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Clarifying the Relation Between Epistemic Emotions and Learning by Using Experience Sampling Method and Pre-posttest Design

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Epistemic emotions (surprise, curiosity, enjoyment, confusion, anxiety, frustration and boredom) have an object focus on knowledge or knowledge construction and are thus hypothesized to affect learning outcomes. In the context of upper secondary school science, the present study clarifies this relation by examining the students' pre- and posttest performance (n = 148 students) and their experiences of situational epistemic emotions (n = 1801 experience sampling method observations). As expected, epistemic emotions correlated with both pre- and posttest performance: curiosity and enjoyment correlated positively, and frustration and boredom correlated negatively with the performance. However, based on structural equation modeling, after controlling for the pretest performance, only boredom was found to have a significant negative effect on posttest performance. The findings underline the complexity of the interplay between emotions and learning. Thus, the state versus trait nature of epistemic emotions, and the implications for research and practice are being discussed.

Keywords: epistemic emotions, learning, academic performace, experience sampling method (ESM), pre-posttest design

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INTRODUCTION

Recently, the role of emotions in educational contexts has received increasing interest (e.g., Pekrun et al., 2018). Especially, the entanglement between affect and cognition has been acknowledged (Muis et al., 2021), and the relation between emotions and learning or academic performance has been addressed in numerous studies (e.g., Muis et al., 2015; Efklides, 2017; Camacho-Morles et al., 2021; Sainio et al., 2021). Emotions are typically defined as affective episodes that are caused by a certain stimulus or antecedent, and have an object (Ekman, 1992; Russell, 2003; Shuman and Scherer, 2014). Thus, they are different from moods or attitudes that are typically more stable and long lasting, and do not necessarily have such a clear stimulus nor an object. However, also moods and attitudes are often related to learning or performance (Beege et al., 2018; Cahill et al., 2018). In turn, learning can be defined as a process in which a person acquires new skills, knowledge or understanding, whereas, performance or achievement can be considered as more stationary constructs, reflecting merely the state of a learning process (Gross, 2015).

Considering the nature of emotions as situational constructs and learning as a dynamic process, two things need to be considered when aiming to study the relation between emotions and learning. First, emotions should be measured in the actual learning situations and not, for example, by using retrospective questionnaires (Goetz et al., 2016). Second, if learning is conceptualized as a change in performance (Gross, 2015), it cannot be studied cross-sectionally, but a person's prior knowledge needs to be taken into account. However, despite the vast of amount of research conducted on the relation of emotions and learning-related variables, many of the previous studies have limitations in terms of using only the retrospective measures of emotions (e.g., Ainley and Ainley, 2011; Ding and Zhao, 2020) or cross-sectional measures of learning or performance (e.g., Ketonen and Lonka, 2012; Putwain et al., 2021). Moreover, there is a paucity of studies conducted in ecologically valid, real-life classroom settings.

In this regard, the aim of the present study is to discover how situational epistemic emotions relate to students' learning in a real-life upper secondary school science context. The objective is to examine the relationship between students' self-reported, real-time experience sampling method (ESM) data about epistemic emotions and their pre- and posttest scores measuring their performance and learning.

Epistemic Emotions

Academic emotions are defined as emotions occurring in educational settings or relating to learning, studying or other academic activities (Pekrun et al., 2018). Based on their antecedents or object focuses, Pekrun et al. (2018) further classify academic emotions into four categories. First, achievement emotions have their stimuli or object focus in success or achievement in academic tasks. Second, topic emotions relate to the actual topics being studied. Third, social emotions occur in educational contexts similar to any other context in people's life; they relate to social relationships, such as those between students and teachers or among peers. And fourth, epistemic emotions have an object focus in knowledge or knowledge construction, and thus relate directly to the learning process itself.

Epistemic emotions, such as surprise, curiosity, enjoyment, confusion, anxiety, frustration and boredom, typically occur in situations where new information is contradictory to student's previous conceptions and experiences, where cognitive representations are questioned or new understandings are developed (Pekrun et al., 2017, 2018). Epistemic emotions can also occur simultaneously or in sequences (Bosch and D'Mello, 2017). Learning new skills or contents can feel enjoyable and interesting. However, if the novel information is incongruous or contradictory, a student may feel surprise or confusion. If confusion is not resolved, it may lead to anxiety or frustration. In turn, if anxiety or frustration persists, a student can eventually get bored and withdraw oneself from the learning situation. Instead, if the cognitive discrepancy that caused the confusion in the first place is resolved, a student may again experience enjoyment and curiosity (Bosch and D'Mello, 2017; Pekrun et al., 2018). Thus, in learning situations, epistemic emotions can give rise to a complex interplay between cognitive and affective factors.

It is worth noting that the four subcategories of academic emotions described above are not clean-cut nor mutually exclusive. Instead, a certain emotion can represent various subcategories depending on its stimuli or object. For example, enjoyment of meeting friends in the class would be a social emotion, but enjoyment of learning new things would appear as an epistemic emotion. Likewise, anxiety for a forthcoming exam is an achievement emotion, but anxiety aroused by a cognitive discrepancy is an epistemic emotion.

