al., 2019; Muis et al., 2015; Pekrun et al., 2017; Vogl et al., 2020, 2021). We believe that those feelings are less suitable in the current recall studies, as they are not unique to epistemic situations (e.g., frustration, anxiety, or enjoyment may occur when a mismatch between new and current knowledge can vs. cannot be resolved, but these feelings may also occur in various non-epistemic situations like interpersonal or self-related processes).

all epistemic emotions and 2) specific distinctions between *individual* epistemic emotions. Such a framework can provide valuable insights into the shared structure of epistemic emotions as a group, while also differentiating between (sub-groups of) epistemic emotions. This can help predict what features are associated with different epistemic emotions. For example, whether a complex news story or an unexpected turn of events may result in curiosity and exploration, or whether such events are more likely to result in confusion and avoidance.

Elicitors, Subjective Experience Components, and Action Tendencies

The specific elicitors, subjective experience components, and action tendencies that were included in the current studies (see Figure 1) were selected based on a review of the relevant literature (see below). *Elicitors* trigger emotions and could help us understand how to evoke distinct epistemic emotions. We included novelty, complexity, amount of information, (dis)confirmed and exceeded expectancies. *Subjective experience components* inform us what an emotion feels like and are therefore very useful for identifying commonalities and differences in how emotions feel. We included valence, arousal, coping potential, interruption, absorption, and feeling small. *Action tendencies* suggest what people might do as a result of an emotion and could thus be used to predict behavior resulting from the emotion. We included exploration and avoidance-approach.

As central element of *all* emotions, valence is a likely candidate (e.g., Barrett, 2012; Frijda, 1986; Russell, 2003), and features related to valence (e.g., approach motivation) could be helpful in grouping emotions together. For instance, awe, curiosity, and interest are associated with positive valence and approach motivation and could thus be labelled as "positive epistemic emotions". Confusion and boredom are more likely to be associated with negative valence and avoidance and could thus be labelled as "negative epistemic emotions". Second, to draw specific distinctions between *individual* epistemic emotions, past studies can

provide insights. Below, we provide an overview of what is known about each emotion to formulate predictions on their features. We start with awe and surprise, followed by curiosity, interest, confusion, and boredom.

Awe

Awe is the emotion that arises in response to vast stimuli that exceed expectancies—such as large aerial views of animals migrating across the savannah, breath-taking displays of fireworks, or the perception of grand ideas (Gocłowska et al., 2021; Keltner & Haidt, 2003; Shiota et al., 2007; see also Pérez et al., 2022). Because vastness involves a challenge to the mental representation of the extremity of what one thought was possible (i.e., exceeding expectancies), awe is associated with a need for accommodation, a sense that one needs to take in and absorb the new and expectancy-exceeding information (Keltner & Haidt, 2003).

Elicitors. Awe-inducing stimuli are likely to be rated as novel but not very complex, as these stimuli go beyond what one thought was possible (which is likely to be new), but they are not completely different than that (which is likely not very complex; Gocłowska et al., 2021). Because awe-inspiring information can be accommodated in existing knowledge structures, the amount of information is likely be rated as relatively sufficient. Awe is clearly linked to expectancies, but instead of *disconfirming* expectancies (different than expected), it is often elicited by *exceeding* expectancies (e.g., in size, like "I did not know a tree could be this big", Gocłowska et al., 2021; Keltner & Haidt, 2003; Shiota et al., 2007).

Subjective Experience. In terms of valence, some have argued that awe is predominantly positive (Campos et al., 2013; Griskevicius et al., 2010), while others have shown that a threat-based variant of awe—accounting for around 20% of awe experiences—is evaluated as negative (e.g., a volcano can be awe-inspiring but also threatening; Chirico et al., 2016; Gordon et al., 2017; Sawada & Momura, 2020; Takano & Momura, 2020). Awe could thus be both positive and negative depending on the type of event that is recalled, but

on average it is likely to be relatively positive as positive awe is more common than threat-based awe. For the same reasons, coping potential is likely to be relatively high on average (Gordon et al., 2017). Awe is likely to be associated with arousal (Gordon et al., 2017) and likely to be an interrupting and highly absorbing experience, because of the overwhelming nature of awe stimuli (Van Elk et al., 2016, 2019). Finally, a well-known effect of awe is that is results in feeling small in one's environment (Keltner & Haidt, 2003; Piff et al., 2015; Shiota et al., 2007; Van Elk et al., 2016, 2019).

Action Tendencies. In terms of action tendencies, predictions for awe are not straightforward. On the one hand, awe may be associated with greater exploration, when people want to know more about the nature of the vast stimulus (i.e., as part of the accommodation process; Keltner & Haidt, 2003). In the case of threat-based awe, however, exploration tendencies are likely to be relatively low. Since positive awe is more common than threat-based awe, exploration is likely to be relatively high on average. Regarding approach-avoidance tendencies, people may be passively engaged with the experience of awe (Shiota et al., 2007), as also suggested by the phrase "standing in awe". The need for accommodation that is theorized to form the awe experience is more likely to involve "taking in" new and expectancy exceeding (but already existing) information rather than actively pursuing answers or information that is not yet available. The latter type of exploration is more characteristic of curiosity or interest rather than awe. Finally, studies comparing awe to other positive experiences suggested that participants do not want the awe experience to stop (Shiota et al., 2007). Since the sensation of "not wanting something to stop" represents a passive stance, in the end we assumed that, on average, awe is likely to be characterized by neither approach nor avoidance.

Surprise

Surprise is the emotion that arises in response to stimuli that are different than expected—such as an unanticipated sight, a sudden computer crash, or an unexpected sound (Meyer et al., 1997; Noordewier et al., 2016, 2021; Parmentier et al., 2018; Reisenzein et al., 2006, 2017). It is associated with the interruption of ongoing thoughts and activities to move one's attention to the surprising stimulus to make sense of it (Hortmann, 2015; Meyer et al., 1997; Noordewier et al., 2016; Reisenzein et al., 2017). Surprise thus facilitates sense-making, to be able to respond quickly and effectively to the unanticipated situation (Reisenzein et al., 2017).

Elicitors. Surprising stimuli are likely to be rated as novel, as people did not anticipate these stimuli to occur (Brosch, 2009; Scherer, 1999). The stimuli can probably be seen as both simple and complex, depending on the ease with which people can make sense of it (e.g., an unexpected taste requires simple updating, while surprising new knowledge may require more elaborate integration; Noordewier et al., 2016; Reisenzein et al., 2017). While complex surprises may be associated with little information, we think that overall, surprising stimuli are likely to be rated as containing sufficient information (i.e., particularly after making sense of the surprise). The key elicitor of surprise is disconfirmed expectancies (Meyer et al., 1997; Noordewier et al., 2016; Reisenzein et al., 2006, 2017), while exceeded expectancies are possible but less likely (as stimuli that go beyond what was thought possible may still be anticipated in their regular size; see logic on awe and Gocłowska et al., 2021).

Subjective experience. The valence of surprise has been debated, most likely because different methodologies have focused on different parts of the temporal dynamics of surprise. That is, initial responses to surprising events are primarily driven by the unexpectedness of the outcome, which can be negative because it is unpleasant not to know what is going on (Noordewier et al., 2016; Noordewier & Van Dijk, 2019). Later responses to surprising

events are more likely to incorporate the valence of the surprising outcome itself, as it reflects the state after sense-making when the outcome is understood. These later responses thus also include affective states that *followed* it after sense-making (e.g., joy after a positive surprise, or disappointment in case the situation turns out to be more negative than anticipated). Since the current studies focused on retrospective evaluations of a situation that involved surprise, the valence ratings thus likely include the valence of the nature of the surprise (i.e., the outcome is already understood). Because people seem to associate the word surprise with relatively positive events (e.g., more so than the word unexpectedness; Noordewier & Breugelmans, 2013), the average ratings in the current studies are likely to be relatively positive[2]. In addition, surprise is associated with increased arousal (e.g., in studies using self-report, or skin-conductance and pupillary dilation; Collet et al., 1997; Fontaine et al., 2007; Niepel, 2001; Reisenzein et al., 2006; see also Proulx et al., 2017). Coping potential most likely depends on the type of event that is recalled (higher when the surprise is positive vs. negative), with relatively high coping on average given the increased likelihood of recalling positive events. Finally, surprise is known to interrupt ongoing thoughts and activities to facilitate sense-making (Horstmann, 2015; Meyer et al., 1997), which is why it may also be a relatively absorbing experience.

Action tendencies. In terms of action tendencies, it seems likely that surprise is associated with exploration and approach, because of the sense-making processes that follows surprise (Horstmann, 2015; Noordewier et al., 2016; Reisenzein et al., 2017). At the same time, however, avoidance may be possible when the surprising event turns out to be difficult to deal with. That is, once people understand the nature of the unexpected event (i.e.,

[2] For a more elaborate discussion on the difference between the initial vs. later responses to surprise, see Noordewier and Breugelmans (2013), Noordewier et al. (2016), Noordewier & Van Dijk (2019). In these papers, we also discuss why retrospective evaluations may not be the best method to study the valence of surprise. In the General Discussion, we also discuss the advantages and limitations of this methodology for the current results.

they made sense of it), they may want to avoid it when they assess they cannot cope with it—for instance, when it is too complex to understand (Silvia, 2010) or when it involves threat (Hagenaars et al., 2014; Noordewier et al., 2021; see also Scherer, 1999).

Curiosity and Interest

Curiosity and interest are the emotions that arise in response lack of information—such as during intellectual challenges or when confronted with teasers and questions (Gruber et al., 2014; Litman et al., 2005; Marvin & Shohamy, 2016, Murayama et al., 2019; Silvia, 2005). Although the two emotions are not identical (Murayama et al., 2019; Pekrun, 2019), their core features are highly overlapping, so it makes sense to discuss them together. Curiosity is typically the product of an information-gap (i.e., specific information is missing; Litman, 2005; Loewenstein, 1994—but see diversive curiosity, Day, 1971; Noordewier & Van Dijk, 2020), while interest involves a more general motivation to engage with new information (Pekrun, 2019; Silvia, 2005).

