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Students' Emotional Responses to Mistakes: An Ecological Momentary Assessment Study in University Chemistry Laboratory

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ABSTRACT

This study explores students' emotions in the undergraduate chemistry laboratory, focusing particularly on emotional responses to making mistakes. Using an ecological momentary assessment design, we collected on-task data from 240 students and 1635 learning situations during the laboratory sessions. A multilevel structural equation modeling framework, including a model with random slopes, was used to examine how situational factors (i.e., type of mistake and support in solving the mistake) and individual factor (i.e., gender, performance level, and subjective task values) affected students' emotional responses. Our findings suggest that mistakes typically trigger negative activating emotions in students. Individual factors also influenced emotional responses—well-performing students were less prone to elevated anxiety and frustration, remaining more relaxed in mistake situations, whereas students with high perceived emotional costs of laboratory activities experienced a more intense increase in anxiety in mistake situations. The type of mistake played an important role: careless mistakes were associated with more positive emotions, whereas students experienced increased anxiety and frustration and decreased positive emotions when the mistake stemmed from skill or knowledge gaps. The form of support also mattered: teacher support was linked to intensified anxiety and frustration in students, while peer support showed no statistically significant impacts on emotional levels. To foster meaningful learning, targeted support in emotional regulation should be provided for lower-performing students and those with high perceived emotional costs in mistake situations, particularly when mistakes stem from a lack of skill or knowledge.

1 | Introduction

The role of mistakes in science education cannot be overemphasized, as the tentative nature of science makes mistakes an intrinsic part of its essence (Allchin 2012, 2020; Firestein 2016; Nunes et al. 2022; Simpson and Maltese 2017). One learning goal of laboratory instruction is learning about the nature of science through engaging in scientific inquiry (Hofstein and Lunetta 2004; Agustian 2020; Allchin 2012). Mistakes can indeed teach important lessons about the nature of science by demonstrating what does not work, thereby creating opportunities to learn how science functions and promoting ways to explore its epistemology (Allchin 2012).

Chemistry laboratories embody an optimal learning environment for learning to deal with mistakes, as students are likely to generate different results based on their design choices or performance (Simpson and Maltese 2017) and frequently make mistakes

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(Kyynäräinen et al. 2024). Mistakes and failures students experience during their undergraduate education can play a significant role in shaping their identity as a scientist (Simpson and Maltese 2017), and accordingly, it is relevant to seek a deeper understanding of how students respond to these events. Ideally, mistakes indicate growth opportunities (e.g., Kapur 2008; Mera et al. 2022), help students build resilience as scientists (e.g., Henry et al. 2019; Keen 2021), and enhance meaningful learning (e.g., Galloway et al. 2016). Meaningful learning combines psychomotor, cognitive, and affective learning (Novak 2010; Galloway et al. 2016). While the embodied nature of laboratory work fundamentally entails the psychomotor domain, it is necessary to ensure proper activation of cognitive and affective domains. Thus, learning stemming from the mistakes students make in the chemistry laboratory should be supported not only through their cognitive processes but also through affective learning (Agustian et al. 2022).

This study is strongly motivated by the aim to better understand students' emotional experiences in situations involving mistakes in the chemistry laboratory. We employ Pekrun (2006; 2024) control-value theory (CVT) as a theoretical lens to examine the relationship between making mistakes and students' activity-related emotions. CVT considers both intraindividual cognitive processes and interindividual social-cultural processes that shape these experiences, including how students regulate and cope with their emotional responses to mistakes (e.g., Pekrun 2006, 2024; Pekrun et al. 2018; Sharabi and Roth 2025; Ryan et al. 2016). In the chemistry laboratory, students engage in individual scientific sensemaking, which can be impacted by their emotional states (see e.g., Pekrun 2006; Vilhunen et al. 2023), yet they collaborate and interact with peers and teachers, influencing their emotional levels (see e.g., Keen and Sevian 2022; Tulis 2013). Thus, we draw on literature from both cognitive and sociocultural learning theories to develop a more comprehensive understanding of the phenomenon (Leach and Scott 2003).

The data for this study were collected using an ecological momentary assessment (EMA) design, which provides repeated self-report data on task in an authentic setting (see Sinatra et al. 2015). We aim to identify how situational and individual factors impact students' emotions and emotional responses to mistakes in the chemistry laboratory, building on previous research in educational psychology (e.g., Pekrun 2006, 2024; Tulis et al. 2016; Schmid et al. 2025; Sharabi and Roth 2025; Steuer et al. 2025) and STEM education (e.g., Corwin et al. 2022; Henry et al. 2019; Keen 2021; Nunes et al. 2022). Previous research highlights the need for further studies exploring the role of teachers and peers in dealing with mistakes (Simpson and Maltese 2017; Simpson et al. 2025), and we address this in our study, investigating how teacher and peer support after mistakes impacts students' emotional levels.

1.1 | Mistakes

Ironically, trying to define mistakes unambiguously is doomed to fail (Allchin 2012). To underline the complexity, previous research often interchangeably uses various terms to describe this phenomenon characterized by deviations from expected trajectories or goals, including, for instance, failures, mistakes, errors, struggles, or uncertainty (Steuer et al. 2025). In this study, we investigate mistakes, viewing them as momentary and context-specific deviations or misalignments from what is generally considered correct, a norm or appropriate (Kipnis 2011; Steuer et al. 2025). Mistakes are often human-centered and associated with judgment (Kipnis 2011). Errors, on the other hand, constitute a more technical, less human-centered subset of mistakes (Norman 1983). A third distinctive and frequently used term, failure, carries a different connotation, as it is inextricably tied to a specific goal or objective, defined as a discrepancy between the intention and outcome (Henry et al. 2019; Keen 2021; Tulis et al. 2016). Importantly, this makes failure inherently negative (Schechtel and Bongers 2026), whereas the valence of mistakes (and errors) is much more situational (Frese and Keith 2015). However, students ultimately emotionally respond to their own perception of what *a mistake* is (see e.g., Pekrun 2006, 2024), so an explicit definition may not always be necessary to address the phenomenon.

An example of what students may perceive as a failure in the chemistry laboratory is not obtaining the "correct results" (Schechtel and Bongers 2026), positioning the achievement of such results as their primary goal. Mistakes, in turn, can be understood as any small misstep from the expected way of carrying out the experiments, such as simply forgetting to calibrate an instrument before using it, even if it does not influence the results. They do not mark the final outcome but are an intrinsic part of the learning process (Allchin 2012, 2020; Simpson and Maltese 2017), although they can sometimes result in not achieving the intended goals, that is, failure. Therefore, mistakes obtain a highly situational nature.

There is a large body of research studying mistakes from the perspective of their cause or cognitive outcomes, as many scholars have investigated misconceptions in science and mathematics (e.g., Tümay 2016; Lamichhane et al. 2018; Rosenthal and Sanger 2012), or error interventions in promoting student achievement (e.g., Darabi et al. 2018). More recently, the research focus has expanded to affective outcomes, such as error beliefs (i.e., whether a student perceives errors as beneficial for learning), engagement, and emotions, as well as adaptive ways of handling mistakes (e.g., Kyynäräinen et al. 2024; Corwin et al. 2022; Keen and Sevian 2022; Schmid et al. 2025; Simpson and Maltese 2017; Tulis and Dresel 2025), which is relevant for comprehensively capturing the learning potential of mistakes (Steuer et al. 2025). Recent findings suggest that while generic error beliefs are relatively stable, more specific mistake-related reactions are indeed contextual, and connected to the occurring situation (Kyynäräinen et al. 2025; Corwin et al. 2022; Henry et al. 2019; Schmid et al. 2025). Thus, understanding students' situational responses to mistakes is of high value (Steuer et al. 2025).

In chemistry laboratories, a variety of different types of mistakes can occur, and they can influence students' emotional experiences in different ways (Allchin 2012). Mistakes can be categorized into *careless mistakes* representing lapses and slips in the execution of activities, or *mistakes caused by a lack of skill or knowledge* (Frese and Keith 2015; Reason 1990). Another alternative could be dividing mistakes into experimental and theoretical ones (Kyynäräinen et al. 2024), as laboratory work encompasses experimental and theoretical phases (Finne et al. 2023). In this study, we utilize the former categorization, and perceive mistakes as a

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specific learning phenomenon, rather than an unwanted byproduct of experimental work or something to be avoided (see also Tulis and Dresel 2025).

Understanding the role of mistakes in chemistry laboratories is significant not only because they occur very frequently in this context (see e.g. Kyynäräinen et al. 2024; Agustian et al. 2024), but also because chemistry laboratories are unique, embodied, and complex environments where students learn to do science, as well as ought to coordinate qualitatively different elements and integrate knowledge, skills, and attitudes (Agustian et al. 2022). Furthermore, they are often depicted as environments where "everything feels like a procedure," and making mistakes, or even yielding unexpected or alternative results, is not necessarily allowed for (Renninger et al. 2018; Schechtel and Bongers 2026).

Regardless, mistakes foster an opportunity to reach the limits of one's knowledge, which can promote further learning (e.g., Kapur 2008; Mera et al. 2022). This can, however, be emotionally challenging and laborious (Allchin 2012; Agustian et al. 2024), and it does not conventionally lead to learning if the mistake is not properly handled (Steuer et al. 2025). Based on previous empirical findings, in the chemistry laboratory, students' struggles (e.g., their mistakes) are typically followed by seeking help or guidance as an action toward resolution (Keen and Sevian 2022; Corwin et al. 2022). This aligns with the concept of productive failure (Kapur 2008), stating that in order to productively deal with mistakes, an instructional activity should follow (Loibl and Leuders 2019). Accordingly, the support following mistakes is framed as a central variable influencing emotional dynamics in mistake situations.