In addition to categorizing academic emotions based on their stimuli or objects, emotions can be also categorized by their valence and activation (Pekrun et al., 2018). In the case of epistemic emotions, curiosity and enjoyment can be considered as positive activating emotions. That is, they are experienced as pleasant or positive, and they are associated with high arousal and activation. In turn, confusion, frustration and anxiety are considered as negative activating emotions, entailing an unpleasant, negative valence and activating nature. Boredom, in turn, represents a negative deactivating emotion. Surprise is considered as an activating emotion, but its valence is more ambiguous. Depending on a situation, surprise can be experienced as a positive, negative or neutral affective experience (Muis et al., 2015; Pekrun et al., 2017).

Science Learning

In general, two types of knowledge or learning can be distinguished: the propositional knowledge of knowing *that*, and the procedural knowledge of knowing *how* (e.g., Siegel, 1998). In the context of science education, these are often referred as disciplinary core ideas and scientific practices, respectively (National Research Council, 2012). However, in science learning these core ideas and practices are often deeply intertwined. When constructing scientific knowledge and developing understanding about scientific phenomena, both are necessarily needed. Thus, also the concept of *epistemic practices* is often used in the context of science learning to emphasize that understanding science implies understanding on how scientific explanations are being generated and scientific knowledge being developed (e.g., Duschl, 2008). Furthermore, Kelly and Licona (2018) define epistemic practices as "socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims" (p. 140). Thus, science lessons can provide versatile learning situations in which students can experience a variety of epistemic emotions.

The Hypothesized Relation Between Emotions and Learning

Based on the model by Muis et al. (2015), epistemic emotions are aroused by cognitive incongruity, and influence learning outcomes through different learning strategies. Also, a number of other studies have indicated this relation between epistemic emotions, learning strategies and performance described in the Muis et al. (2015) model. First, positive activating emotions of enjoyment (Ainley and Ainley, 2011; Obergriesser and Stoeger, 2020; Camacho-Morles et al., 2021; Putwain et al., 2021) and curiosity (Gruber et al., 2014; Wade and Kidd, 2019), in addition to surprise (Chiu et al., 2014; Muis et al., 2018) and confusion (D'Mello et al., 2014; Muis et al., 2018), are related to positive learning outcomes through deep-processing learning strategies, such as elaboration and critical thinking (Muis et al., 2015, 2021). Also, surprise can have an indirect effect on learning strategies by inducing curiosity and confusion (Vogl et al., 2019). Some studies suggest that confusion is beneficial for learning only at appropriate levels, but if it goes unresolved, it can also detract from learning (D'Mello and Graesser, 2012; Schneider et al., 2016). Second, negative activating emotions of anxiety (Ketonen and Lonka, 2012; Putwain et al., 2021) and frustration (Bosch and D'Mello, 2017) are related to negative learning outcomes through shallow processing strategies, such as maintenance rehearsal (Muis et al., 2015). And third, a negative deactivating emotion of boredom (Mann and Robinson, 2009; Pekrun et al., 2014; Tze et al., 2016; Camacho-Morles et al., 2021) impairs the use of any learning strategies, thus also leading to negative learning outcomes (Muis et al., 2015).

Based on the research reviewed above, the effect of emotions on performance seems evident. Furthermore, some research shows that performance can also influence students' emotional experiences. For example, Sainio et al. (2021) found that students with learning difficulties tend to experience more negative academic emotions than students without such difficulties. Also, previous research suggests that academic emotions can play a mediating role between learning difficulties and achievement (Sainio et al., 2019). Thus, it seems that prior knowledge can influence how students perceive new, and often complex, information, thus arousing varying emotional experiences in them. Together these findings suggest a reciprocal relationship between emotions and performance, and a possible mediating role of emotions in learning processes.

Although a number of studies have been carried out on the relation between emotions and learning-related variables, most of them have used only cross-sectional measures of performance (Mann and Robinson, 2009; Ketonen and Lonka, 2012; Bosch and D'Mello, 2017; Ding and Zhao, 2020; Putwain et al., 2021) and/or retrospective measures of emotions (Mann and Robinson, 2009; Ainley and Ainley, 2011; D'Mello et al., 2014; Pekrun et al., 2014; Sainio et al., 2019, 2021; Ding and Zhao, 2020). Thus, albeit providing valuable and solid evidence on the existing relations between affects and performance, these studies give very little, if any, information about the relation between the emotional experiences in the actual learning situations and the change in performance (i.e., learning). In addition, studies that use situational measures of emotions are typically conducted under highly controlled, laboratory experimental conditions (e.g., Chiu et al., 2014; D'Mello et al., 2014; Gruber et al., 2014; Muis et al., 2015, 2018; Wade and Kidd, 2019; Obergriesser and Stoeger, 2020). While experimental laboratory studies provide an important perspective on situational emotions and learning, their ecological validity is limited, since students' affective experiences in experimental settings may differ from those in real-life classroom setting. In experimental settings, the arousal of emotions is typically manipulated. Instead, authentic classroom situations are ought to arouse more natural range of emotions in students. To our knowledge, there are no prior studies conducted in a real-life classroom setting that take into account both prior knowledge to examine learning progress, and the situational nature of emotions.