Elicitors. For curiosity, novelty and complexity ratings may depend on the type of situation that is recalled: Stimuli are likely to be rated low on novelty and complexity when they concern rather simple information-gaps (e.g., trivia questions or hints about what is to come; Gruber et al., 2014; Hsee & Ruan, 2016; Noordewier & Van Dijk, 2017; Van Dijk & Zeelenberg, 2007), but ratings will be higher in situations related to epistemic or intellectual curiosity (Fayn et al., 2019; Litman & Spielberger, 2003). For interest, novelty and complexity ratings are more likely to be high, as interest is typically the consequence of novelty-complexity appraisals (Silvia, 2005; see also Gocłowska et al., 2017; Murayama et al., 2019; Noordewier & Van Dijk, 2016; Pekrun, 2019). For both curiosity and interest, the available information is likely to be rated low, as these emotions are often the consequence information that is missing. Finally, we saw no clear basis to predict that disconfirmed or exceeded expectancies are key features of interest and curiosity.

Subjective Experience. The valence of curiosity and interest is both relatively positive because people enjoy exploring and anticipating new information (Kashdan et al., 2018; Kashdan & Silvia, 2012; Peterson & Hidi, 2019; Silvia & Kashdan, 2009). However, because interest involves a more general exploratory state—rather than a focus on specific information that is missing, which can also feel like deprivation—interest is likely to feel more positive than curiosity (Noordewier & Van Dijk, 2017, 2020; see also Pekrun, 2019). Regarding arousal, we are not aware of studies testing this directly, but it seems plausible that curiosity and interest involve moderate levels of arousal due the motivating nature of these emotions (cf. drive theories or the search for optimal levels of arousal, e.g., Berlyne, 1960; Litman, 2005; Loewenstein, 1994). Next, coping potential is likely to be high for both curiosity and interest, as curious people anticipate they will find the missing information (i.e., they have a sense of control regarding this; Pekrun, 2019; Peterson & Cohen, 2019) and interested people feel they are able to deal with the information (i.e., this is part of their appraisal structure; Silvia, 2010). There does not seem to be a particular relation between curiosity and interest and interruption, but curiosity and interest may be relatively absorbing because of the (intrinsic) motivation to engage with the information (e.g., Pekrun, 2019).

Action Tendencies. In terms action tendencies, curiosity and interest should be associated with exploration and approach, because these emotions involve a relatively strong motivation to find new or missing information (Noordewier & Van Dijk, 2020; Niehoff & Oosterwijk, 2020; Silvia, 2010).

Confusion

Confusion is the emotion that arises in response to an ongoing mismatch between new information and prior knowledge—such as when art, science, or philosophy is hard to understand, or when someone is unsure how to proceed in a complex problem-solving task (Arguel et al., 2019; D'Mello et al., 2014; Fayn et al., 2019; Muis et al., 2015b; Silvia, 2010).

Confusion is characterized by an impasse, but it also involves a motivation to figure out what is not yet known or understood (Di Leo et al., 2019; D'Mello & Graesser, 2011, 2012; Lodge et al., 2018; Muis et al., 2018)

Elicitors. Confusing stimuli are likely to be rated novel and complex, as these appraisals are known to be central to confusion (Fayn et al., 2019; Silvia, 2010). Similarly, the amount of information will likely be rated as low, as confusion involves a situation where people feel they need more information to better understand what is going on (D'Mello et al., 2014, Silvia, 2010). For disconfirmed and exceeded expectancies, we see no particular relation—unless people would not see their confusion coming (i.e., disconfirming the notion that one is knowledgeable in a certain domain).

Subjective Experience. Confusion feels negative because it is generally unpleasant to be in an impasse that involves lack of understanding (D'Mello et al., 2014; Fayn et al., 2019; Silvia, 2010; see also Harmon-Jones et al., 2009; Proulx et al., 2012). It may be somewhat arousing, as part of the motivation to figure it out and possible frustration that may arise (D'Mello & Greasser, 2011, 2012; Di Leo et al., 2019). Coping potential ratings are likely to be low because confusion involves appraisal of low comprehensibility and the feeling of being stuck (D'Mello et al., 2014; Fayn et al., 2019; Silvia, 2010, 2013). We do not see a particular reason for increased interruption or feeling small and predictions for absorption are not completely clear; it may be high when one engages effort to figure out what is not understood, but it may also be low when one is demotivated to deal with it.

Action Tendencies. Whether confusion is associated with exploration and approach likely depends on whether people see a way out of their confusion. Even when people are in an impasse and a stimulus it difficult to understand, confusion can result in exploration and approach because people to engage in efforts to figure it out (Arguel et al., 2019; D'Mello & Graesser, 2012; Lodge et al., 2018). This is also the explanation for the fact that confusion

may be beneficial for learning (D'Mello et al., 2014; see also Spann et al., 2019). However, when confusion endures and lack of understanding remains, it may become (too) frustrating. At this stage, people will have low exploration tendencies and become motivated to avoid the situation (Arguel et al., 2019; D'Mello & Graesser, 2012; Lodge et al., 2018; Silvia, 2010).

Boredom

The picture of epistemic emotions would not complete without boredom. This emotion is quite different from other epistemic emotions, as it involves lack of stimulation. Boredom arises in response to a mismatch between actual and desired levels of attentional engagement—such as when a stimulus lacks stimulation because they are mundane, meaningless, or highly repetitive (Bench & Lench, 2013; Eastwood et al., 2012; Tam et al., 2021; Van Tilburg & Igou, 2012).

Elicitors. Boredom-inducing stimuli are likely to be rated low on novelty and complexity, because of the unchallenging nature of these type of stimuli (Daschmann et al., 2011; Harris, 2000; Martin et al., 2006; O'Hanlon, 1981)[3]. For the same reasons, the amount of information is likely to be rated as highly sufficient, while disconfirmed and exceeded expectancy ratings will likely also be low (Tam et al., 2021).

Subjective Experience. Boredom is a negative emotion (Martin et al., 2006; Van Tilburg & Igou, 2017) that is associated with non-optimal arousal that can fluctuate from low arousal (e.g., when one is apathetic or lonely) to high arousal (e.g., when one gets frustrated or restless; see Tam et al., 2021, for a more elaborate discussion on this). Coping potential may not be particularly low or high, as boredom typically results from lack of challenge,

[3] Note that boredom can also occur when stimuli are too challenging, as it can be difficult to sustain attention when being over-challenged (Tam et al, 2021; see also D'Mello & Graesser, 2012, Pekrun et al., 2010). We think, however, that with the autobiographical recall procedure as used in the current studies, it is more likely that people will recall under-challenged events (see also Harris, 2000, who showed that "lack of things to do" and "having to wait" were the most frequently mentioned causes of boredom). Following this, we think it is more likely that novelty and complexity ratings will be low. Be come back to the advantages and disadvantages of recall in the General Discussion.

while there are also connections to low control (Pekrun, 2006; Smith & Ellsworth, 1985; Van Tilburg & Igou, 2012, 2017). Finally, we see no reason to expect a particular relation with interruption, absorption, or with feeling small.

Action Tendencies. In terms of action tendencies, boredom is likely to be associated with a strong desire to avoid the boring stimulus (Smith & Ellsworth, 1985; Van Tilburg & Igou, 2012), which will also result in low exploration ratings[4].

The Current Studies

Taken together, there is some evidence about key elicitors, subjective experience components, and action tendencies associated with different epistemic emotions, but there is no systematic comparison of epistemic emotions *together*. This makes it hard to predict which emotions group together and how emotions can be differentiated. Interest, curiosity, and confusion are a good example here: they can all arise when information is missing, but confusion is negative and associated with low coping potential, while curiosity and interest are more enjoyable and associated with high coping potential. Equally, awe, interest, and curiosity may arise in reaction to novelty, but awe (vs. interest and curiosity) could potentially associate with less information seeking. Studying epistemic emotions together could thus help us understand what features of emotions distinguish between groups of epistemic emotions, as well as between individual emotions within those groups.

Our first aim was to uncover the central features of all epistemic emotions. To do so, we used network analyses and explored which emotion features are most central to and defining of epistemic emotions as a *group*. The most central and defining features of epistemic emotions can explain the most variance among those emotions and may be the most useful for making broad general distinctions (e.g., positive vs. negative epistemic

[4] Note that exploratory motivation and approach towards meaningful *alternative* activities is also possible, to reach the desired level of attentional engagement again (Bench & Lench, 2013; Martin et al., 2006; Tam et al., 2021; Van Tilburg & Igou, 2012, 2019). But as our measure focused on the emotional experience, low exploration and avoidance are most likely.

emotions). Our second aim was to make distinctions between *individual* emotions (e.g., awe stands out as being associated with feeling small). Our predictions regarding features of each individual emotion were tested a priori. We focused on features that stand out as high or low for each emotion (compared to all other epistemic emotions together). Figure 2 summarizes our (preliminary) predictions, which were derived from our literature review (see earlier sections).

To test our predictions, we conducted two studies. Study 1 had a mixed exploratory and confirmatory nature, while Study 2 aimed to confirm the findings from Study 1 by testing whether the findings would replicate (pre-registered). Given the plausible variety of the different events that people will recall, we ran highly powered studies where we aimed to recruit 450 participants (i.e., 75 participants per knowledge state condition)[5]. The general approach in both studies was similar, such that we followed the method used by Campos et al. (2013, Study 1) in their study of positive emotions. In Campos' research, participants were asked to recall an event in which they felt one of eight positive emotions. Participants then rated their experience on various dimension (e.g., valence) and additionally, elicitors, appraisals, and action tendencies were coded by independent coders. In the current studies, we followed a similar approach, but rather than employing coding procedures, which can be somewhat subjective, we asked participants to rate all features themselves.

Transparency and Openness

The studies include sensitivity power analyses. We report all data exclusions, all manipulations, and all measures in the study. All data, analysis code, and research materials are available at DataVerseNL (https://dataverse.nl/dataverse/SocPsy). Data were analyzed

[5] The actual distribution is different (see Method of Studies 1 and 2). Possibly, some emotions were easier to recall than others (e.g., awe vs. boredom), resulting in somewhat unequal drop-out.

using R version 4.1.2 (network analyses) and SPSS version 27 (emotion-specific comparisons). Study 2 was pre-registered, and Study 1 was not.