1.2 | Emotions

Emotions are, by definition, affective states caused by a stimulus and directed toward a specific object (e.g., Shuman and Scherer 2014). In comparison to other affective states, such as moods, they are shorter in duration and more specific in focus (Pekrun et al. 2018). For instance, feeling excited about starting a new experiment in the laboratory may fade quickly, whereas being in a good mood can last much longer. Another distinction is that emotions typically arise in response to specified objects or events, while moods are more general and might lack a clear external cause (Pekrun 2006; Pekrun et al. 2018).

This study adopts Pekrun (2006; 2024) control-value theory of achievement emotions (CVT) to explain how students' emotions emerge in the context of the chemistry laboratory (see Figure 1). It postulates that students' emotions arise from their personal appraisals of control over learning activities and outcomes (success or failure), along with the subjective value attached to them. The appraisals, which can be routinized and nonreflective (Pekrun and Stephens 2010), are shaped by individual characteristics (e.g., performance and motivational traits) and context, highlighting how students' emotional experiences are rooted in both their cognitive evaluations and the learning environment (Pekrun 2006, 2024). Thus, the theory bridges individual dispositions together with the sociocultural context.

In this theoretical framework, emotions are categorized based on several factors, but these categories are not mutually exclusive. In this study, we consider three key factors: (1) object focus, (2) valence and arousal, and (3) stability. For example, consistently feeling anxious after failing a laboratory experiment can be classified simultaneously as an achievement emotion (object focus), a negative activating emotion (valence and arousal), and a trait emotion (stability). The three classification approaches are presented in more detail in this subsection.

First, even though emotions are holistic by nature, they are often categorized based on a specific object focus, referring to the events and objects that trigger the emotion (Pekrun 2006; Pekrun et al. 2018) (see Figure 2). Here, we approach students' emotions as achievement emotions, associated with the ongoing laboratory activities and related outcomes of success and failure (Pekrun 2006, 2024). We focus especially on the emotions that students experience during mistake situations. As mistakes are operationalized as a specific learning phenomenon, we consider these emotions to be primarily activity-related (Pekrun 2024).

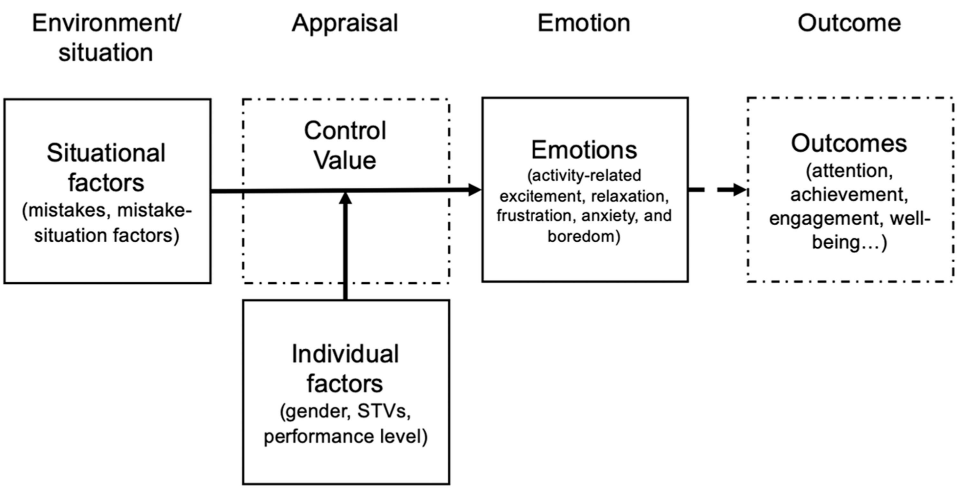

FIGURE 1 | The dynamics focused on in this research, embedded in Pekrun's control-value theory framework (2006). The variables and associations presented in dotted boxes or with dotted arrows are not measured in this study.

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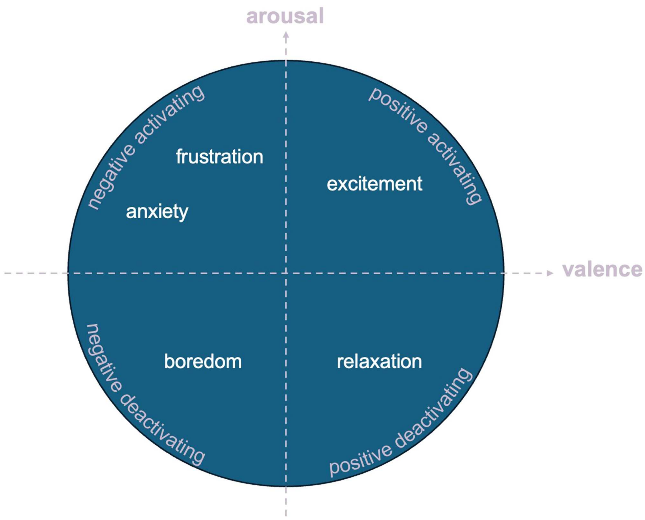

FIGURE 2 | Excitement, relaxation, boredom, frustration, and anxiety presented in the two-dimensional- circumplex model of emotions, adapted from Russell (1980).

Alternatively, emotions in mistake situations could be tied to the achievement outcome of failing—prospective failure if the student worries about failing the experiment because of the mistake, and retrospective if they equate the mistake with failure (Pekrun 2024). In this study, we focus on excitement, relaxation, frustration, anxiety, and boredom as activity-related emotions. While frustration and anxiety share similarities, the former relates to the activities more retrospectively, whereas the latter is oriented towards the future and is linked to prospective failure.

Second, emotions can be categorized based on two dimensions: valence and arousal (Pekrun et al. 2018) (see Figure 2). Typically, positive emotions are associated with and thought to foster learning. On the contrary, some negative emotions, such as confusion and even anxiety, can promote learning if their intensity and duration are not overpowering (D'Mello et al. 2014; D'Mello and Graesser 2011). Arousal refers to related physiological activity, with activating emotions increasing heart rate and respiration, preparing oneself for quick reaction, whereas deactivating emotions decrease physical activity and promote rest (Pekrun et al. 2018; Ketonen et al. 2023). These dimensions further categorize emotions into positive activating (such as excitement, joy), positive deactivating (such as relaxation, relief), negative activating (such as anxiety, frustration), and negative deactivating (such as boredom, hopelessness). The five emotions we study cover the four quadrants of the two-dimensional circumplex model (Russell 1980; Pekrun et al. 2018). Nonetheless, these dimensions are not unambiguous, and there is variability in how individuals, for example, categorize emotions based on valence (e.g., Imbir and Pastwa 2021).

These emotions are also related to different control and value appraisals (Pekrun 2024). Excitement is often associated with high control and high value appraisals of the ongoing activity, reflecting competence and enjoyment. Relaxation is, in turn, related to high control and low to moderate value, reflecting a situation where one feels like they can manage, but the stakes of the task are low. Frustration reflects moderate control and moderate to high value, and oftentimes a temporal overchallenge. Anxiety, in turn, can be associated with prospective failure, connected to particularly low control, high value and a feeling that failure is inevitable. Boredom is linked to low control and low value, where the activity can feel unimportant and overchallenging. In line with these ideas, learning activities that encourage higher student control and autonomy seem to promote positive emotions in science classrooms (Beymer et al. 2021; Murphy et al. 2019). However, in general, laboratory activities have been associated with relatively low perceptions of control, probably due to the strict protocols students are expected to follow, yet they are still linked to relatively high excitement and low boredom (Beymer et al. 2021).

Third, emotions can be classified into state and trait emotions (Pekrun 2006; Pekrun et al. 2018). State emotions occur momentarily in response to specific stimuli, such as mistakes, whereas trait emotions reflect individuals' more stable dispositions to experience a particular state emotion across similar situations. There are some differences in how individuals experience state and trait emotions based on individual factors, like gender (Goetz et al. 2013). For example, females are reported to experience higher STEM-related trait anxiety than males (Pelch 2018; Goetz et al. 2013), even though there is no significant difference between their state anxiety (Goetz et al. 2013).

This study focuses on the impact of mistakes on students' emotional states on task, perceiving students' emotions as state emotions. Following the assumptions of CVT, we consider both individual and situational determinants as predictors of students' emotional levels (Pekrun 2024). We are also interested in students' individual dispositions to experience certain emotions in mistake situations, which can be understood as trait-like emotions. Therefore, we investigate how individual factors affect individuals' trait-like emotional responses to mistakes.

Although this study does not empirically link emotional experiences to further outcomes, the CVT proposes a variety of potential outcomes (Pekrun 2024). First, the nature of an emotional state defines the related psychological processes; thus, emotions are inextricably intertwined with cognitive and behavioral actions, such as concentration, attention, memory, reasoning, engagement, scientific sensemaking, and decision-making (e.g. Agustian et al. 2024; Vilhunen et al. 2023; Corwin et al. 2022; Pekrun 2006; Pierson et al. 2023). Boredom, for instance, has been linked to increased challenges and even unwillingness to conduct scientific observations during practical work, whereas curiosity, surprise, and confusion have been associated with higher scientific sensemaking abilities (Vilhunen et al. 2023). That is, deep learning can be achieved when the learner is presented with adequate challenges (D'Mello and Graesser 2011). There is also a well-established relationship between emotions and academic performance in chemistry laboratories and classrooms, as positive emotions have been repeatedly linked to higher achievement (see e.g., Galloway et al. 2016; Brown and Nedungadi 2024).