The Current Study

In the present study, we examine how epistemic emotions relate to students' performance and learning, in the context of upper secondary school science, by analyzing real-time ESM data about situational epistemic emotions with pre- and posttest scores measuring performance. We conceptualize pretest performance as prior knowledge and posttest performance as learning outcome. We aim to investigate the relations between emotions, performance and learning both correlationally, and by a causal model. The causal model enables us to examine the effect of situational epistemic emotions on learning outcomes after controlling for prior knowledge, as well as investigate the mediating role of epistemic emotions in the learning process, as depicted in **Figure 1**.

Based on the Muis et al. (2015) model and on previous research, we posed the following hypotheses:

H1 (correlational relations):

Situational epistemic emotions are correlated with prior knowledge and learning outcome. Situational surprise, curiosity, enjoyment, and confusion have a positive relation; and situational anxiety, frustration and boredom have a negative relation with performance. We also expect prior knowledge to correlate positively with learning outcome.

H2 (causal model):

Prior knowledge predicts situational epistemic emotions, and situational epistemic emotions in turn predict learning outcome. Epistemic emotions also mediate the effect of the prior knowledge on the learning outcome. Situational surprise, curiosity, enjoyment and confusion have a positive relation with prior knowledge and learning outcome; and situational anxiety, frustration and boredom have a negative relation with prior knowledge and learning outcome. We also expect learning outcome to be positively predicted by prior knowledge.

MATERIALS AND METHODS

Context and Participants

The data for this study was collected in Finnish upper secondary school physics classes during autumn 2019. The participants of the study (n = 148) were first year upper secondary school students from six classes, from two schools located in the Helsinki metropolitan area. A total of 64 students responded to the background questionnaire. Based on this incomplete information, students were on average 15.90 (SD = 0.56; range between 15 and 18) years old; and, 73.4% of the students identified themselves as female and 25.0% as male. Furthermore, 92.2% of the students were Finnish native speakers. In the Finnish education system, students start the first year of upper secondary level typically at the age of 15 to16 and, in Finland, females are

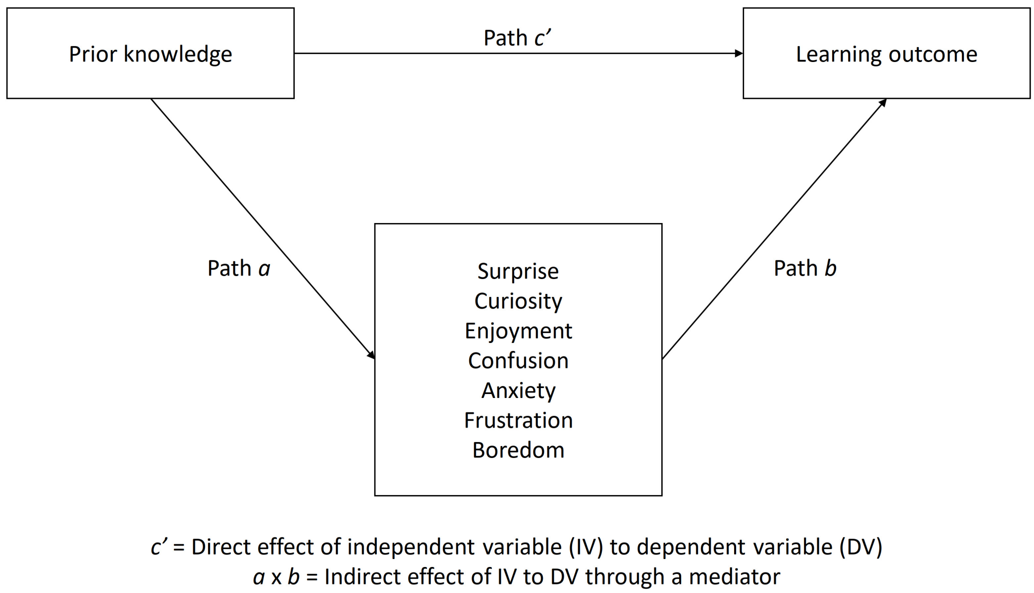


FIGURE 1 | A conceptual model in which the effect of the prior knowledge on the learning outcome is mediated by situational epistemic emotions.

slightly overrepresented among upper secondary school students, 58.2% in 2019 (Official Statistics in Finland, 2020).

In each of the participating classes, the data collection was conducted during a study period of six or seven consecutive lessons (á 75 min). There were typically three physics lessons per week, so the data collection lasted for 2 to 3 weeks for one class. The study period familiarized students with the models that describe the movement of objects with constant and changing velocity, as well as with a model (Newton's second law) describing the reasons behind the changes in motion. Instruction followed the Finnish core curriculum (Finnish National Board of Education, 2016), in which disciplinary core ideas and scientific practices (National Research Council, 2012) are emphasized.