Study 1

Study 1 aimed to explore the network structure of epistemic emotions appraisals and to test the predictions that were formulated based on the current state of the literature. The study was approved by the Psychology Research Ethics Committee of Leiden University (CEP18-0314/160).

Method

The study was conducted on Prolific Academic, where we selected UK-based and native English participants between 18 and 65 years old[6]. A total of 453 participants completed our experiment (M_{age} = 36.63, SD_{age} = 11.57; 329 females, 123 males, 1 other/rather not say). They were randomly assigned to one of the six emotion conditions (awe, surprise, curiosity, interest, confusion, boredom). We excluded 42 participants who indicated that they understood less than 80% of the instructions[7]. We report analyses from the remaining 411 participants (M_{age} = 36.96, SD_{age} = 11.69; 299 females, 111 males, 1 other/rather not say). A sensitivity power analysis (calculated in G*Power 3.1; Faul et al., 2009) indicated that with $\alpha = .05$, and a power of $\beta = .80$, this sample size provides sufficient power to detect effects of $f = 0.18$ (i.e., $\eta_p^2 = .03$, omnibus effect).

Procedure and Materials

Participants were asked to recall a recent situation in which they experienced awe (n = 56), surprise (n = 72), curiosity (n = 68), interest (n = 68), confusion (n = 70), or boredom (n

[6] We checked these selection criteria with answers to country and language questions. This confirmed that all participants were UK-based, except one participant who was located in Sweden. Given that this participant was native English, the participant was included in the data. Next, all participants were native English, except one native German and one native Chinese participant. Given that both participants reported to have sufficient levels of understanding, we kept both in the data.

[7] This exclusion criterium was pre-registered in Study 2. For consistency, we used the same criterium in the current study.

= 77). We asked them to describe this in as much detail as possible, following the procedure as described in Campos et al. (2013). Specifically, participants could use different text boxes to answer the following questions (where [emotion] referred to the emotion-labels of each condition):

- "Describe in as much detail as possible what made you to feel [emotion]"
- "Describe in as much detail as possible how you felt and what you thought *while* experiencing [emotion]. Note that we are not asking about feelings and thoughts that you had before or after your experience of [emotion]. Instead, we want you to describe was going through your mind during your experience of [emotion]. Describe everything about the experience that you can remember: What were your feelings? What was going through your mind? What physical signs of [emotion] did you experience or display (i.e., what happened to your body)?
- "Did your experience of [emotion], in the moment described above, change you in any way (e.g., did it lead to any long-lasting changes in your relationship with people or in how you view the world)?"
- "Can you add anything that would help us understand your experience more fully?"

Dependent Measures. After participants completed the recall task, they answered questions about what caused the experience (elicitors), how it made them feel (subjective experience), and what it made them do (action tendencies). This allowed us to surpass the need to subjectively code participants' responses, leaving it to the research participants to rate the features of their emotional experience. All items could be completed on 7-point Likert-scales from 1 = *strongly disagree*, to 7 = *strongly agree*.

Elicitors. First, participants rated whether the situation they experienced was associated with having *(too) little information,* using the items "too little information" and "sufficient information" (reverse coded; $\alpha = .84$)[8]. Next, participants rated the *novelty* of the situation using the items "novel" and "familiar" (reverse coded; $\alpha = .49$[9]), and the *complexity* of the situation on the items "complex" and "simple" (reverse coded; $\alpha = .79$). Finally, participants rated whether the event *disconfirmed* and/or *exceeded* their expectancies with the items "disconfirmed", "confirmed" (reverse coded; $\alpha = .79$), and "exceeded". These items were presented after we explained to participants that expectancies are disconfirmed when something is "different than expected", confirmed when something is "similar as expected", and exceeded when something is "more than expected" (see Appendix A).

Subjective Experience. Next, participants proceeded to rating of subjective experience components. We measured *valence* with the items "I felt positive", "I felt negative" (reverse coded; $\alpha = .96$). We measured *arousal* with "I felt energized", "I felt my energy decrease" (reverse coded; $\alpha = .89$). We measured *coping potential* with "I felt like I had the means to deal with the situation", "I didn't think I could cope with the situation" (reverse coded), "I could understand what was required in the situation", "I felt unsure how to cope with the situation" (reverse coded; $\alpha = .83$). *Interruption* was measured with the question "interrupted my prior thoughts and activities". *Absorption* was measured with "consumed my attention". Finally, *feeling small* was measured with "made me feel small relative to the environment.

[8] For the sake of data reduction, we aggregated the items "too little" and "sufficient info" into an index of having (too) little information. Results of each item separately were highly similar. Note that high scores on this index are interpreted as having (too) little information and low scores on this index are interpreted as having sufficient information. We dropped the item "too much information". Results for Studies 1 and 2 showed that boredom was rated higher on this item (2.94 and 2.78, respectively) than the mean of all other emotions (2.35 and 2.29, respectively).

[9] Given that this reliability is too low, we analyzed the single item "novel".

Action Tendencies. Finally, participants rated action tendencies. *Exploratory motivation* was measured with "I wanted to know more about the situation", "I wanted to learn more about the source of [emotion]", "I wanted to explore what was going on" (α = .85). *Avoidance motivation* was measured with "I wanted for the experience to continue" (reverse coded), "I wanted to move away from the source of [emotion]", "I didn't want to feel [emotion]", "I wanted the experience to stop", and "I wanted to do something else" (α = .96; low avoidance scores can thus be interpreted as approach). These exploration and avoidance motivation items were presented together and in a mixed order.

Demographics and Background Questions. At the end of the study, we asked participants to report their gender (male, female, other/rather not say) and age (open question). Next, to capture our selection criteria, we asked participants about their country of residence and their first language (open questions). Finally, to check for the level of understanding of the study, we asked "How much did you understand of the instructions in this study, expressed as a percentage?" on a rating scale from 10% to 100%, in steps of 10. Participants could then leave remarks before they were fully debriefed and rewarded for the time spent on the study[10].

Results

We aimed to identify 1) central features to *all* epistemic emotions and 2) specific distinctions between *individual* epistemic emotions. We used network analyses to test which emotion features are most central to and defining of the *group* of epistemic emotions. The most central and defining features of all epistemic emotions should be able to explain the most variance among those emotions. These features may be the most useful for making

[10] To be able to check whether all emotions were equally difficult to recall we also asked participants to report how difficult was it to recall the situation on a scale from 1 = *not at all,* to 7 = *extremely*. Analyses can be found in the Supplemental Materials and show that reported difficulty was low, with no differences between conditions for Study 1 and somewhat higher/lower difficulty for curiosity/boredom in Study 2.

broad general distinctions between epistemic emotions. Following the network analyses, we used one-way ANOVAs with deviance contrasts to distinguish between *individual* emotions and test our *a priori* predictions.

Step 1: Network Analyses

Centrality of emotion features could be established using network analysis. Network analysis can help identify and analyze patterns of statistical associations in multivariate psychological data. Unlike traditional factor-analytic approaches, network analysis makes no assumptions about latent structures and is typically conducted on the level of observed variables (i.e., individual appraisal items; see Epskamp et al., 2012). This was useful for our purpose because we wanted to observe which characteristics drawn from a broad (but not necessarily unitary) pool of features are most important to how *all* epistemic emotions are experienced. In Study 1, this was done in an exploratory and descriptive fashion. The network analysis was intended to illustrate and structure our argument and the resulting theory.

To uncover what features are central (vs. peripheral) to epistemic emotions across the board, we entered the emotion features as input for a correlation[11] network analysis. In network analysis all observed variables are plotted as nodes and their associations as edges within a network. The strength of the associations and the position of the individual nodes provide information about the importance of each variable to the network. Important nodes are placed more centrally while strong relationships between nodes are indicated with a thicker edge weight. Beyond visual inspection of the network (Figure 6), the analysis provides centrality indices of respective nodes (Figure 7). In our study we decided to rely on the index of strength, which reflects the overall connectivity of a node with other nodes by

[11] Because we focused on centrality, irrespective of whether it results from direct or indirect relations, we analyzed a correlation (vs. partial correlation) network. When the shared variance of an item with multiple other items is controlled for in a partial correlation network, this makes the items extremely hard to interpret (Lynam et al., 2006; Verschuere et al., 2018), and using a correlation network helped us avoid such problems.

summing up the (absolute values of) weights of the node's associations with other nodes. The higher the strength index the greater the centrality (i.e., importance) of a node (i.e., observed variable) within the network.

Estimation Method. Correlation network analysis computes a network structure based on bivariate marginal correlations producing a saturated model with edges included in the model. This was computed using the *cor* procedure in the *qgraph* package (Epskamp et al., 2012) for R version 4.1.2 (2021-11-01). Using the *bootnet* package we conducted additional robustness checks (edge weight estimates and their confidence intervals; centrality stability) the results of which can be found in the online Supplemental Materials (Figures S1 and S2). These analyses should be routinely conducted as part of a network analysis (Burger et al., 2023) but are not central to the current paper.

Network Visualization. Thirteen variables measuring features of epistemic emotions were entered into the network analysis[12]. We chose to compute the network based on correlational data (pairwise comparisons) from participants across all conditions ($N = 411$), as we were looking to find out what features are most central to all epistemic emotions and should then be strongly considered when distinguishing epistemic emotions from one another.

Figure 6 (left panel) represents the network structure of the features of epistemic emotions. The strength of relations between items can be inferred from the thickness of the edges and the distance between the individual nodes. Positive correlations are plotted as a continuous line while negative correlations are plotted as a dashed line. Edge thickness represents the magnitude of correlation. Very small correlation coefficients ($r < .10$) were not plotted, while large correlation coefficients ($r > .80$) have been emphasized by bolding the

[12] Note that in Study 2, we dropped one coping potential item, one exploration item, and three approach-avoidance items (see Method Study 2). To keep the studies comparable, the network analyses included only the items that occur in both studies.

respective edges. For ease of interpretation, items from the same functional group (e.g., elicitors) have been plotted using the same color, however this visual grouping has no bearing on the statistical analysis or its outcomes.