Beyond the cognitive-motivational lens, students' emotions can impact their engagement in collaborative work (e.g., Ballard and Winfield 2024; Camacho-Morles et al. 2019; Ippolito and Kingsbury 2024; Pietarinen et al. 2020). When students experience

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more positive emotions, they are more likely to invest effort and subsequently engage in collaborative actions (Camacho-Morles et al. 2019; Pietarinen et al. 2020). A psychologically safe environment where students feel comfortable in openly expressing all kinds of emotions, including negative ones, can also foster participation and shared engagement (Ballard and Winfield 2024). Previous findings from the undergraduate chemistry laboratory propose that this could foster healthy coping mechanisms and help build a positive relationship with struggles (Keen 2021). Furthermore, experiencing positive emotions has been linked to a stronger identity as a scientist (Park 2022). A strong science identity can, in turn, support students' persistence (Schultz et al. 2011). This persistence could be reflected in their adaptive coping with mistakes on a situational level (Simpson and Maltese 2017), as well as in their integration into the scientific community and their more longitudinal career-path choices (Estrada et al. 2011, 2018).

1.3 | Subjective Task Values

We follow the interpretation of Berweger et al. (2022), combining theoretical assumptions of Pekrun (2006; 2024) CVT and Eccles and Wigfield's (2020) situated expectancy-value theory (SEVT). As was described in the subsection entitled Emotions, CVT is based on individuals' experiences of ongoing activities, and their success and failure outcomes, and it postulates that individuals' control and value appraisals are important in shaping achievement emotions (Pekrun 2006). Similarly, Eccles and Wigfield's SEVT of motivation indicates that students' expectancies of success (or failure) partially determine their subjective valuing of the activities, although it posits that subjective task values (STVs) are stronger predictors of their choices regarding them. SEVT also implies that success and failure experiences might be important in the development of learners' STVs (Eccles and Wigfield 2020).

As both theories rely on learners' success and failure expectancies and experiences, students' STVs may be linked to their actions, values, and emotions in situations where they deal with failure (Berweger et al. 2022). Thus, we view STVs, utility and cost (Wigfield and Eccles 2020; Eccles and Wigfield 2020) of laboratory activities as interpretative of students' emotions. Utility value can be associated with extrinsic motivation because it underscores the idea that the activities are useful for one's future ambitions rather than important in themselves (Eccles and Wigfield 2020). It does not mean, however, that students with a high utility value would automatically be extrinsically motivated; they just find importance in the activities as a means to an end. Cost value, on the other hand, describes how stressful and burdensome students perceive learning to be (Eccles and Wigfield 2020).

Based on previous findings, higher perceived utility value amplifies positive emotions and sometimes anxiety (Pekrun et al. 2018; Berweger et al. 2022), whereas high perceived costs are associated with higher levels of negative emotions (Berweger et al. 2022). STVs are highly contextual and should be understood in diverse contexts (Wigfield and Eccles 2023); there is some previous research from the undergraduate chemistry context, for instance, on the relationship between STVs and choice, suggesting that cost plays a central role in academic career choices (Perez et al. 2014). We hypothesize that students with different STVs encounter failure and experience mistake situations differently.

1.4 | Mistakes and Emotions in Chemistry Laboratories

According to previous research (DeKorver and Towns 2015; Keen 2021), students' learning goals in the chemistry laboratory are primarily driven by the affective domain, even compromising cognitive or psychomotor learning. For example, students might have reported spending time practicing techniques and understanding concepts as their learning goal, which eventually conflicted with and became compromised by the goal of feeling good by finishing experiments early (DeKorver and Towns 2015). Thus, it is important to understand students' affective experiences that might shape the affective goals they set for themselves (DeKorver and Towns 2015; Keen 2021).

Previous studies indicate that students experience a wide range of emotions while engaging in practical work (e.g., Agustian et al. 2024; Vilhunen et al. 2021). These emotions can vary based on the different dimensions of laboratory instruction, including conducting experimental work, interpreting data, doing calculations, facing challenges, succeeding, encountering failure and all things that pertain to conducting scientific work (Agustian et al. 2024; Seery 2020). In general, engaging with challenges and complex cognitive processes is associated with a diversity of emotions, which students construct and make meaning of relative to their developing relationship with knowledge—one of the central aims of university education (Ippolito and Kingsbury 2024). Even though students should be comfortable encountering difficulties, mistakes, and ultimately even failure, previous research has shown that struggling to understand uncertain experimental results or facing these phenomena is likely to induce negative emotions, such as anxiety and frustration (Agustian et al. 2024; Galloway et al. 2016; Simpson and Maltese 2017). Making mistakes has also been associated with feeling less interested and skilled, and more challenged, while individual and situational factors seem to affect students' experiences in the chemistry laboratory (Kyynäräinen et al. 2024).

First, previous research has identified significant individual differences in how students cope with their mistakes in the chemistry laboratory context (Agustian et al. 2024; Galloway et al. 2016; Schechtel and Bongers 2026). Based on the findings, a wide range of emotional reactions was observed even when students underwent similar mistake experiences—yet it remains unclear which individual factors might contribute to these varying emotional responses (Agustian et al. 2024). There are some empirical findings on the matter from other STEM contexts, for example, a study from secondary-level mathematics classrooms states that males may be more likely to adaptively react to mistakes than females (Soncini et al. 2022). Also, motivational factors and performance are proposed as important antecedents of students' reactions (Tulis et al. 2016).

Second, alongside these intraindividual dimensions, inter-individual elements and the sociocultural environment should

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also be considered as significant factors shaping students' mistake experiences (Kyynäräinen et al. 2024). For instance, teachers play a crucial role in guiding students through laboratory work, shaping the sociocultural norms of learning environments, which in turn affect the socioemotional struggles students encounter (Keen and Sevian 2022). These socioemotional struggles can arise from, for example, unclear division of labor in the laboratory, as students might feel like they are bugging or annoying the teacher with their questions (Keen 2021; Keen and Sevian 2022). For example, if students feel like they are expected to manage the experiment on their own, they may hesitate to seek help from the teacher, even when facing difficulties or making mistakes in their work. In contrast, students who trust their instructors are more willing to openly discuss their mistakes (Leighton et al. 2018).

In addition to student–teacher interactions, students engage with one another, and the classroom culture among peers and the support they provide can also impact their emotional experiences (Keen and Sevian 2022). For instance, humor among peers has been noted as a standard way of dealing with mistakes or socioemotional struggles students encounter in the chemistry laboratory (Lamminpää and Vesterinen 2018; Agustian et al. 2024; Keen and Sevian 2022), possibly by regulating the negative emotions induced by mistakes. Nevertheless, there is very little research on how teacher and peer support influence students' emotions and emotional responses to mistakes, although they might arguably be significant factors (Simpson and Maltese 2017; Simpson et al. 2025).

In general, students' adaptive reactions to mistakes, including maintaining positive affect, could be supported by cultivating a positive error climate within the sociocultural norms of the learning environment (Leighton et al. 2018; Soncini et al. 2022; Tulis 2013; Wan et al. 2023). In a positive error climate, teachers' positive perceptions about mistakes are reflected upon their pedagogical practices, embracing the learning potential of mistakes by using students' misconceptions to promote learning, portraying mistakes as normal, natural, or sensible, and not negatively evaluating students based on their mistakes (Käfer et al. 2019; Simpson et al. 2025; Tulis and Dresel 2025; Wan et al. 2023). This positive framing of mistakes should be done before instruction and not only after mistakes have already occurred. After making mistakes, students are naturally more vulnerable and contemplating mistakes as useful can feel like there is too strong an emphasis on the mistake itself (Wan et al. 2023). Instead, in the moments, students could benefit from more detailed feedback addressing the erroneous idea they had proposed (Nunes et al. 2024; Wan et al. 2023).

However, despite these previous research findings, failure and mistakes still seem to carry a relatively negative stigma, and students may even feel like they are judged by their instructors for making mistakes (Nunes et al. 2022; Schechtel and Bongers 2026). Ideally, students should be allowed to experience all emotions that emerge, fostering intrapersonal, integrative emotional regulation and adaptive coping (Sharabi and Roth 2025). Emotional regulation is an important, and tightly intertwined, underlying process of experiencing emotions, particularly in practical contexts such as chemistry laboratory courses (Pekrun 2006; Ryan et al. 2016; Sharabi and Roth 2025). Integrative emotional regulation, considered the most mature and adaptive form of regulation, is an intraindividual process characterized by accepting, affirming, and taking interest in one's own emotional experiences, either positive or negative, without judgment, avoidance, or distortion (Ryan et al. 2016). Emotional regulation practices can impact students' coping in challenging situations, for instance, after making mistakes (Sharabi and Roth 2025). To support the emotional regulation and transformation of negative affective experiences into positive meta-affects, that is, meta-affective learning through reappraisal (Radoff et al. 2019; Pekrun et al. 2018), students should be explicitly taught not to fear challenges, confusion, or frustration but to recognize these as possibilities for meaningful learning (Galloway et al. 2016). This can promote students' positive affect toward the learning process (Vilhunen 2023; Sharabi and Roth 2025).

Emotional regulation can also be social and influenced by interaction with others, and its social dimension should not be overlooked in examining how students cope with their mistakes (Keen 2021; Sharabi and Roth 2025). It should also be noted that there are differences in individuals' emotional regulation abilities across age groups (Puente-Martínez et al. 2021). Typically, older people demonstrate higher levels of emotional regulation, particularly in situations where they deal with negative affect (Puente-Martínez et al. 2021). Thus, university students may be more likely, compared to their younger peers, to engage in integrative emotional regulation.

1.5 | The Present Study

There is very little research on the situated emotional responses to mistakes (Schmid et al. 2025). This is particularly true beyond the field of educational psychology, specifically in the laboratory environment, although mistakes have been recognized as a characteristic of the embodied nature of laboratory work (Kyynäräinen et al. 2024; Agustian et al. 2024; Corwin et al. 2022; Keen 2021; Schechtel and Bongers 2026). This study focuses on students' emotional responses to mistakes in the undergraduate chemistry laboratory and responds to the call for research about direct interactions between students' state emotions and mistakes (Schmid et al. 2025).