In this study, student anonymity was carefully maintained, and informed consent was required from all the participants. Participation was voluntary. Research activities and data collection were planned together with teachers in order to disturb the schoolwork as little as possible.

Measures and Data Collection

Performance

Students' prior knowledge and learning outcomes in a study period were evaluated using a pre-posttest design. The pretest was conducted just before the study period to measure students' prior knowledge on the topic, and the posttest was conducted after the study period as part of the course exam, to measure the learning outcome. The exact same test served as both a pretest and a posttest, and it covered the disciplinary core ideas and scientific practices related to force and motion phenomena, i.e., the topics covered during the study period. In the test, understanding of the following disciplinary core ideas were measured: velocity, acceleration, force, and Newton's laws. In addition, the understanding of following scientific practices were tested: asking questions; planning and carrying out investigations; analyzing and interpreting data; developing and using models; and engaging in argument from evidence. The test was co-designed together with science education researchers and in-service physics teachers within the teacher-researcher partnership (Schneider et al., 2020; Juuti et al., 2021). The test was further developed through pilot studies and teacher reflection.

Both in pre- and posttest, students had 30 min time to complete the test. The test included altogether 13 questions. Although all items aimed to measure both understanding of disciplinary core ideas and scientific practices, each item was designed to focus either on core ideas (6 items; see an example of a test item in **Figure 2**) or practices (7 items; see an example of a test item in **Figure 3**). Thus, both types of knowledge were needed for answering the questions. There were three multiple choice items and ten open answer items. The test was conducted in Finnish, in a computer-based platform.

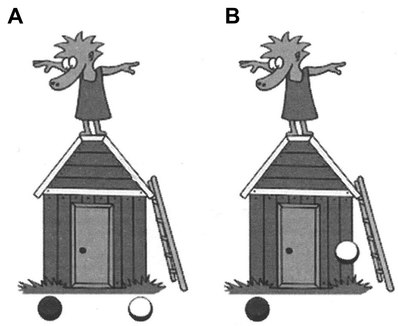
The maximum score of the test was 26. Before the assessment of the students' answers, a criteria-based scoring manual was constructed and revised after preliminary review of the answers. In the manual, typical right answers and also wrong answers were described. The right answers were constructed according to the curriculum aims in order to increase the validity of the coding. All the answers were compared to correct or incorrect answers in the coding manual to further increase the validity of the coding. All assessment was done based on those criteria by science education researchers.

Epistemic Emotions

Data on students' experiences of situational epistemic emotions was gathered using ESM (Goetz et al., 2016). Students filled out an ESM questionnaire on the basis of beeps coming to their smartphones during science lessons. The smartphones were for

The test item:

The cartoon character simultaneously drops two heavy balls of equal size. The darker ball is twice as heavy as the white ball. Which of the options below is correct?



a) Figure A is correct. The mass of an object does not affect the force with which the Earth attracts the object.

b) Figure A is correct. All objects fall in the same way if the air resistance is low compared to the weights of the balls.

c) Figure B is correct. The ground attracts the black ball more strongly, so it is the first to hit the ground. In addition, the air resistance slows down the lighter ball more.

d) Figure B is correct. The ground attracts the black ball more strongly, but the air resistance is equal for both balls because they are the same size.

e) Figure B is correct. The mass affects the falling of the objects, but air resistance has no effect when the objects are the same size.

Correct answer and coding:

Maximum scores: 1

1 score is given for a correct answer: b).

0 scores are given for any other answer.

FIGURE 2 | An example of a multiple-choice test item focusing on disciplinary core ideas (gravitational acceleration).

research use only and thus collected no personal data outside the questionnaire. The smartphones were preprogrammed to beep randomly, three times per every science lesson in the study period, however, simultaneously for each student. Thus, during the study period, each student received 18 or 21 opportunities to answer the ESM questionnaire, depending on if the teacher used six or seven lessons to cover the contents of Newtonian mechanics. This resulted in altogether 1801 answered ESM questionnaires. Each ESM questionnaire included identical items on social, emotional, and contextual aspects. In the questionnaire, epistemic emotions were measured using a modified seven-item short version of The Epistemically-Related Emotions Scales (Pekrun et al., 2017) in which students were asked: "What do you think about the activity you did? Did you feel you were... surprised/curious/excited/confused/anxious/frustrated/bored?". It should be noted that according to The Epistemically-Related Emotions Scales, the emotion of enjoyment is measured with a single item of excitement (Pekrun et al., 2017). A four-point Likert scale with the response categories from 1 = *not at all* to 4 = *very much* was used. The questionnaire was conducted in Finnish. The ESM data collection design used in this study is described in more detail by Schneider et al. (2016) and by Vilhunen et al. (2021).