The results reveal that the subjective components of valence (POS, NEG), arousal (EN, LEN) and coping potential (COP, NCO, NSU), as well as the action tendency of avoidance (EXS, NOF)[13] are the central and defining features of the epistemic experiences. Action tendencies indicating approach motivation (LMR, KMR) as well as subjective experiences to do with attention processes (DAT, INT) and with feeling small (SMA) were less central to the network. None of the elicitors (NOV, FAM, CMP, SIMP, DIS, CON, EXC, LIN, SIN, MIN) emerged as central to the network suggesting that, while these variables might be useful to researchers in order to understand more subtle differences between discrete emotions, they are not considered as central *to the experience of* epistemic emotions across the board.

Centrality Index. For a further confirmation of the above findings, we produced an index of node strength (raw strength scores; representing the overall connectivity of one node to all other nodes), which is helpful in interpreting the centrality (i.e., importance) of each node within the network. The higher the strength index of a node the more central that node is within the network of variables. Additional analyses plotting centrality over increasingly smaller bootstrapped sub-samples indicated that the above order of the strength index is stable (see Figure S2). This was further supported by a correlation stability coefficient that was well over the recommended value of .50 (CS-coefficient cor = .75), indicating we can confidently interpret differences in strength.

[13] Note that for the network analyses, all items are entered individually, while in the emotion-specific comparison, we aggregate the approach-avoidance items into an avoidance index.

Figure 7 (left panel) depicts strength indices of the various appraisals in Study 1 (collapsed across epistemic emotions). Appraisals of valence (POS, NEG), arousal (EN, LEN) and coping potential (COP, NCO, NSU), as well as the action tendency of avoidance (EXS, NOF) have high centrality scores. Action tendencies indicating approach motivation (LMR, KMR) as well as subjective experiences to do with attention processes (DAT, INT) and with feeling small (SMA) were less central to the network, and so were all elicitors (NOV, FAM, CMP, SIMP, DIS, CON, EXC, LIN, SIN, MIN).

Taken together these results illustrate that valence, arousal, coping potential, and avoidance are the most central features of all epistemic emotions and should guide our attention when trying to build a framework that helps distinguish between various epistemic emotions (e.g., positive vs. negative epistemic emotions), whereas the remaining features of emotions might be more helpful in making comparisons between discrete emotions of a similar kind (e.g., disconfirmation of expectations may help us distinguish between awe and surprise, but not between all epistemic emotions in general).

Step 2: Ratings of the Emotions

Next, we tested our predictions regarding specific differences between *individual* emotions by comparing the different emotions in terms of elicitors (what caused the experience), subjective experience components (how it felt), and action tendencies (what behavior it motivated). One-way ANOVAs revealed that the emotions differed on all the above classes of constructs (see Table 1). Omnibus effects were followed up with deviance contrasts. Deviance contrasts were chosen because they compare the mean of one condition (e.g., awe) to the mean score collapsed across the remaining conditions (e.g., the mean across surprise, interest, curiosity, confusion, boredom). This type of comparison allowed us to identify dimensions on which each epistemic emotion stood out against the remaining

emotions (see Figures 3-5), while keeping the results relatively brief. Readers interested in comparing distinct emotions can explore our online datasets.

Below we thus describe how each emotion stood out (i.e., was significantly different) relative to the overall mean of all epistemic emotions together. For the predictions, see Figure 2. To increase readability and to avoid drawing conclusions from null effects, we only report whether an emotion is statistically different (rather than similar) in comparison the overall mean. Given the number of comparisons, we do not report marginal differences.

Awe. Regarding elicitors (see Figure 3), awe stood out in terms of having sufficient information, low disconfirmed expectancies, and high exceeded expectancies[14]. Regarding subjective experience (see Figure 4), awe stood out in terms of positive valence, high arousal, high coping potential, high absorption, and high levels of feeling small. Finally, regarding action tendencies (see Figure 5), awe stood out in terms of low avoidance.

Surprise. Next, we analyzed the ratings of surprise. Regarding elicitors, surprise stood out in terms of high novelty, high disconfirmed expectancies, and high exceeded expectancies. Regarding subjective experience, surprise stood out in terms of positive valence, high arousal, high coping potential, and low levels of feeling small. Regarding action tendencies, surprise stood out in terms of low avoidance.

Curiosity. Regarding elicitors, curiosity stood out in terms of having little information. Regarding subjective experience, curiosity stood out in terms of positive valence, high arousal, and high coping potential. Regarding action tendencies, curiosity stood out in terms of high exploration and low avoidance.

Interest. Regarding elicitors, interest stood out in terms of having sufficient information. Regarding subjective experience, interest stood out in terms of positive valence,

[14] Note that "stood out" always denotes "was significantly different from, at $p < .05$". Using this simple phrase allows us to clearly and efficiently describe large numbers of significant findings.

high arousal, high coping potential, lower interruption, high absorption, and low levels of feeling small. Regarding action tendencies, interest stood out in terms of high exploration and low avoidance.

Confusion. Regarding elicitors, confusion stood out in terms of high complexity, having little information, high disconfirmed expectancies, and low exceeded expectancies. Regarding subjective experience, confusion stood out in terms of negative valence, low arousal, low coping potential, high interruption, high absorption, and high levels of feeling small. Regarding action tendencies, confusion stood out in terms of high avoidance.

Boredom. Finally, we focused on boredom. Regarding elicitors, boredom stood out in terms of low novelty, low complexity, and low disconfirmed/exceeded expectancies. Regarding subjective experience, boredom stood out in terms of negative valence, low arousal, and relatively lower coping potential, lower interruption, lower absorption, and higher levels of feeling small. Finally, regarding action tendencies, boredom stood out in terms of low exploration and high avoidance.

Discussion

Taken together, we see many but not all of our predictions confirmed. Given the exploratory nature of some of the predictions and the number of statistical comparisons, we are conservative in our interpretation of the results of Study 1 and therefore, we conducted Study 2 as a direct replication to test which results would replicate. At the end of Study 2, we will provide a full summary of the results based on the findings that are obtained in both studies (i.e., those that replicate).

Study 2

Study 2 was a near-direct and pre-registered replication of Study 1 (https://osf.io/xvn8h[15]). The study was approved by the Psychology Research Ethics Committee of Leiden University (CEP18-0314/160).

Method

The study was conducted on Prolific Academic, with the same selection criteria as Study 1[16]. A total of 426 participants completed our experiment (M_{age} = 36.91, SD_{age} = 12.18; 302 females, 121 males, 3 other/rather not say). They were randomly assigned to one of the six emotion conditions (awe, surprise, curiosity, interest, confusion, and boredom). We excluded 34 participants who indicated that they understood less than 80% of the instructions. We report analyses of the remaining 392 participants (M_{age} = 36.94, SD_{age} = 12.16; 276 females, 113 males, 3 other/rather not say). A sensitivity power analysis (calculated in G*Power 3.1; Faul et al., 2009) indicated that with $\alpha = .05$, and a power of $\beta = .80$, this sample size provides sufficient power to detect effects of $f = 0.18$ (i.e., $\eta_p^2 = .03$, omnibus effect).

Procedure and Materials

Participants were again asked to recall an event where they experienced awe (n = 67), surprise (n = 65), curiosity (n = 61), interest (n = 66), confusion (n = 56), or boredom (n = 77). We followed the same procedure as Study 1, except for the following changes to the dependent measures: To increase reliability of the novelty measure, we changed the item "familiar" to "unfamiliar". In addition, to shorten the questionnaire, we dropped one coping

[15] Changes relative to the pre-registration: We aggregated "disconfirmed" and "confirmed" (reverse coded), as well as "too little information" and "sufficient information" (reverse coded). We dropped "too much information" (see note 8). We refer to absorption (rather than consumed attention) and exploration (rather than know more). Changes relative to the research proposal on OSF: See logic in the Introduction section and note 3.
[16] We again checked the selection criteria with the answers to the country and language questions. This confirmed that all participants were UK-based, except one participant who was located in France. Given that this participant was native English, we kept him/her in the data. Next, all participants were native English.

potential item ("could understand what was required in the situation"), one exploration item ("wanted to explore what was going on"), and three avoidance items ("wanted to move away from the source of [emotion]", "wanted to do something else", and "wanted for the experience to continue").

The remaining items were the same as Study 1: As elicitors, we measured novelty (with the adapted item: $\alpha = .56$, which is still rather low, so we continue to analyze the item "novelty"), complexity ($\alpha = .88$), having (too) little information ($\alpha = .87$), disconfirmation of expectancies ($\alpha = .78$), and exceeding expectancies. As subjective experience components, we measured valence ($\alpha = .96$), arousal ($\alpha = .90$), coping potential ($\alpha = .87$), interruption, absorption, and feeling small. Finally, as action tendencies, we measured exploratory motivation ($\alpha = .85$) and avoidance motivation ($\alpha = .95$).

Results

We analyzed the data in the same steps as Study 1, such that we first conducted network analyses (to identify shared features) and then compared the different emotions using ANOVAs and deviance contrasts (to understand the key and replicable differences between discrete emotions).

Step 1: Network Analysis

The network analysis was conducted in an identical way as in Study 1 with the exception that this time our aim was to identify patterns of centrality that are consistent across both studies. For the network structure see right-side panel in Figure 6 and for centrality indices right-side panel in Figure 7 (CS-coefficient cor = .75). Identical to Study 1, we computed the network based on correlational data (pairwise comparisons) from participants across all conditions ($N = 392$). Results supported what we have uncovered in Study 1: valence (POS, NEG), arousal (EN, LEN), coping potential (COP, NCO, NSU), and avoidance (EXS, NOF) are the most central features of epistemic emotions together. These

features should guide our attention when trying to build a theoretical model that helps distinguish between *groups* of epistemic emotions (e.g., positive vs. negative epistemic emotions), whereas the remaining features of emotions might be more helpful in making comparisons between *individual* emotions.