We build on and deepen previous studies (see Corwin et al. 2022; Agustian et al. 2024) and focus on five activity-related emotions (excitement, relaxation, frustration, anxiety, and boredom) in responses to mistakes. These emotions together represent the four quadrants of the two-dimensional (valence and arousal) circumplex model of emotions (Pekrun et al. 2018). The specific research questions are as follows:

1. To what extent does making mistakes impact students' levels of excitement, relaxation, frustration, anxiety, and boredom in the chemistry laboratory?
2. To what extent do the students' gender, performance level, and subjective task values affect and moderate the levels of these emotions during mistake situations in the chemistry laboratory?
3. To what extent does the cause of the mistake or receiving help to solve the mistake affect the levels of these emotions?

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2 | Methods

The data was collected in the fall semesters of 2023 and 2024 from the first undergraduate chemistry laboratory course. The research design was identical in both years, containing a background questionnaire and 13 ecological momentary assessment (EMA) questionnaires during laboratory sessions. EMA questionnaires provide highly situational self-report data without significant recall bias (Hektner et al. 2007; Mulligan et al. 2005). This method is well-suited to capture the dynamic nature of emotions in response to situational matters, like making mistakes (Pekrun 2024). Additionally, self-reports enable studying the actual emotional states students perceive in each given moment, as in prior research, it has been noted that observers typically over- or underestimate the duration of an emotional state. For instance, learners' perceived engagement and frustration are likely to last longer than observed, while conversely, many other states are observed to be longer in duration than they actually are (D'Mello and Graesser 2011).

2.1 | Participants and Context

The participants in this study were university students in their first chemistry laboratory course. In total, 240 students voluntarily participated in the research (138 in 2023 and 102 in 2024). Typically, students take the course at the very beginning of their university studies, so most of the participants (174, 72.5%) were first-year students, 30 (12.5%) were second-year students, and 27 (11.3%) were third-year or above. Females represented the majority in this study, as 173 (72.1%) of the participants reported female as their gender, and 61 (25.4%) reported male. The study majors of the participants included biochemistry (77, 32.1%), biotechnology (57, 23.8%), chemistry (42, 17.5%), physics (20, 8.3%), biology (9, 3.8%), mathematics (8, 3.3%), geology (8, 3.3%), food technology (6, 2.5%), material technology (5, 2.1%).

The primary learning goals of the course were to be able to safely carry out standard laboratory experiments under supervision and to master some standard chemical analysis and separation methods. In addition, students are expected to learn about and participate in the epistemic work of science. In this course, students performed seven practical laboratory experiments once a week. Before each 3–4-h-long experiment, students were asked to take an online quiz as a preparative exercise for the upcoming laboratory session. Students' grades, representing their performance level, were determined by comparing their total score of the preparative learning exercise against the maximum score. The distribution of the grades is presented in Table 1.

The seven laboratory experiments in the course were: (1) Preparing standard solutions and measuring concentration, (2) Finding the equilibrium constant spectrophotometrically, (3) Distillation, (4) Liquid–liquid extraction, (5) pH-titration, (6) Complexometric titration, (7) Buffer solutions. The course began with experiment 1, but after that, students performed the experiments in one of three alternative orders (1, 2, 3, 5, 7, 4, 6 or 1, 3, 2, 4, 6, 5, 7 or 1, 2, 5, 3, 4, 6, 7). The experiments were recipe-style with a low level of open inquiry (Buck et al. 2008). All experiments were performed in pairs, with the same partner throughout the course. There was a maximum of 16 students per teacher in the laboratory, and there were no teaching assistants. Although there were multiple teachers in the course, all 16-student groups had the same teacher each week. Students did not receive numerical grades for the course but simply passed or failed the course. To pass the course, students needed to score two-thirds of the prelab activity exercise points and perform all seven experiments.

2.2 | Data Collection

A background questionnaire was implemented at the beginning of the course on the online learning platform. In addition to their gender identity (male, female, or other), major, and study years, students were asked about their perceptions of laboratory work, to which students responded on a 5-point Likert scale with response categories from 1 = *totally disagree* to 5 = *totally agree*. The responses were used as indicators of latent variables representing students' utility and cost values of laboratory activities. Utility value of laboratory activities was measured with two items: "It is useful for me to do the practical work in chemistry" and "During practical work in chemistry, I learn skills that are important for my career." Similarly, cost value, representing the perceived emotional costs of lab activities, was measured with two items: "Doing practical work in chemistry exhausts me," and "Doing practical work in chemistry stresses me."

The data collection spanned four laboratory experiments: (4) Liquid–liquid extraction, (5) pH-titration, (6) Complexometric titration, and (7) Buffer solutions. All students had conducted the first experiment before the data collection in the laboratory began, and therefore, they were already familiar with the standard practices and the chemical equipment in the teaching laboratories. The laboratory data were collected using an ecological momentary assessment design (EMA). By dividing the laboratory experiment into multiple sections with respective EMA questionnaires, we were able to investigate students'

TABLE 1 | The distribution of the grades among the students.

% of the maximum score	Performance level	Frequency	Percentage of participants (%)
< 33.3	0	3	1.3
33.4–46.6	1	6	2.5
46.7–60.0	2	15	6.3
60.1–73.2	3	52	21.7
73.2–86.6	4	114	47.5
> 86.7	5	50	20.8

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experiences within one session. Thus, there were three or four EMA questionnaires during each laboratory session, accumulating a total of 13 EMA questionnaires. In all, we got 1635 responses (1049 in 2023 and 586 in 2024), and the compliance rate was 52.4%.

Links to EMA questionnaires, which only took approximately 1–3 min to respond to, were embedded in the laboratory work instructions. Students were instructed to respond to the questionnaires on their phones at the predetermined points of the laboratory experiment. EMA questionnaires were administered after completing a specific section of the experiment with the intention to minimize their impact on students' workflow and perhaps emotional experiences. The last questionnaire in each laboratory session took place after completing the experiment but before discussing the laboratory work with the teacher.

Students reported their activity-related levels of excitement, relaxation, frustration, anxiety, and boredom in the EMA questionnaires on a 5-point Likert scale with response categories from 1 = *not at all* to 5 = *very much*. Additionally, students were asked whether they had noticed making a mistake in the prior section of the laboratory work. Responding yes, they were instructed to select all applicable claims concerning the mistake they had made. These claims were: "The mistake was a careless error." that we named as *Mistake, careless*, "The mistake was caused by the lack of my skills or knowledge." that is, *Mistake, lack of skill*, "Teacher helped me to solve the error." that is, *Mistake, teacher helped*, "My peers helped me to solve the error." that is, *Mistake, peers helped*. As mistakes cannot be unambiguously defined, we decided to leave the identification and, thus, the definition of mistakes up to the students' perspectives. We assume that the perception of making a mistake triggers an emotional response, rather than meeting any fixed criteria regarding what a mistake is.

2.3 | Analytical Approach

A multilevel structural equation modeling (MSEM) framework was used for the analyses. The MSEM framework considers the hierarchical structure in our data, as the situational responses are nested within individuals. Therefore, individuals were treated as clusters in all analyses. Within (situational) level predictors included situational factors of making a mistake, different causes of mistakes, and receiving support to solve the mistakes. Between (individual) level predictors included gender (grouped as 1 = male, 0 = female or other), cost and utility value of laboratory activities, as well as performance. A multilevel approach was adopted because intraclass correlations (ICCs) were above 0.10 for all situational-level variables, that is, emotions. ICC values were 0.42 for excitement, 0.38 for relaxation, 0.26 for frustration, 0.40 for anxiety, and 0.35 for boredom, indicating that the variances are meaningfully distributed across the two levels. Importantly, the MSEM framework also allows latent variables to be incorporated into the models not only as predictors (utility and cost value) but also as dependent outcomes (between-level emotions and slopes).

We created three models to answer all research questions. The first model is a basic MSEM model, estimating how mistakes influence students' emotions at the situational level and how individual factors influence students' emotions at the individual level. The model provides a simple starting point and a baseline to compare the more complex MSEM results against. Model 1 is presented in Figure 3.

The second model (Model 2, presented in Figure 4) incorporated higher complexity, as it was a multilevel structural equation model with random slopes (Rockwood 2020), allowing for the inclusion of latent variables and the estimation of cross-level associations (i.e., moderation) (Hall and Malmberg 2020). In this context, the moderation effects provide information about how individual factors (gender, performance, STVs) impact the direction and intensity of change in students' emotions in mistake situations, indicated by the extent to which the individual factors predict the random slopes. These random slopes are estimated as individual (between) level variables. They represent the intensity and direction of the change between students' average levels of emotions under two conditions: (1) no mistake, and (2) having made a mistake (see Figure 5 in Results).

The third model was estimated as a simple linear regression-based multilevel model to establish the basic within-level associations among observed variables, still considering the between-level correlations, means and variances of the measured emotions. Model 3 is presented in Figure 6.

All analyses were conducted using Mplus 8.11 (Muthén and Muthén 1998–2017). We applied the maximum likelihood for robust standard error (MLR) estimator in all analyses. The sample size was 240 at between (individual) level and 1635 at within (situational) level, which is adequate for MSEM analyses (Hox and Maas 2001). To evaluate the model fit for the first model (see Figure 2), we used five fit indices that Mplus provides (RMSEA = 0.018; CFI = 0.995; TLI = 0.983; SRMR = 0.000 (within), SRMR = 0.042 (between); $\chi^2 = 29.429$ ($p = 0.058$), $df = 19$), suggesting an excellent model fit. According to the summary of previous research (Schreiber et al. 2006), the cutoff values for acceptable scores are < 0.06 for Root Mean Square Error of Approximation (RMSEA), > 0.95 for Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI), and < 0.08 for Standard Root Mean Square Residual (SRMR). RMSEA reflects the approximate error of the model, CFI compares the model to a baseline model, TLI is similar to CFI, but it penalizes the model for complexity, and SRMR measures residual variance that remains unexplained by the model (Hooper et al. 2008).