Analyses

The correlational relation of the epistemic emotions and test performance was examined by bivariate Pearson correlations, conducted with IBM SPSS Statistics 26.0. The data of this study is measured at two levels: pre- and posttest performance are measured at the student level (i.e., between level), and epistemic emotions are measured at the situational level (i.e., within level). Thus, the aggregated mean values of epistemic emotions were used for the correlation analyses.

To examine the effect of epistemic emotions on the learning outcome after controlling for the prior knowledge, a parallel mediation analysis was conducted with Mplus 8.3 (Muthén and Muthén, 2017), in which a multilevel structural equation modeling (MSEM) framework was applied (Preacher et al., 2010). In a parallel mediation model all the mediating variables, in this case epistemic emotions, are included in the same model. The

The test item:

Watch the video about sledging. http://youtube.com/watch?v=3pk8gOFgmnw

Pose two questions that can be used to examine the relations between the measurable variables related to the phenomenon in the video.

Correct answer and coding:

Maximum scores: 4 (2+2)

2 scores are given for a question that examines the relation between two relevant and measurable variables. For example, "What is the correlation between the mass of the sledge (how many people in the sledge) and the time it takes to go down?" or "What is the correlation between the base area of the sledge and the time it takes to go down?"

1 score is given for

- a question that can be answered with "very much/little" or "yes/no". For example, "How much does the surface area influence the acceleration?"

- an obvious statement without a question term. For example, "The mass influences the acceleration".

0 scores are given for a question with one variable and a simple answer. For example, "How long does the way downhill take?" or "Is the velocity constant?"

FIGURE 3 | An example of an open answer test item focusing on scientific practices (formulation of questions and recognizing of problems).

ESM data of this study is hierarchical, meaning the situational observations are nested within students. Since each student answered to an ESM questionnaire multiple times, the data is clustered, and the observations are not independent. Thus, a multilevel approach is needed to take into account the nesting of the data. First, the intraclass correlations (ICC) for the epistemic emotions were calculated, to examine the level of the nestedness. Second, a two-level parallel mediation analysis was conducted to estimate the direct and indirect effects between prior knowledge, epistemic emotions and learning outcomes. In our model, both pre and posttest performance were measured at the person level (i.e., single measure, level 2) and epistemic emotions were measured at the situation level (i.e., repeated measures, level 1), leading to a 2-1-2 design (Preacher et al., 2010). The model includes two cross-level effects: a 2-1 part (the effect of pretest performance on epistemic emotions) and a 1-2 part (the effect of epistemic emotions on posttest performance). Both parts of the model were examined simultaneously and furthermore, the direct and indirect multivariate pathways were estimated. Since the predictor (pretest performance) and dependent variable (posttest performance) were measured at the between level, and only mediators (epistemic emotions) were measured at the within level, all the interpretations of the model were done on a between level. The mediator residuals were allowed to covary both in the within and between level, leading to a perfect model fit (RMSEA = 0.00; CFI = 1.00; TLI = 1.00). All variables were standardized into z-scores before the analysis.

RESULTS

Descriptive Statistics and Bivariate Correlations

The descriptive statistics of the variables are shown in **Table 1**. The ICCs of the emotions were all high and statistically significant. This indicates high similarity between observations within students and rationalizes the use of multilevel approach in subsequent analyses.

As expected, results of the correlation analyses (**Table 2**) show a significant association between pretest and posttest performance. Furthermore, positive epistemic emotions of curiosity and excitement were found to correlate positively to pre- and posttest performance, measuring prior knowledge and learning outcomes, correspondingly. In addition, negative epistemic emotions of frustration and boredom were found to correlate negatively with the pre- and posttest performance.

TABLE 1 | Descriptive statistics of the observed variables.

	$n_{between}$	n_{within}	*M*	*SD*	*ICC*
Pretest performance	136		9.70	4.09	
Posttest performance	141		12.38	4.19	
Surprise	148	1800	1.77	0.82	0.391***
Curiosity	148	1797	2.29	0.86	0.348***
Excitement	148	1798	2.32	0.88	0.510***
Confusion	148	1798	1.93	0.90	0.415***
Anxiety	148	1796	1.66	0.84	0.508***
Frustration	148	1799	1.95	0.94	0.379***
Boredom	148	1799	2.28	0.94	0.377***

*$n_{between}$, the number of students; n_{within}, the number of ESM observations; the maximum score of the pretest and the posttest was 26, epistemic emotions were measured at the Likert scale from 1 to 4; *** $p < 0.001$.*

In contradiction to our hypotheses, surprise, confusion, and anxiety had no statistically significant correlation with performance measures.

Also, epistemic emotions correlated with each other. Surprise had a statistically significant positive correlation with all the other emotions. Mainly, positive emotions correlated positively with each other and negatively with negative emotions, and vice versa. However, curiosity was found to correlate positively with confusion and anxiety.