Step 2: Ratings of the Emotions

Next, we compared the different emotions in terms of elicitors, subjective experience components, and action tendencies. The emotions differed on all measured constructs (see Table 2). We compared each emotion in terms of differences relative to the overall mean of *all emotions together* (i.e., deviance contrasts; see Figures 3-5). Like in Study 1, we do not report marginal differences. Below, we describe the findings of Study 2 in term of how they differed from Study 1. See the General Discussion for a summary of all results (Studies 1 and 2 combined).

For *awe* results replicated Study 1, except that awe also stood out in terms of high novelty and low complexity, while we no longer found differences on disconfirmed expectancies. For *surprise* results replicated Study 1, except that surprise also stood out on sufficient information, while we no longer found differences on novelty. Also unlike in Study 1, surprise stood out in terms of high interruption, while we no longer found differences on coping potential. For *curiosity* results replicated Study 1, except that curiosity now stood out with low levels of feeling small, while we no longer found differences for valence and coping potential. For *interest* results replicated Study 1, except that interest stood out in terms of low disconfirmed expectancies and high exceeded expectancies. Also unlike in Study 1, we no longer found differences in interruption. For *confusion* results replicated Study 1, except that we no longer found differences on absorption (although ratings are very high). Also unlike in Study 1, confusion also stood out with high exploration. Finally, for *boredom* results for boredom fully replicated Study 1.

Discussion

Taken together, the results of Studies 1 and 2 (i.e., those findings that replicate) show features that categorize and distinguish different epistemic emotions (see Figure 8 for a summary). A summary of these findings is presented in the General Discussion.

General Discussion

Epistemic emotions occur as a function of various properties of the information provided, like information that is complex, unexpected, or in another way not understood. They can thus arise in numerous situations: in reaction to an intellectual challenge, vast aerial views, trivia questions, or an unexpected turn of events. Epistemic emotions are key to people's willingness to explore and update knowledge representation (e.g., Keltner & Shiota, 2003) and with that, they are responsible for various important outcomes related to learning, interest, or openness (e.g., D'Mello et al., 2014; Fayn et al., 2019; Gocłowska et al., 2017; McPhetres, 2019; Muis et al., 2018, Silvia, 2010).

Epistemic emotions are hardly ever studied together, making it difficult to predict what features are shared and what features are unique to each emotion. In the current research, we studied the main epistemic emotions side-by-side, with the aim to identify 1) central features to *all* epistemic emotions and 2) specific distinctions between *individual* epistemic emotions. In two experiments, we compared awe, surprise, curiosity, interest, confusion, and boredom in terms of their elicitors, subjective experience components, and actions tendencies. Participants were asked to recall an experience in which they felt one of the epistemic emotions, and they rated this emotion on various measures related to what caused the experience, how it made them feel, and what it made them do. We analyzed these rating using network analyses, to describe which features are the central and defining for all epistemic emotions together. Next, we compared the ratings of each specific emotion to the overall mean of all emotions, to test which features are key for each specific emotion.

Summary of Results

Our conclusions are based on findings that were found in both studies (i.e., the findings that replicate, with some exceptions; see also Figure 8). First, the network analyses suggests that valence, arousal, coping potential, and avoidance tendencies are central features of all epistemic emotions. Comparing epistemic emotions (i.e., comparing the rating of each emotion to the mean of all emotions) on those central features can reveal distinct sub-groups of emotions. Specifically, we found that awe, surprise, and interest are relatively positive emotions, which together with curiosity, were characterized by high arousal, high coping potential (for surprise and curiosity only in absolute sense in Study 2), and approach tendencies. Confusion and boredom are, on the other hand, relatively negative emotions that were characterized by low arousal, low coping potential, and avoidance tendencies.

Next, while not central in the network analyses, we saw high (absolute) ratings of interruption and absorption for all epistemic emotions—with particularly high interruption for confusion, and particularly high absorption for awe and interest (and lower scores for boredom). This contradicts previous literature, which suggested more specific predictions—such that surprise (and possibly awe) would be interrupting (Meyer et al., 1997, Reisenzein et al., 2017; Van Elk et al., 2016, 2019); and that awe (and possibly surprise, curiosity, and interest) would be absorbing (Pekrun, 2019; Van Elk et al., 2016, 2019). Feeling small was, as predicted, part of awe (Piff et al., 2015; Van Elk et al., 2016, 2019), but we also found it for confusion, and for boredom (with low scores for surprise and interest). Next, while all emotions except boredom were associated with high exploration in an absolute sense, curiosity and interest scored higher in exploration than all other emotions did (see also Murayama et al., 2019; Noordewier & Van Dijk, 2020; Silvia, 2010).

Finally, while none of the elicitors appeared as a central feature in the network analyses, we found them useful for making distinction between individual emotions.

Specifically, novelty did not differentiate between emotions, expect for boredom for which, as predicted, novelty was low (see also Daschmann et al., 2011; Harris, 2000; Martin et al., 2006; O'Hanlon, 1981; Tam et al., 2021). As predicted, confusion stood out in terms of high complexity (see also Fayn et al., 2019; Silvia, 2010), while boredom stood out in terms of low complexity. Next, as predicted, curiosity and confusion stood out as having high scores on (too) little information (in line with e.g., D'Mello et al., 2014; Litman, 2005; Loewenstein, 1994), while awe and interest stood out as high in terms of sufficient information. Awe and surprise stood out as high in exceeding expectancies (see also Gocłowska et al., 2021; with low scores for boredom and confusion), with surprise additionally scoring high in terms of while disconfirmed expectancies (see also Meyer et al., 1997; Noordewier et al., 2016; Reisenzein et al., 2017). Unlike our predictions, confusion additionally stood out for reports of high disconfirmed expectancies.

Implications and Future Directions

These findings provide several valuable insights into the central and more specific features of epistemic emotions. First, epistemic emotions can be clearly grouped in terms valence, and this positive vs. negative dimension corresponds almost always with a differentiation into high vs. low coping potential, high vs. low arousal, high vs. low exploration, and approach vs. avoidance tendencies. An emotion that stands out, however, is confusion—with high exploration *and* high avoidance tendencies at the same time. This may reflect a mixed motivational state, where people want to figure out what they do not understand yet, but at the same time want to avoid the negativity of feeling low ability to cope (see also Arguel et al., 2019; D'Mello et al., 2014; Silvia, 2010). Future studies could test whether low coping potential indeed underlies avoidance. The unexpected finding that confusion is associated with disconfirmed expectancies suggests that people may not always see confusion coming. Following this, it would be interesting to test whether people feel

better equipped to deal with confusion when they are prepared for it (e.g., by informing them that confusion is common when dealing with complexity; see also Muis et al., 2018; Spann et al., 2019). In addition, it seems relevant to include measures on whether the situation was resolved or not, as confusion may disconfirm expectancies less when one was able to figure things out. Such a measure can also be relevant for other epistemic emotions. For example, surprise may be more negative when people could not yet make sense of the unexpectedness.

Next, while all emotions (except boredom) scored high on exploration, there were some differences in intensity. Specifically, curiosity and interest scored systematically higher than all other emotions on exploration (and confusion is higher only in Study 2). Awe and surprise, om the other hand, scored high on exploration only in an absolute sense (compared to the scale midpoint rather than the mean of all emotions). Some explanation of these differences may be gleaned from the elicitors of surprise and awe. Surprise is associated with a motivation to make sense of disconfirmed expectancies and after one made sense of this unexpectedness, there may be nothing left to explore (e.g., Noordewier & Van Dijk, 2019; Reisenzein et al., 2017). Awe results from a sense of exceeded expectancies. People who feel awe are likely to be engaged in "taking in" and accommodating expectancy exceeding information, but this type of state is more static (when compared to interest and curiosity). Contrary, the exploration associated with curiosity and confusion is better described as a motivation to find (missing) information, as these emotions are both elicited by having (too) little information, which for confusion is related to complexity (see also D'Mello et al., 2014; Loewenstein, 1994; Niehoff & Oosterwijk, 2020; Noordewier & Van Dijk, 2020). The emotion that is markedly different than curiosity and confusion is interest. Contrary to predictions, interest did not stand out in terms of its association with complexity and (too) little information (contradicting e.g., Silvia, 2005, 2010). Instead, interest was (together with awe) associated with having *sufficient* information. The fact that interest was still

systematically high on exploration fits with the view that interest involves a rather general motivation to explore, which is different from a more specific search for missing information in curiosity and confusion (Murayama et al., 2019; Noordewier & Van Dijk, 2020; Pekrun, 2019).

Future studies could more systematically test motivations underlying exploration. For example, curiosity, confusion, and interest could be differentiated more clearly by testing specific vs. more general exploratory motivation against each other (i.e., finding specific information vs. exploration for the sake of exploration; see also Day, 1971; Noordewier & Van Dijk, 2020). Also, it would be interesting to test whether a motivation to immerse oneself in a situation (which may for example differ for awe as compared to interest) lowers exploration. Future studies could also test when and why exploration stops. For example, when people made sense of unexpectedness or found the information they were looking for, their surprise, curiosity, or confusion will likely dissipate, and exploration stops. Yet, when outcomes present new questions or information-gaps, a new cycle may start, where different epistemics emotions follow each other, such when interest or confusion can follow surprise.

Future research could also address the possibility that features are interpreted differently depending on the specific emotion that is recalled. For example, feeling small might be interpreted more positively in the context of awe (e.g., as part of a bigger whole) versus in the context of confusion and boredom (e.g., falling short). The current studies included definitions of (dis)confirmed and exceeded expectancies, but additional definitions could address any interpretation issues. Next, on a more conceptual level, it would be interesting to compare the structure of epistemic emotions to other types of emotions (e.g., positive emotions). Studies could test whether epistemic emotions have a different network structure or different central features than other emotions. This will provide valuable insights into whether and how epistemic emotions are a unique group of emotions.