Because the random slopes are estimated in the second statistical model (see Figure 4), requiring integration over random effects and preventing the computation of traditional covariance-based fit statistics, no absolute fit indices were available (cf. Hall et al. 2020). As the third model (see Figure 6) did not include any latent variables and the residuals were allowed to covariate freely, the model was overfitted with zero degrees of freedom and statistically equivalent to a multilevel regression model (Lüdtke et al. 2008). Accordingly, model fit statistics, such as RMSEA, CFI, TLI, and SRMR, do not provide meaningful information about the model adequacy of the model in this case, and they are not reported.

The structural validity of utility and cost values was examined with confirmatory factor analysis using a maximum likelihood

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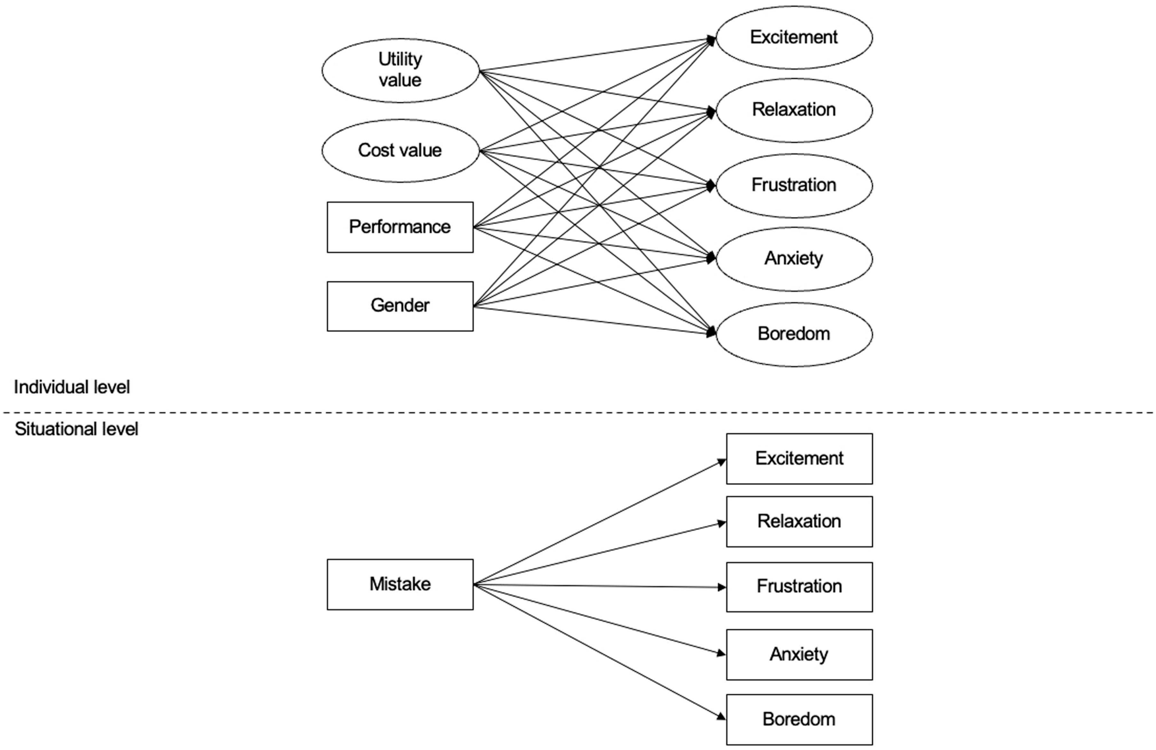

FIGURE 3 | Model 1, a multilevel structural equation model aiming to answer RQ1, also controlling for the variances in individuals' emotions.

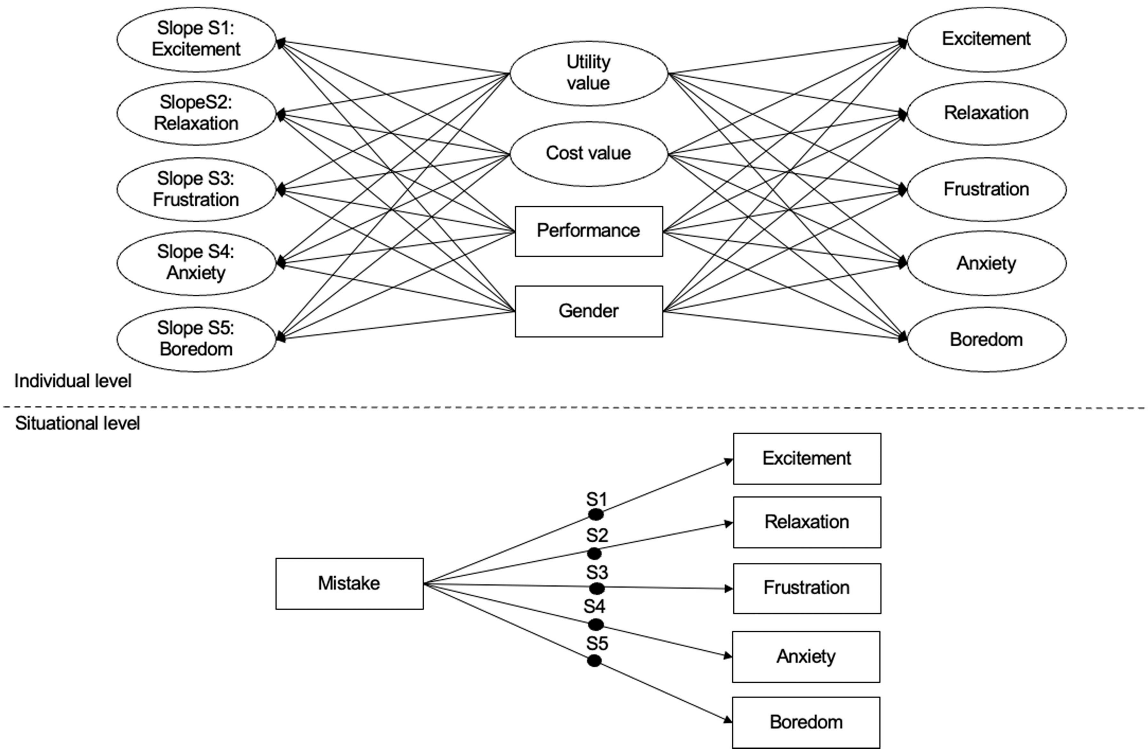

FIGURE 4 | Model 2, a two-level multilevel structural equation model with random slopes, aiming to answer RQ2.

(ML) estimator. The model was evaluated based on the same fit indices: $\chi^2 = 0.097$ ($p = 0.7555$), RMSEA = 0.000, CFI = 1.000, TLI = 1.000, SRMR = 0.002, indicating an excellent fit. Factor loadings for utility value items were 0.675 ($p < 0.001$) and 0.851 ($p < 0.001$), and for cost value items 0.863 ($p < 0.001$) and 0.753 ($p < 0.001$). Utility and cost value structures correlated negatively −0.461 ($p < 0.001$), which aligns with previous studies (e.g., Rosenzweig et al. 2020). These structures were used as individual-level predictors in the MSEM analyses (Models 1 and 2).

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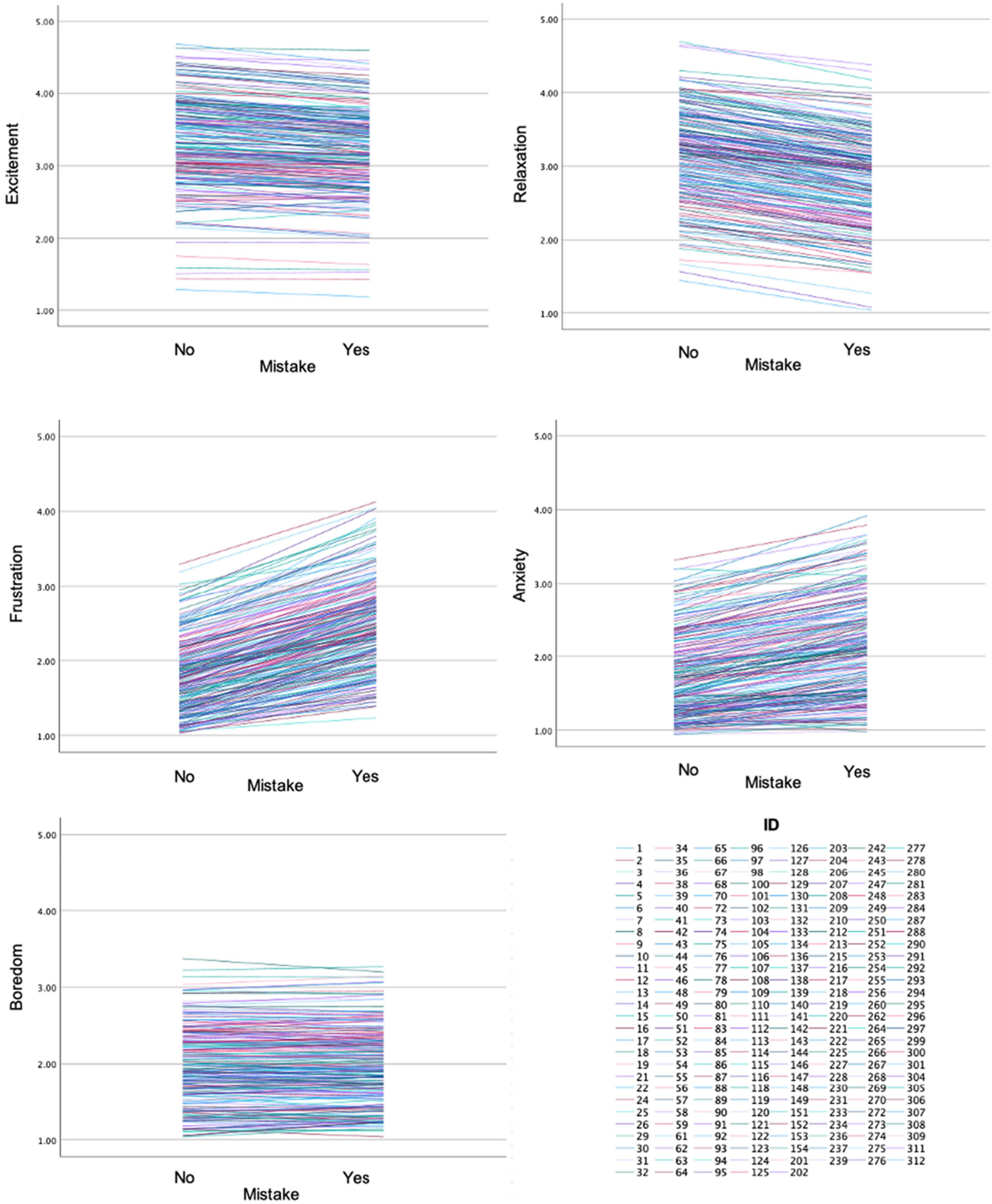