The Causal Model

According to the MSEM (**Figure 4**), the pretest performance was the strongest predictor of the posttest performance, as expected. Pretest performance also predicted significantly all other epistemic emotions except surprise. Students' with high scores in the pretest experienced higher levels of curiosity and excitement, and lower levels of confusion, anxiety, frustration, and boredom during the study period. However, after accounting for the effect of pretest performance in the model, only boredom appeared as a significant ($p < 0.05$) predictor of posttest performance. Other epistemic emotions were not found to have a significant effect on posttest performance, which was contradictory to our hypotheses. Furthermore, according to mediation analysis, none of the situational epistemic emotions appeared as a statistically significant mediator between pretest performance and posttest performance (**Table 3**).

DISCUSSION

In this study, we examined how epistemic emotions are related to upper secondary school students' prior knowledge and learning outcomes in science, and both if and how they mediate performance during a study period. The results of the study are based on data collected with summative pre- and posttests, and with real-time ESM observations, capturing the situational nature of the epistemic emotions experienced in the authentic classroom learning situations.

The Interplay Between Epistemic Emotions and Learning

As hypothesized, we found positive epistemic emotions (curiosity and enjoyment) to correlate positively with performance, and negative epistemic emotions (frustration and boredom) to correlate negatively with performance. This finding is consistent with previous literature (Ainley and Ainley, 2011; Gruber et al., 2014; Pekrun et al., 2014; Muis et al., 2015; Bosch and D'Mello, 2017), and thus further confirms the association between epistemic emotions and performance. However, the emotion of surprise was not found to correlate with performance, even though the results of some previous, experimental studies suggest the existing relation between surprise and learning (Chiu et al., 2014; Muis et al., 2018). On the other hand, surprise can also have an indirect effect on performance by inducing other epistemic emotions, as suggested in previous research (Vogl et al., 2019). Indeed, in our data, surprise correlates positively with all other epistemic emotions. The relation with both positive and negative emotions also indicates the neutral or changing valence of this emotion. Also, previous research suggests that epistemic surprise can be considered as a positive, negative, or neutral emotion (Muis et al., 2015; Pekrun et al., 2017). Especially, surprise is relatively strongly correlated with other activating emotions, and as Pekrun et al. (2017, p. 1272) discuss, "emotions during epistemic activities are primarily linked along the arousal dimension of emotion rather than

TABLE 2 | Bivariate pearson correlations of the observed variables.

	1	2	3	4	5	6	7	8
1 Pretest performance	–							
2 Posttest performance	0.613***	–						
3 Surprise	−0.029	−0.019	–					
4 Curiosity	0.273**	0.248**	0.365***	–				
5 Excitement	0.305***	0.251**	0.277***	0.569***	–			
6 Confusion	−0.136	−0.081	0.416***	0.108***	−0.063**	–		
7 Anxiety	−0.165	−0.120	0.326***	0.097***	−0.060*	0.502***	–	
8 Frustration	−0.221*	−0.179*	0.263***	−0.073**	−0.209***	0.537***	0.515***	–
9 Boredom	−0.235**	−0.280**	0.055*	−0.212***	−0.331***	0.319***	0.247***	0.485***

*For calculating the Pearson correlations between performance measures and emotions, the aggregated mean values (n = 148) of emotions were used. Correlations between the emotions are calculated on a within level (n = 1793–1799). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.*

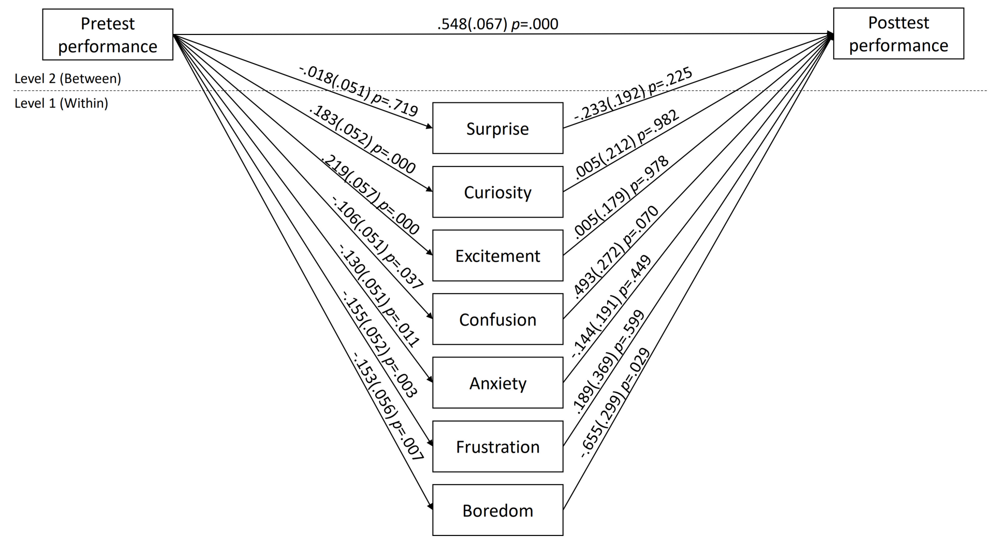


FIGURE 4 | The MSEM with epistemic emotions as parallel mediators between prior knowledge and learning outcome. Regression coefficients correspond to standardized parameter estimates β (standard errors S.E. in parentheses). The mediator residuals were allowed to covary both in the within and between level, the arrows representing the residual covariance were omitted for clarity.