Finally, it is worth considering practical implications of the current findings. With the numerous situations in which epistemic emotions can occur, the directions are plenty. Our findings could for example be relevant to institutions like science museums or art centers, as they could help to understand the effectiveness of exhibitions and learning contexts (e.g., measure whether exhibitions evoke positive epistemic emotions and desirable outcomes like exploration). Likewise, our findings could be applied to the design of exhibitions elements to promote more specific responses (e.g., highlight exceeding features like the size of a T-Rex or the number of stars in the galaxy, to promote absorption and approach). Our findings can also have implications for communication professionals. When communicating about unknown information (e.g., new policies or scientific discoveries), it is useful to understand the central features of epistemic emotions (e.g., boost coping potential with the use of visualizations or clear language to promote curiosity and approach rather than confusion and avoidance). Thus, all in all, there is plenty of scope for practical implications in the study of epistemic emotions.

Limitations

The current research provides various valuable insights into the central and more specific features of epistemic emotions, but it is of course not without limitations. First, it is important to note that even though autobiographical recall is a useful and often-used method in emotion research (De Hooge et al., 2011; Gadeikis et al., 2017; Ozawa et al., 2021; Siedlecka & Denson, 2019), a downside is that it may have obscured some of the dynamics of epistemic emotions. Particularly surprise is known to be a transient emotion that quickly turns to other affective states, which can be hard to "catch" with recall procedures (Noordewier et al., 2016, 2021). Therefore, the current results may also incorporate some of the affective states that occurred after sense-making (e.g., a positive valence, when the recalled surprise was a positive event; see also Noordewier et al., 2016). More generally, the

retrospective evaluations of the emotions may miss some of the intensity or complexity of the real-life emotion. Therefore, although conditions may become more difficult to compare, it is important to replicate the current findings with more incidental emotion induction paradigms.

A second limitation is that the current research design was not suited to check the impact of specific appraisals. For some measures, we predicted that scores could be both low and high—for example that both approach *and* avoidance would be possible for confusion, depending on whether people want to solve their impasse or avoid their negative state. With the current general measures, we may have missed such moderating effects—where positive and negative scores would be aggregated around, for example, the midpoint of the scale. Future studies could include more specific measures that incorporate moderating appraisals.

Third, our analyses focused on how emotions stand out *relative* to the mean of all emotions. We did this to identify which features stand out for specific emotions and to streamline the large amount of data. However, this approach leaves out some nuance in the results that would have been found when emotions were compared directly to each other (e.g., that awe and interest are more positive than surprise). Similarly, these relative results should not be confused with the *absolute* scores on the different features. That is, when there is little differentiation between emotions on a measure, or when a feature stands out for only one emotion, this does not mean that scores are low or irrelevant on other emotions (see for example the results on absorption or exploration, which are high for almost all emotions but particularly high for some). We aimed to develop a framework for understanding the different epistemic emotions together and future studies could build on this to uncover more nuanced differences, by comparing epistemic emotions directly on a selection of features.

Fourth, the features in our studies were selected based on a careful literature review, but we may have missed some. For example, Vogl et al. (2020) showed that confidence in one's knowledge impacted surprise, curiosity, and confusion (i.e., the more certain one is that

knowledge is correct the more impact it has when it appears incorrect). A relevant elicitor could therefore be the extent to which information violated prior knowledge or the certainty of one's priors. Similarly, Muis et al. (2015a) pointed to the relevance of epistemic beliefs more broadly (see also Chevrier et al., 2019; Hofer & Pintrich, 1997). They showed that seeing information as part of evolving (vs. certain) knowledge and seeing knowledge construction as an active (vs. more passive) process predicted emotions like curiosity and confusion in a learning task. It may therefore be relevant to consider the impact of beliefs about knowledge and the process of knowing and future studies could replicate and extend the current work with such additional features.

Constraints on Generality. Finally, we relied on samples from the UK, which may constrain the generality of our findings (Henrich et al., 2010; Simons et al., 2017). Cultures may vary in elicitors, subjective experience components, and action tendencies of epistemic emotions. For example, East Asian vs. Western cultures are more likely to engage in dialectical thinking, which involves a higher tolerance of contradictory beliefs (Peng & Nisbett, 1999). Following this, contradiction or inconsistency may be less surprising or confusing in East Asian vs. Western cultures (see also Valenzuela et al., 2010). In addition, it is key to take language into account. To illustrate, in Polish, which is the native language of the second author, "awe" translates as either "groza", denoting an intense sense of terror, or "zachwyt" denoting intense delight, however there is not one word that would denote both the positive and the threat-based awe variant at the same time. Translational issues should thus be considered before generalizing our findings to non-English samples.

Conclusion

In sum, our comparison of epistemic emotions allowed us to identify central features of all emotions as well as specific features of (sub-groups of) individual emotions. We showed that valence, arousal, coping potential, and avoidance tendencies are central features

of all epistemic emotions. The positive emotions are awe, surprise, and interest, which together with curiosity, are associated with arousal, high coping potential, and approach. The negative emotions are confusion and boredom, which are both associated with low arousal, low coping potential, and avoidance. In the more specific analyses, we saw that novelty did not differentiate emotions (except low sores on boredom), while complexity was only high in confusion. Expectancies were associated with awe (exceeded expectancies) and surprise (exceeded/disconfirmed expectancies), while (too) little information was linked to curiosity and confusion. All emotions (except boredom) scored high on exploration, but the motive underlying exploration seemed to differ, such that awe and surprise were motivated by makings sense of how reality is different than expected, while curiosity and confusion were better described by a motivation to find missing information. Interest stood out in this context, as people reported having sufficient information, suggesting a rather general motivation to explore. An unanticipated but interesting effect is that all emotions were evaluated as relatively interrupting and absorbing. This may reflect the engaging nature of the different epistemic emotions and with that, we think it highlights the relevance of people's motivation to know and understand one's environment.

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Appendix A

Instructions to ratings of event in terms of relation to expectancies

Next, we would like to ask you how the moment you described related to your expectations. People enter situations with different expectations. Sometimes those expectations can be (1) disconfirmed, and sometimes they can be (2) confirmed or (3) exceeded. To better illustrate this distinction, think of what you know about dinosaurs, and what expectations you may have when attending an exhibition featuring a scientifically accurate replica of a dinosaur.

(1) By “disconfirming expectations” we mean that something was completely different than we expected it to be. For example, before coming to the exhibition you may have thought that dinosaurs were covered in scales, however the dinosaur featured in the exhibition was actually covered in feathers. This dinosaur disconfirmed your expectations.

(2) By “confirming expectations” we mean that something was exactly the way you expected it to be. For example, before coming to the exhibition you may have thought that dinosaurs were covered in scales. As expected, the dinosaur featured in the exhibition was indeed covered in scales. This dinosaur confirmed your expectations.

(3) By “exceeding expectations” we mean that something was better, greater, more intense, stronger etc. than you expected. For example, before coming to the exhibition you may have thought that dinosaurs were very large. As expected, the dinosaur featured in the exhibition was very large. However, it was also much, much larger than you expected. This dinosaur exceeded your expectations.

Table 1

Effects of Emotion (awe, surprise, curiosity, interest, confusion, boredom) on elicitors, subjective experience components, and action tendencies (one-way ANOVAs, Study 1).

		Statistics			
Feature group	**Feature**	***df***	***F***	***p***	η_p^2
Elicitors	Novelty	(5,405)	11.58	< .001	.13
	Complexity	(5,405)	7.46	< .001	.08
	Too little information	(5,405)	21.67	< .001	.21
	Disconfirmed expectancies	(5,405)	15.71	< .001	.16
	Exceeded expectancies	(5,405)	24.25	< .001	.23
Subjective Experience	Valence	(5,405)	116.07	< .001	.59
	Arousal	(5,405)	119.33	< .001	.60
	Coping potential	(5,405)	29.77	< .001	.27
	Interruption	(5,405)	5.17	< .001	.06
	Absorption	(5,405)	17.23	< .001	.18
	Feeling small	(5,405)	13.22	< .001	.14
Action Tendencies	Exploration	(5,405)	51.53	< .001	.39
	Avoidance	(5,405)	185.14	< .001	.70

Table 2

Effects of Emotion (awe, surprise, curiosity, interest, confusion, boredom) on elicitors, subjective experience components, and action tendencies (one-way ANOVAs, Study 2).

		Statistics			
Feature group	**Feature**	***df***	***F***	***p***	η_p^2
Elicitors	Novelty	(5,386)	5.73	< .001	.07
	Complexity	(5,386)	8.97	< .001	.10
	Too little information	(5,386)	25.43	< .001	.25
	Disconfirmed expectancies	(5,386)	15.72	< .001	.17
	Exceeded expectancies	(5,386)	32.38	< .001	.30
Subjective Experience	Valence	(5,386)	79.08	< .001	.51
	Arousal	(5,386)	81.78	< .001	.51
	Coping potential	(5,386)	20.66	< .001	.21
	Interruption	(5,386)	7.97	< .001	.09
	Absorption	(5,386)	11.34	< .001	.13
	Feeling small	(5,386)	10.99	< .001	.13
Action Tendencies	Exploration	(5,386)	50.92	< .001	.40
	Avoidance	(5,386)	140.95	< .001	.65

Figure 1

The elicitors, subjective experience components, and action tendencies included in Studies 1 and 2.