FIGURE 5 | Students' individual shifts in excitement, relaxation, frustration, anxiety, and boredom in mistake situations, each line representing an individual.

3 | Findings

Students reported that they had made a mistake in 466 situations (304, 29.0% of all learning situations in 2023, and 162, 27.6% in 2024). Out of these mistake situations, in 136 (93 in 2023, 43 in 2024) situations, students received help from a teacher, and in 98 (67 in 2023, 31 in 2024) situations, they received help from their peers. 201 (139 in 2023, 62 in 2024) of the mistakes were reported as careless mistakes, whereas 68 (59 in 2023, 9 in 2024) were reported to be caused by a lack of students' skills or knowledge.

On a general level, students experienced more positive emotions in the laboratory. The mean values for the five emotions studied were 3.24 (SD = 1.02) for excitement, 3.05 (SD = 1.05) for relaxation, 1.97 (SD = 1.12) for frustration, 1.84 (SD = 1.01) for anxiety, and 1.91 (SD = 0.96) for boredom. We plotted the estimated slopes for each individual and for each emotion, representing the individual (between-level) shift in the level of the emotion when students had made mistakes. These slopes are depicted in Figure 5. A steep slope represents an intense emotional response to mistakes, whereas a horizontal slope would represent no change in the level of emotion due to making mistakes.

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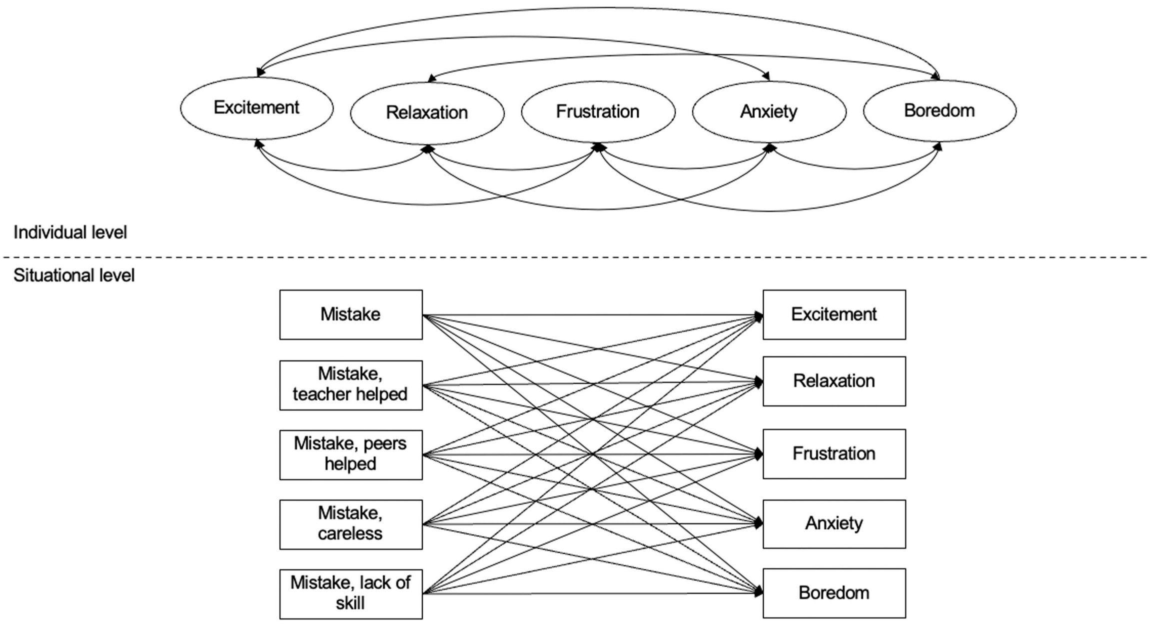

FIGURE 6 | Model 3, a two-level regression-based model, aiming to answer RQ3.

RQ1. *To what extent does making mistakes impact students' levels of excitement, relaxation, frustration, anxiety, and boredom in the chemistry laboratory?*

Based on the situational-level findings of Model 1 (see Figure 3 and Table 2), students were likely to experience lower levels of excitement ($\beta = -0.14$, $p = 0.005$), significantly lower levels of relaxation ($\beta = -0.38$, $p < 0.001$), and significantly higher frustration ($\beta = 0.67$, $p < 0.001$) and anxiety ($\beta = 0.38$, $p < 0.001$), in learning situations where they reported that they had made a mistake. The model results showed no statistically significant relationship between student-reported boredom level and making a mistake.

TABLE 2 | The situational-level effect of mistakes on students' emotions using MSEM.

	Mistake		
	β	SE	*p* value
Excitement	−0.14	0.05	0.006
Relaxation	−0.38	0.05	< 0.001
Frustration	0.67	0.06	< 0.001
Anxiety	0.38	0.05	< 0.001
Boredom	0.01	0.04	0.896

RQ2. *To what extent do the students' gender, performance level, and subjective task values affect and moderate the levels of these emotions during mistake situations in the chemistry laboratory?*

To answer the second research question, another MSEM model with random slopes (see Figure 4) was created. Statistically significant paths in that model are presented in Figure 7. The results, displaying the impact of student factors on their emotional experiences in the chemistry laboratory, are presented in Table 3. Their effects on the intensity and direction of the change (i.e., slopes) in the levels of these emotions in mistake situations are presented in Table 4. The results reveal individual differences not only in students' emotions but also in the slopes, indicating variability in the intensity and direction of the change in the levels of these emotions in mistake situations due to individual factors.

The results on the relationships between students' emotions and individual factors suggest that students with a high utility value of laboratory activities were more likely to experience positive emotions, especially excitement ($\beta = 0.51$, $p < 0.001$), and less likely to experience negative emotions. High emotional costs of laboratory activities predicted lower levels of the positive deactivating emotion of relaxation ($\beta = -0.22$, $p = 0.009$) and significantly higher levels of the negative activating emotions of frustration ($\beta = 0.26$, $p < 0.001$) and anxiety ($\beta = 0.30$, $p < 0.001$). Additionally, the results suggest that students who identified themselves as males are more relaxed during laboratory instruction ($\beta = 0.47$, $p < 0.001$), and that students' emotions during laboratory sessions are not associated with their performance level.

To examine how individual factors moderate students' emotional responses to mistakes (see the results of RQ1), we investigated how these factors affect the random slopes S1–S5 (see Figures 4 and 5). Based on the results, well-performing students were likely to experience a significantly smaller increase in anxiety and frustration in mistake situations ($\beta = -0.15$, $p = 0.001$), while lower-performing students, in contrast, were likely to get more anxious and frustrated. Well-performing students were also likely to remain more relaxed in mistake situations ($\beta = 0.11$, $p = 0.048$). Finally, based on the results, students who perceive high emotional costs of laboratory activities seem to get more anxious in mistake situations ($\beta = 0.21$, $p = 0.029$).

RQ3. *To what extent does the cause of the mistake or receiving help to solve the mistake affect the levels of these emotions?*

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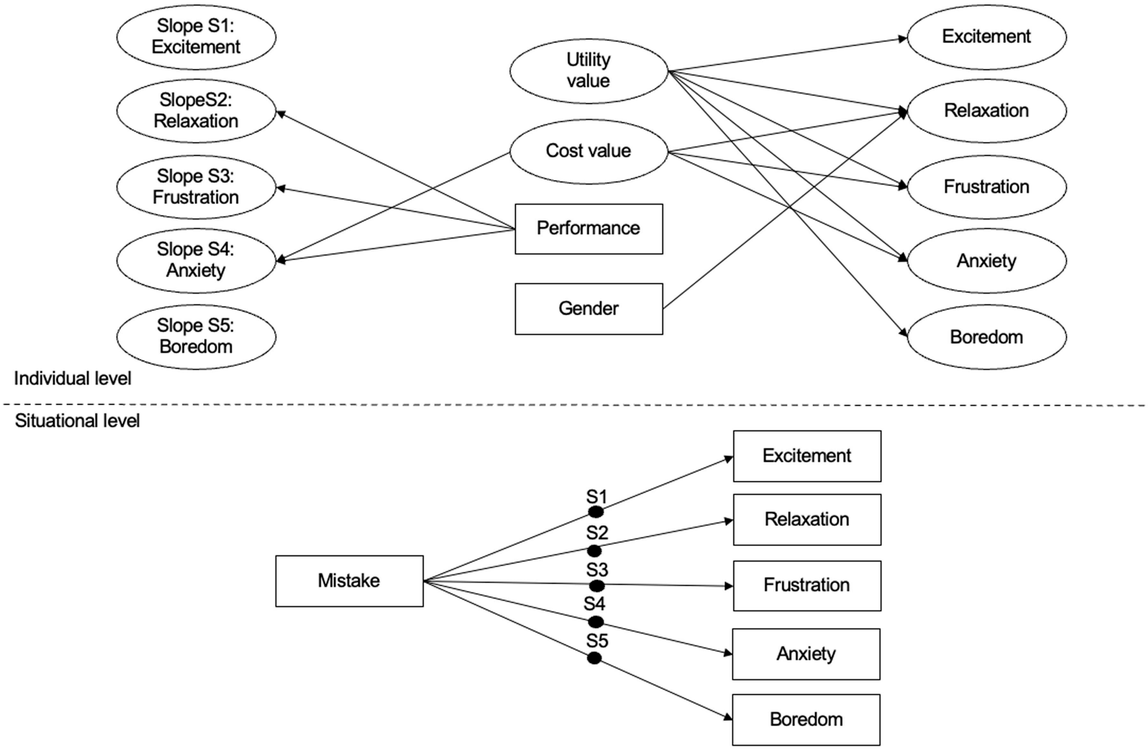

FIGURE 7 | Results of MSEM analysis with random slopes, displaying only significant paths.