the valence dimension." Interestingly, in our study, we also found a statistically significant ($p < 0.05$) correlation between surprise and a deactivating emotion of boredom. However, the correlation coefficient of 0.055 can be considered very low, indicating only a minimal, if any, interrelation between these constructs. Furthermore, negatively valenced emotions of confusion and anxiety did not correlate significantly with test performance, even though they correlate relatively strongly with other negatively valenced epistemic emotions that have a negative relation to performance. However, confusion and anxiety also have a positive correlation with curiosity, which may indicate that all these emotions occur simultaneously in situations, where curiosity is triggered by new knowledge, but high cognitive demands also cause confusion and anxiety. This finding is in line with those of previous studies indicating a positive correlation between curiosity, confusion and anxiety (Pekrun et al., 2017; Trevors et al., 2017; Di Leo et al., 2019).

Using MSEM, we estimated the effect of epistemic emotions on the change in performance, and their mediating role in the learning process. As expected, prior knowledge (the pretest performance) was the strongest predictor of the learning outcome (the posttest performance). Taking this into account, boredom was found to be the only epistemic emotion having a significant effect on learning outcome. So, the more bored students are when studying, less likely they are to learn. However, even boredom did not reach statistical significance as a *mediator* from prior knowledge to learning outcome. These results are in line with and complement the previous findings on the negative relation of boredom and learning (Pekrun et al., 2014; Tze et al., 2016). Since other epistemic emotions than boredom were not found to have an effect on learning outcome, our hypothesis on causal relations was only partly supported. This finding is further discussed in the following sections.

TABLE 3 | Total and indirect effects of the parallel mediation model.

	Posttest performance		
Pretest performance	**β**	***S.E.***	***p***
Total effect ($c = c' + a \times b$)	0.592	0.066	0.000
Indirect effects ($a \times b$)			
via surprise	0.004	0.013	0.733
via curiosity	0.001	0.039	0.982
via excitement	0.001	0.039	0.978
via confusion	−0.052	0.041	0.202
via anxiety	0.019	0.026	0.476
via frustration	−0.029	0.056	0.600
via boredom	0.100	0.059	0.088

Trait Versus State Emotions in Learning Processes

Based on MSEM conducted in this study, only boredom has an effect on learning outcomes after controlling for prior knowledge. Even though curiosity, enjoyment and frustration correlated strongly with both pre- and posttest performance, they did not relate to change in performance during the study period. However, also the correlation with performance can tell us something about their relation to learning. Students with high situational experiences of curiosity and enjoyment and low experiences of frustration performed better already in the pretest and, due to strong autoregression, also in the posttest. This means that, at some point, these students have either learned more due to a tendency to experience high curiosity and enjoyment and low frustration, or they have developed a tendency to have these emotional experiences due to their previous performance. This leads us to a question about trait versus state nature of epistemic emotions.

Even though emotions are typically defined as affective states (Ekman, 1992; Russell, 2003; Shuman and Scherer, 2014), some students may have a trait-like disposition to experience certain types of emotional states, as discussed also previously for example by Graham and Taylor (2014). And, this trait-type dispositional enjoyment, curiosity or frustration can have an effect on students' performance and situational emotions. Or, perhaps state-type situational emotions become trait-type through performance related feedback and appraisals. Based on previous literature, also interest can develop from a state-type situational interest to a trait-like individual interest (Hidi and Renninger, 2006). Thus, we suppose that this could happen also with other affective factors, such as epistemic emotions in this case. However, trait-like emotions come by definition close to attitudes and should then not be called emotions at all (Shuman and Scherer, 2014). On the other hand, also attitudes can play an important role in learning (Cahill et al., 2018), and thus should not be ignored.

Implications for Research and Practice

The findings of the present study clearly suggest that the relations between emotions and performance look very different depending on whether they are examined correlationally or with causal models. This implies that, when interested specifically in situational emotions and learning as a longitudinal construct, cross-sectional measures of performance or retrospective measures of emotions do not provide an adequate basis for the examination of this relation. It is essential to account for students' prior knowledge when interested in learning processes, to actually be able to detect the change in performance, and further, make some causal inferences. Furthermore, emotions should be measured in the particular situations of interest. Otherwise, if retrospectively measured, they may reflect more on students' moods or attitudes than the actual situational experiences.

Based on the mediation analysis, none of the epistemic emotions mediated the effect of prior knowledge on learning outcome. This implies that there is likely to exist yet undiscovered mediators (Zhao et al., 2010). Based on a relatively strong correlational relations between some epistemic emotions and performance measures, we also argue, that there is another variable (or variables) that have an effect on both situational emotions and performance. We assume that, for example moods or attitudes, which are concepts closely related to emotions, can have an effect on the constructs measured in this study. Also, this finding underlines the importance of controlling for trait-like affective variables when interested specifically on situational emotions. Thus, further studies regarding the effects of different affective variables on learning would be worthwhile.