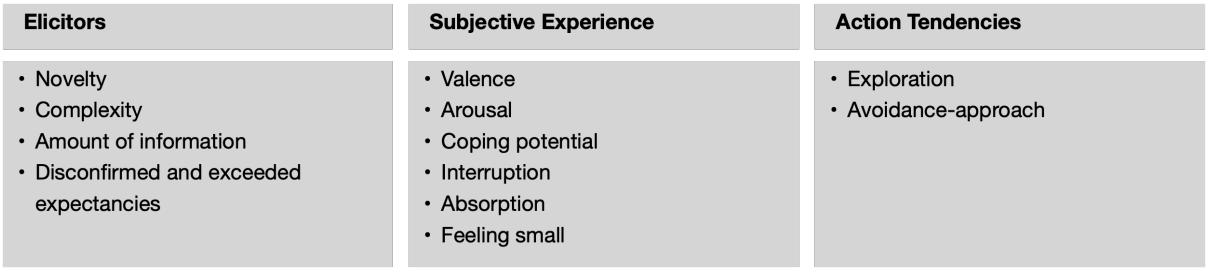
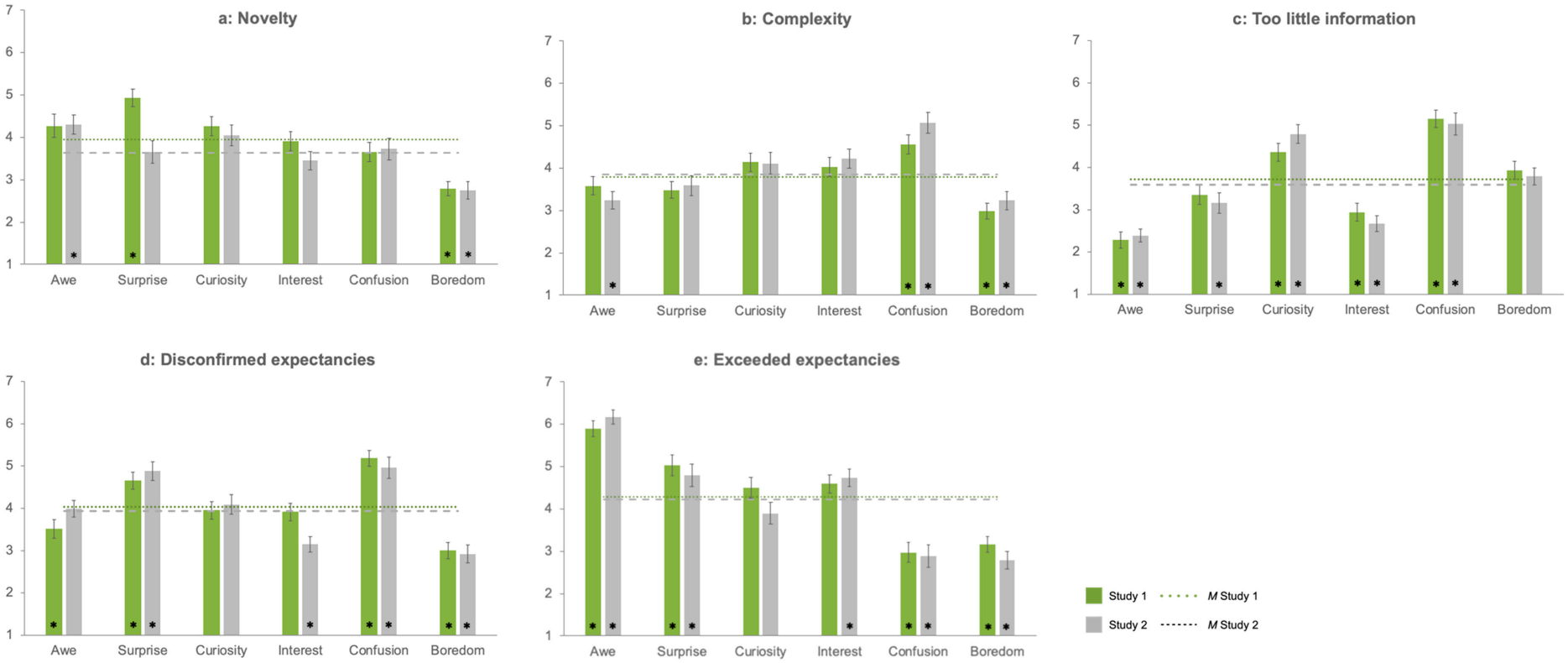


Figure 2
Summary of (preliminary) predictions based on a literature review.

Awe	Surprise	Curiosity	Interest	Confusion	Boredom
• Novelty • Sufficient information • Exceeded expectancies	• Novelty • Sufficient information • Disconfirmed expectancies	• Little information	• Novelty • Complexity • Little information	• Novelty • Complexity • Little information	• Low novelty • Low complexity • Sufficient information • Confirmed expectancies • Low exceeded expectancies
• Positive* • Arousal • High coping potential* • Interruption • Absorption • Feeling small	• Positive* • Arousal • High coping potential* • Interruption • Absorption	• Positive • Arousal • High coping potential • Absorption	• Positive • Arousal • High coping potential • Absorption	• Negative • Arousal • Low coping potential • Low or high absorption	• Negative • Low or high arousal
• Exploration* • No approach no avoidance	• Exploration • Approach*	• Exploration • Approach	• Exploration • Approach	• Low or high exploration • Approach or avoidance	• Low exploration • Avoidance

Note. The asterisk indicates the likely average result, but high variance across situations is possible. Predictions were formulated regarding the features on which a particular emotion is high (as compared to other emotions).

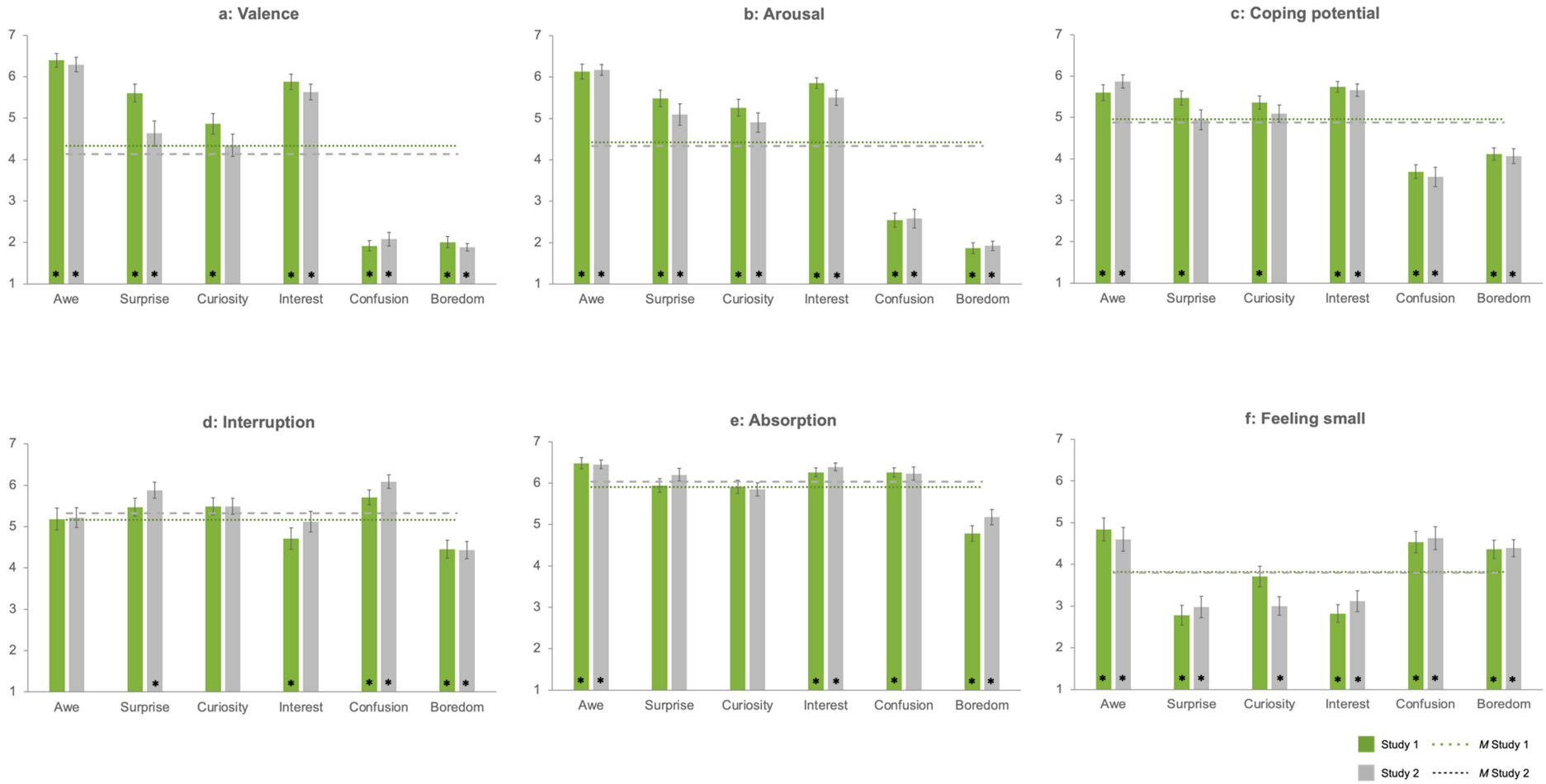
Figure 3
Elicitors as a function of Emotion.



Note. Error bars indicate +/- 1 SE. *****Significant difference within the specific study at $p < .05$ in deviance contrast analyses. Deviance contrasts are comparisons to the overall mean of all emotions, presented with dotted lines for Study 1 and dashed lines for Study 2. An asterisk thus indicates a significant difference relative to this mean of all emotions, within Study 1 (left bars) or Study 2 (right bars).

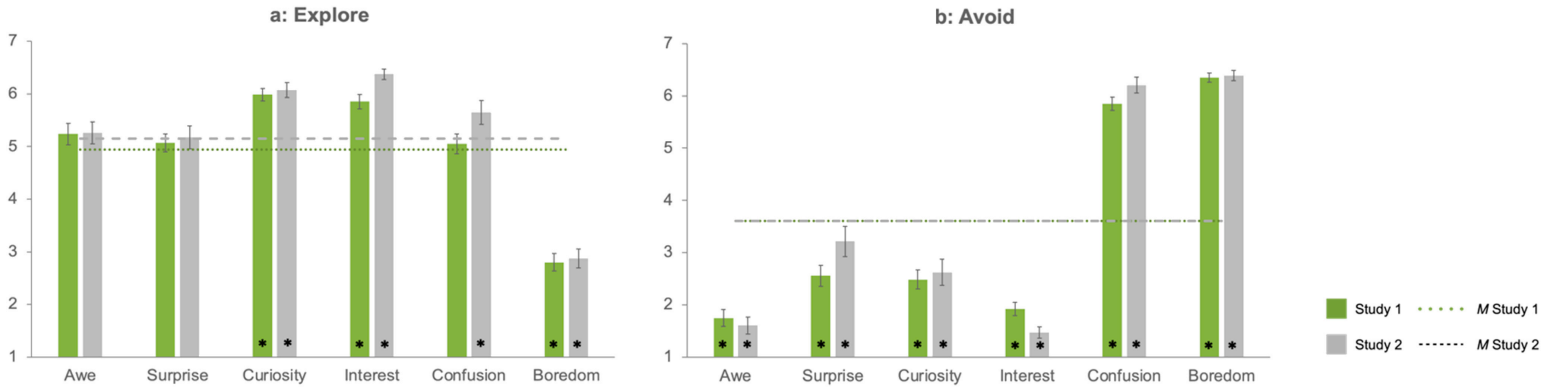
Figure 4

Subjective experience components as a function of Emotion.