To understand the role of situational factors in mistake situations, we examined how situational factors affect students' emotional responses to mistakes (see Figure 6). The results are presented in Table 5. Taking situational factors into consideration (cf. Model 1), the relationship between excitement and mistakes becomes nonsignificant, but the relationships between mistakes and student-reported frustration, anxiety and relaxation remain statistically significant.

Our results suggest that the cause of the mistake can impact students' excitement. If the mistake was a careless mistake, students were likely to experience higher levels of excitement ($\beta = 0.16$, $p = 0.036$). On the other hand, mistakes that were caused by a lack of one's skill or knowledge predicted not only lower excitement ($\beta = -0.38$, $p = 0.018$) but also significantly higher levels of frustration ($\beta = 0.82$, $p < 0.001$) and anxiety ($\beta = 0.61$, $p = 0.001$) and lower relaxation ($\beta = -0.44$, $p = 0.015$). Based on the results, receiving teacher support intensified the effects of mistakes on students' emotions, proposing a greater decrease in relaxation ($\beta = -0.37$, $p < 0.001$) and an increase in frustration ($\beta = 0.36$, $p = 0.001$) and anxiety ($\beta = 0.28$, $p = 0.003$). Peer support, in turn, did not show a similar statistically significant impact on students' emotions.

4 | Discussion

This study aims to deepen the understanding of students' situational, on-task responses to mistakes in the undergraduate chemistry laboratory. Previously, mistakes have been established as an intrinsic aspect of laboratory work and in line with this notion, mistakes occurred in at least 28.5% of all learning situations in this study (Agustian et al. 2024). We discuss our findings in the light of the CVT, integrating both individual and sociocultural (situational/environmental) determinants of learning-related emotions (see Figure 1). We discuss the limitations of this study, and at the end of this section, we address some implications for both practice and research.

RQ1. *To what extent does making mistakes impact students' levels of excitement, relaxation, frustration, anxiety, and boredom in the chemistry laboratory?*

In line with previous findings (Agustian et al. 2024; Corwin et al. 2022; Galloway et al. 2016; Simpson and Maltese 2017), we observed a significant increase in frustration and anxiety in situations where students had made mistakes. Along with the increase in these emotions, the level of relaxation decreased. Although the relationship between relaxation and making mistakes had not been established in previous studies, it was not surprising, considering that relaxation is situated at the opposite end of anxiety and frustration on the two-dimensional circumplex model of emotions (see Figure 2). Mistakes also seemed to have a small negative effect on the level of excitement. Based on these findings, mistakes likely evoke more negative and activating emotions in students. Moreover, the results indicate that, regarding negative activating emotions, mistakes increase levels of activity-related frustration more intensely than anxiety, which may also relate to prospective failure (Pekrun 2024). This supports our conceptualization of mistakes as a situated phenomenon (Schechtel and Bongers 2026; Schmid et al. 2025). Considering the underlying control and value appraisals, the results suggest that mistakes may be related to higher value and lower control, positioning them as important activities that provide students with temporal challenges (Pekrun 2024).

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TABLE 3 | The effects of student characteristics on their levels of emotions during laboratory work using MSEM with random slopes.

	Excitement			Relaxation			Frustration			Anxiety			Boredom		
	β	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE.**	***p* value**
Utility	0.51	0.14	< 0.001	0.25	0.11	0.039	−0.26	0.11	0.012	−0.20	0.10	0.046	−0.30	0.13	0.020
Cost	−0.12	0.09	0.165	−0.22	0.09	0.009	0.23	0.07	0.001	0.30	0.07	< 0.001	0.12	0.07	0.070
Performance	−0.02	0.05	0.667	−0.02	0.06	0.741	−0.03	0.04	0.444	0.02	0.04	0.649	−0.06	0.05	0.268
Gender	−0.06	0.11	0.566	0.47	0.11	< 0.001	−0.03	0.09	0.715	−0.07	0.09	0.466	0.05	0.10	0.613

Note: In the analyses, gender 1 = male, 0 = female or other.

TABLE 4 | The effects of student characteristics on the slopes, indicating the change in emotions during mistake situations, using MSEM with random slopes.

Slope	Change in excitement (S1)			Change in relaxation (S2)			Change in frustration (S3)			Change in anxiety (S4)			Change in boredom (S5)		
	β	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE**	***p* value**	**β**	**SE**	***p* value**
Utility	−0.07	0.12	0.548	−0.16	0.14	0.253	−0.04	0.14	0.784	0.14	0.12	0.248	−0.06	0.09	0.523
Cost	0.05	0.09	0.564	−0.07	0.11	0.541	0.11	0.10	0.304	0.21	0.10	0.029	−0.08	0.07	0.265
Performance	0.05	0.05	0.257	0.11	0.06	0.048	−0.15	0.05	0.004	−0.15	0.05	0.001	0.05	0.04	0.269
Gender	0.15	0.10	0.149	−0.04	0.11	0.727	−0.20	0.12	0.101	−0.14	0.09	0.127	−0.12	0.09	0.186

Note: In the analyses, gender 1 = male, 0 = female or other.

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TABLE 5 | The effects of mistakes and mistake situation factors on students' levels of emotions using a linear regression model controlling for student-level effects.

	Excitement			Relaxation			Frustration			Anxiety			Boredom		
	β	SE	*p* value	*β*	SE	*p* value	*β*	SE	*p* value	*β*	SE	*p* value	*β*	SE	*p* value
Mistake	−0.10	0.06	0.112	**−0.27**	**0.08**	**0.001**	**0.48**	**0.08**	**< 0.001**	**0.20**	**0.07**	**0.002**	0.03	0.06	0.638
Receiving support															
Mistake, teacher helped	−0.15	0.09	0.104	**−0.37**	**0.10**	**< 0.001**	**0.36**	**0.11**	**0.001**	**0.28**	**0.09**	**0.003**	0.04	0.09	0.603
Mistake, peers helped	−0.05	0.10	0.610	−0.11	0.11	0.275	0.08	0.13	0.566	0.08	0.11	0.473	0.01	0.10	0.946
Cause of mistake															
Mistake, careless	**0.15**	**0.07**	**0.039**	0.17	0.09	0.070	−0.09	0.10	0.392	0.01	0.09	0.946	−0.06	0.07	0.454
Mistake, lack of skill	**−0.38**	**0.16**	**0.018**	**−0.44**	**0.18**	**0.015**	**0.82**	**0.19**	**< 0.001**	**0.61**	**0.19**	**0.001**	−0.08	0.12	0.523

When students make mistakes, they are forced to decide on the next course of action and suddenly have control beyond the predetermined steps of the laboratory manual. This promotes their agency in the learning process (Galloway et al. 2016), supporting the observed increase in activating emotions. In theory, this could also increase their sense of control, assuming that they feel like they can manage the situation (Pekrun 2024). The increased activation or agency can help students overcome or even embrace their mistakes and alleviate their negative emotions (Pekrun 2006; Corwin et al. 2022). However, if students' emotional schemes remain too negative, it can hinder their learning (Pekrun 2006; Vilhunen et al. 2023) and participation in collaborative laboratory work (Ballard and Winfield 2024; Camacho-Morles et al. 2019; Pietarinen et al. 2020).

RQ2. *To what extent do the students' gender, performance level, and subjective task values affect and moderate the levels of these emotions during mistake situations in the chemistry laboratory?*

There are individual differences in students' emotional levels in the laboratory in general, and not everyone responds to mistakes or failure in the same way (Nunes et al. 2022; Agustian et al. 2024). Based on our findings, students' STVs, that is, utility and cost values of laboratory activities, alike gender, significantly impacted students' emotions during the laboratory work, mainly aligning with previous understanding (Berweger et al. 2022; Liu et al. 2025). Students with high perceived utility of laboratory work experienced higher levels of situational positive emotions and lower levels of situational negative emotions, and those who perceived laboratory work as stressful or burdensome experienced higher levels of situational anxiety and frustration and lower levels of situational relaxation. Although previous linkages between students' STVs and emotional levels are mainly from the educational psychology field, our results from the chemistry laboratory context are well aligned (Berweger et al. 2022). However, our findings regarding the role of gender do not support the previous understanding of females experiencing higher trait anxiety in the laboratory (e.g., Pelch 2018). Based on our findings, gender only impacted the level of relaxation, as males, in general, experienced higher levels of relaxation. Although anxiety is situated at the crossface of the two-dimensional circumplex model of emotions (Russell 1980; see Figure 2), it was not associated with gender in our study.