Taken together, the findings of the present study corroborate the existing relations between epistemic emotions and learning. This implies that the role of emotions should be acknowledged also in everyday educational practices, as well as in teacher training and educational policymaking. Especially the detrimental effect of boredom on learning should be considered. Thus, to engage students in active science learning is an important mission for all practitioners (e.g., Schneider et al., 2020). Previous research shows that in classroom situations, epistemic emotions can be managed for example by instructional activities (Vilhunen et al., 2021): orienting and engaging activities can be implemented to arouse curiosity and enjoyment in students, whereas to avoid the occurrence of boredom, teacher talk should be limited or restrained. However, further research should be undertaken to investigate how to engage students to curiously study science, and to tackle boredom.

Limitations

By definition, epistemic emotions have an object focus on knowledge or knowledge construction. In this study, we investigated seven emotions described as epistemic by Pekrun et al. (2017). However, in our questionnaire students were first asked to think about the activity they were doing, and then to indicate the extent to which they felt surprised, curious, excited, confused, anxious, frustrated or bored, and not what the object of their emotion was. Thus, the emotions being studied were not necessarily *epistemic* in nature. For example, emotions such as enjoyment or anxiety may often have an object focus on something different than the knowledge processed in a given situation (e.g., in the topic or achievement). Some emotions, such as confusion and curiosity can be regarded as more likely to have an object focus on knowledge itself.

The ESM data in this study was collected three times, at random times, during each science lesson of the study period. Researchers and teachers together considered this to be the maximum number of beeps per lesson, in order to disturb the instruction as little as possible. However, emotions typically occur in episodes of varying length (Verduyn et al., 2009), which most probably leads to a situation in which not all the emotional episodes are captured in the ESM data. We suppose this to be the case especially with surprise, which is a relatively short-lived emotion (Horstmann, 2006; Noordewier et al., 2016). Surprise had no significant relation with performance or learning in our data. To capture more detailed data on emotions, data collection should be more intensive (e.g., focusing on facial expressions) or focused on predetermined points of the instruction.

The data collection of this study took place during one predetermined study period of six to seven lessons. This 2 to 3 week period can be considered as a relatively short time to find a significant change in performance, and thus detect learning. On the other hand, that is the time, when students are taught this specific content about Newtonian mechanics, and thus the time when students are supposed to learn these skills and knowledge. Thus, we consider these few weeks to be a sufficient time to detect learning on this particular topic.

The generalizability of these results is subject to certain limitations. First, all the data is gathered within upper secondary school physics courses, in the context of studying Newtonian mechanics, and in one geographically limited area in Finland. A more versatile data collection, including for example different school subjects or participants from different backgrounds, would give results that are more generalizable. Second, the sample size of this study is relatively small, thus leaving open the possibility that repeating the study might give us slightly different results. Furthermore, this implies that even though in our causal model we did not find significant path coefficients in most of the cases, a claim about non-causality cannot be made. Especially, the role of confusion in learning processes should be studied further with versatile research settings and methods: in our study, the regression coefficient from pretest performance to situational confusion was negative (and significant), but the regression coefficient from situational confusion to posttest performance was positive (but not significant, $p = 0.07$). This underlines the complexity of the interplay between learning and situational confusion (D'Mello et al., 2014).

CONCLUSION

In summary, the purpose of the current study was to examine the relation between situational epistemic emotions and performance both correlationally and by a causal model, to address important gaps in the literature concerning the longitudinal nature of learning processes and the experiences of epistemic emotions in the real-life classroom contexts. We used a pre-posttest design to examine students' learning during the study period, and ESM to capture the situational nature of the epistemic emotions in an ecologically valid science-learning environment. The relevance of emotions in the learning context is clearly supported by the findings. Positive epistemic emotions of curiosity and enjoyment were found to correlate positively with students' pre- and posttest performance, whereas the negative epistemic emotions of frustration and boredom had an opposite relation. However, MSEM revealed that after controlling for the prior knowledge, only boredom had a significant effect on learning outcomes, which raises important questions about the state versus trait nature of epistemic emotions. Finally, we see the need for further studies to examine the situational factors influencing learning, and to clarify the dynamic relations between epistemic emotions and academic performance.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available due to ethical and privacy restrictions. Requests to access the datasets should be directed to EV, elisa.vilhunen@helsinki.fi.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Review Board in the Humanities and Social and Behavioral Sciences, University of Helsinki. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

EV: conceptualization, methodology, formal analysis, investigation, and writing the original draft. MT: methodology, investigation, and reviewing and editing the manuscript. JL and KS-A: conceptualization, reviewing and editing the manuscript, project administration, and funding acquisition. KJ: conceptualization, methodology, reviewing and editing the manuscript, supervision, project administration, and funding acquisition. All authors contributed to the article and approved the submitted version.

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