Note. Error bars indicate +/- 1 SE. *Significant difference within the specific study at $p < .05$ in deviance contrast analyses. Deviance contrasts are comparisons to the overall mean of all emotions, presented with dotted lines for Study 1 and dashed lines for Study 2. An asterisk thus indicates a significant difference relative to this mean of all emotions, within Study 1 (left bars) or Study 2 (right bars).

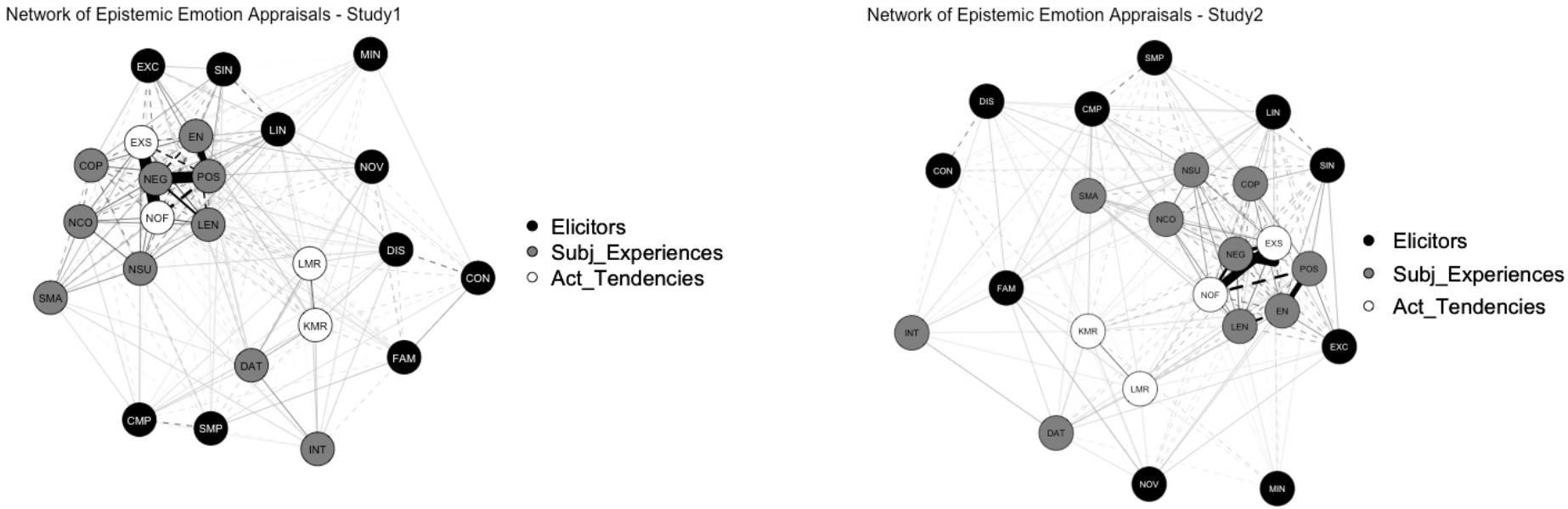
Figure 5
Action tendencies as a function of Emotion.



Note. Error bars indicate +/- 1 SE. *Significant difference within the specific study at $p < .05$ in deviance contrast analyses. Deviance contrasts are comparisons to the overall mean of all emotions, presented with dotted lines for Study 1 and dashed lines for Study 2. An asterisk thus indicates a significant difference relative to this mean of all emotions, within Study 1 (left bars) or Study 2 (right bars).

Figure 6

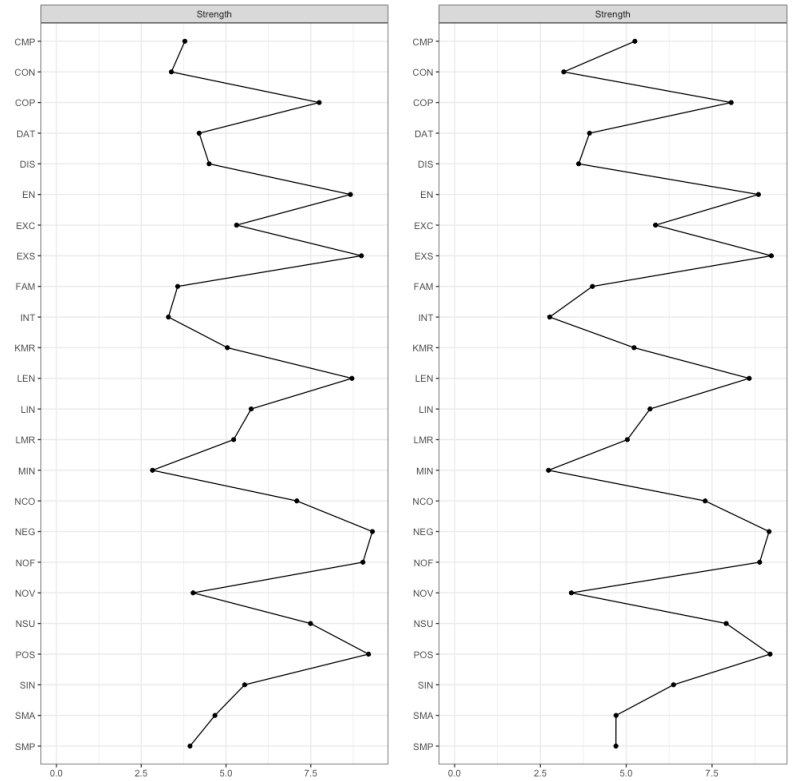
Network structure (collapsed across all epistemic emotions) in Study 1 (left panel) and Study 2 (right panel).



Note. The network structure suggests that the subjective components of valence (POS, NEG), arousal (EN, LEN), and coping potential (COP, NCO, NSU), as well as the action tendency of avoidance (EXS, NOF) are the central and defining features of the epistemic experiences.
Elicitors include NOV = novel, FAM = familiar, CMP = complex, SMP = simple, DIS = disconfirmed expectancies, CON = confirmed expectancies, EXC = exceeded expectancies, LIN = too little information, SIN = sufficient information, and MIN = too much information. Subjective experience components include COP = Had means to deal with the situation, NCO = Didn't think I could cope with the situation, NSU = Felt unsure how to cope with the situation, INT = interrupted my prior thoughts and activities, DAT = consumed my attention, SMA = made me feel small relative to the environment, NEG = negative, POS = positive, EN = energized, LEN = low energy. Action tendencies included KMR = wanted to know more about the situation, LMR = wanted to learn about the source, NOF = didn't want to feel, EXS = wanted the experience to stop.

Figure 7

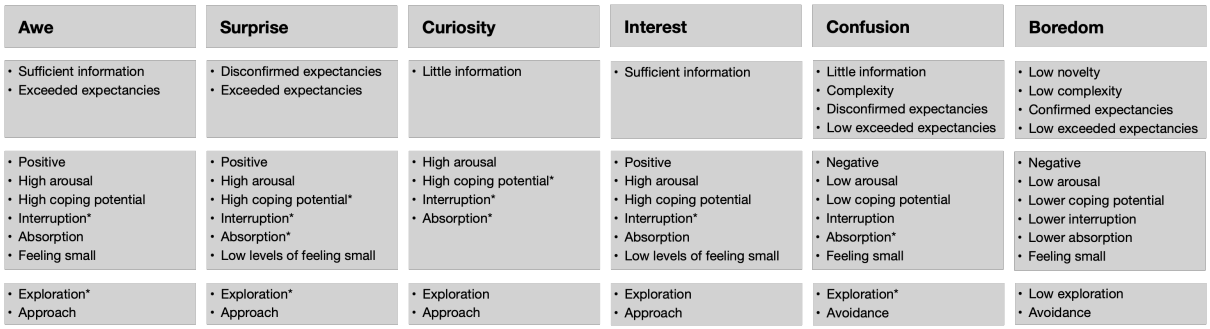
Network strength indices (collapsed across all epistemic emotions) in Study 1 (left panel) and Study 2 (right panel).



Note. The network strength indices suggest that the subjective components of valence (POS, NEG), arousal (EN, LEN), and coping potential (COP, NCO, NSU), as well as the action tendency of avoidance (EXS, NOF) are the central and defining features of the epistemic experiences.
Elicitors include NOV = novel, FAM = familiar, CMP = complex, SMP = simple, DIS = disconfirmed expectancies, CON = confirmed expectancies, EXC = exceeded expectancies, LIN = too little information, SIN = sufficient information, and MIN = too much information. Subjective experience components include COP = Had means to deal with the situation, NCO = Didn't think I could cope with the situation, NSU = Felt unsure how to cope with the situation, INT = interrupted my prior thoughts and activities, DAT = consumed my attention, SMA = made me feel small relative to the environment, NEG = negative, POS = positive, EN = energized, LEN = low energy. Action tendencies included KMR = wanted to know more about the situation, LMR = wanted to learn about the source, NOF = didn't want to feel, EXS = wanted the experience to stop.

Figure 8

Summary of results as found in both Studies 1 and 2.



Note. The central features of epistemic emotions (valence, arousal, coping, and avoidance tendencies) help divide emotions into a group of positive emotions (awe, surprise, interest) with high arousal, high coping, and approach tendencies (surprise, awe, curiosity, interest) and negative emotions, with low coping, low arousal, and avoidance tendencies (boredom, confusion). Other emotion features help make more subtle distinctions within each of those groups—for example between approach emotions that are linked to sufficient information (interest, awe) or insufficient information (curiosity) The asterisk indicates that the means are high only in an absolute sense, not in comparison to the mean of all other emotions.