Moreover, our findings provide new insights into the individual differences in students' responses to mistakes. Concerning students' emotional responses to mistakes, well-performing students seem to remain more relaxed and get less frustrated and anxious in mistake situations, whereas low-performers experience a more intense increase in frustration and anxiety, along with a decrease in relaxation. Perhaps high-performers do not associate such a high reputational cost with making mistakes (Nunes et al. 2022) and thereby stay more positive. They may also feel more in control, perceiving the activities as manageable, which would align with their more positive emotional experience (Pekrun 2024). Reciprocally, their adaptive reactions could also promote productive learning and, subsequently, higher academic performance. Low-performers may, in

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contrast, feel less competent overall, and mistakes may further undermine their sense of control. We thus suggest that activity-related frustration and outcome-related anxiety may be viewed as trait-like emotions in mistake situations for lower-performing students (Pekrun et al. 2018).

Students with high perceived emotional costs of laboratory activities appear to experience a more intense increase in anxiety than others when they make mistakes. Anxiety could thus be viewed as a trait-like emotional response to mistakes, also for those with high perceived emotional costs (Pekrun et al. 2018). This could potentially contrast the findings of a previous study in an undergraduate chemistry course where emotional costs were not linked to perseverance (Perez et al. 2014). If emotional costs were not associated with perseverance even at the situational level, we would expect students to demonstrate little or no change in the level of anxiety.

Instead, we propose that the high perceived emotional costs of laboratory work may be associated with lower persistence and an undervaluing of mistakes as learning opportunities, thereby intensifying negative emotional responses (Tulis and Dresel 2025; Soncini et al. 2022; Simpson and Maltese 2017). This aligns with the finding that these students experienced an increase specifically in anxiety, which may reflect a fear of prospective failure, rather than in frustration that is more related to the ongoing activity (Pekrun 2024). Indeed, these students may be apprehensive about failing due to the mistakes they make. On the other hand, these students may be likely to experience excessive anxiety in the laboratory, particularly during mistake situations, which can hinder their cognitive processing, engagement, and subsequently, learning from mistakes (Pekrun 2006; Pierson et al. 2023; Vilhunen et al. 2023; Corwin et al. 2022).

Maladaptive coping with mistakes, expressed by low-performers and students with high emotional costs, can be detrimental to learning (Tulis et al. 2018). Furthermore, their excessively negative emotional experiences can become a threat to their science identity development and, thus, persistence (Schultz et al. 2011), STEM-career path choices (Estrada et al. 2018), and ultimately, their general well-being (Pekrun 2024).

RQ3. *To what extent does the cause of the mistake or receiving help to solve the mistake affect the levels of these emotions?*

Supporting students in dealing with mistakes is not an easy task because, in addition to managing student emotions, teachers must support their cognitive learning as well (Allchin 2012; Keen and Sevian 2022). According to our results, students experienced significantly higher levels of frustration and anxiety and lower levels of relaxation in learning situations where they had received teacher support in solving the mistake. In terms of the underlying control and value appraisals, this could mean that students relate lower control and higher value with these situations, suggesting that they perceive them as important but something they cannot manage by themselves (Pekrun 2024). Particularly, anxiety, reflecting the fear of future failure, is linked to very low control appraisals, suggesting that students may feel incompetent and not in control of their learning when they need to seek help from teachers.

The results do not, however, establish whether seeking support from a teacher increases the negative activating emotions and decreases relaxation or whether students are solely more likely to seek support when they are more frustrated and anxious or less relaxed. Previous research suggests that experiencing negative emotions could facilitate reliance on external guidance, such as teacher support (Pekrun 2006). On the other hand, the shifts in frustration, anxiety and relaxation could also be attributed to a previous empirical result suggesting that students feel like they are bugging or annoying the teacher with their questions (Keen and Sevian 2022; Schechtel and Bongers 2026) or that they are afraid of negative evaluation based on their mistakes (Tulis 2013; Leighton et al. 2018). Empirical findings also indicate that students who perceive mistakes as beneficial for learning, that is, hold more positive error beliefs, are more likely to engage in help-seeking (Leighton et al. 2018; Tulis and Dresel 2025).

Our results imply that peer support does not have a similar negative impact on students' emotional experiences in the chemistry laboratory. Students may be more likely to seek support from their peers when the mistake they are dealing with is easier to solve, and this could impact their emotional experiences. Keen and Sevian (2022) suggested that seeking support from peers could feel more acceptable in the sociocultural context of the laboratory. They also argued that peers might be more likely to provide one another with socio-emotional support when dealing with each other's mistakes, whereas teachers might tend to focus on the cognitive struggles of students. This socioemotional support has been found to significantly promote students' reengagement in the laboratory work and plausibly mediate the shifts in students' emotional levels in these situations (Keen and Sevian 2022).

The effect of peer support may have, however, remained non-significant due to a large variation in the quality of support provided by the peers. While some students may be very proficient in providing support, both cognitive and emotional, to their peers, others may be less so. If they cannot help tackling the problem, merely offering emotional support may not influence students' situational appraisals and thus emotions. In contrast, instances where they can do so may support students' feelings of control, as solving mistakes with peers can be related to higher self-competence and agency, differentiating peer support from the frustration- and anxiety-inducing, relaxation-decreasing teacher support. Nevertheless, there is still a need for further research investigating how the form of support can help students overcome their mistakes.

In addition, the results also suggest that the cause of the mistake plays a significant role in how students emotionally respond to it. Careless mistakes were associated with higher levels of excitement, indicating enthusiasm and plausibly subsequently higher risk-taking and lower carefulness (Nunes et al. 2022). Thus, in these situations, students may feel like they are in control regardless of their mistakes (Pekrun 2024). When students make mistakes due to a lack of skills or knowledge, it indicates that they have faced challenges beyond their capabilities. This inherently suggests low control over the activity or outcome, and along those lines, these types of mistakes appear to be a significant factor in increasing

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students''frustration and anxiety (see also Pekrun 2006; Pekrun et al. 2018; Allchin 2012). Furthermore, these mistakes diminish students' positive emotions, excitement, and relaxation, which are both linked to high control. As these mistakes appear to be related to lower self-efficacy, they could negatively impact students' science identity (Estrada et al. 2011)—particularly if not properly attended to.

4.1 | Limitations

The most significant limitation of this study is the relatively low compliance rate in the EMA questionnaires (52.4%), which results in many missing responses. As the EMA questionnaires were positioned within the laboratory session, the participants had multiple things to consider, even without the data collection. Therefore, having to respond to the EMA questionnaires can also alter their emotional experiences. For example, if students associate low value with the questionnaires, they may experience negative emotions like boredom as a response. In addition, the questionnaires may influence students' workflow, altering their emotional experiences. To account for this, the data collection points were positioned between different procedures or sections for minimal interruption.

Furthermore, due to the estimation of the random slopes, no absolute fit indices were available, and thus, Model 2 cannot be falsified like a conventional SEM model. This is also true for Model 3, which was saturated. Therefore, the results provided by these models should be interpreted cautiously. Next, it should also be noted that utility value and emotional costs were each measured using items that have been previously used to measure context-specific utility and emotional costs in the Finnish context (Ronkainen et al. 2024) but have not been validated in the undergraduate chemistry laboratory context. Each structure was measured using only two items (Ronkainen et al. 2024), which contrasts with the common recommendation of at least three indicators (Hayduk and Littvay 2012). Therefore, conventional evidence for the measurement validity cannot be provided. However, strong factor loadings and the theoretically expected correlation between utility and cost support the validity of these constructs (Hayduk and Littvay 2012). These suggest that the items strongly represent the underlying constructs and ensure sufficient reliability (Hair et al. 2022). Using fewer indicators also reduces the excessive complexity of the already complex models.

Another limitation is that mistakes cannot be unambiguously defined, and students were not asked what they understood by the term mistake (cf. Käfer et al. 2019), but only if they noticed that they had made mistakes. This also extends to the mistake situation factors, particularly the cause of the mistake, as these measures lack objectivity. Still, we view students''perceptions of mistakes and mistake situations as primarily significant, especially when focusing on the affective domain. Emotions are, by definition, triggered by individuals' own subjective appraisals (Pekrun 2024).

The holistic nature of emotions also sets a potential limitation to this study, as we measured the levels of students' activity-related emotions but did not ask about the object focus, making it unclear whether the emotions truly were achievement emotions. Moreover, we did not ask students to report their emotional responses specifically to mistakes. Instead, we asked about the levels of their emotions during previous activities and then whether they had made a mistake. Although this approach may not explicitly reveal students' emotions caused by mistakes, it provides information on how they have affected the levels of students' emotions during laboratory instruction in general. This puts the phenomenon into perspective, which we view equally, if not even more relevant. It is also unclear how students perceived the valence of each emotion across different situations (cf. Imbir and Pastwa 2021). For instance, in-situ boredom has been associated with varying degrees of negativity depending on the situational experience (Goetz et al. 2014). However, anxiety and frustration are consistently categorized into negative valence (e.g., Pekrun 2024). Experiences of excitement and relaxation also strongly correlate with the physiological processes that indicate a positive valence as well as high and low arousal, respectively (Ketonen et al. 2023).

Finally, this study was conducted at one Finnish university in the context of chemistry laboratory education. There was a significant gender imbalance among the participants of this study, as the large majority identified as female. Although this represents the current gender distribution of students in the fields of natural sciences in Finland (Statistics Finland 2024), this is a potential limitation to the generalizability of the findings related to gender differences. The findings support the framing of mistakes as situational and context-specific, setting limitations on the generalizability across other fields. Nevertheless, we propose that these findings may apply to other tentative sciences, such as physics, biology and engineering, because the mistakes that occur in these contexts may share many similarities. To gain insights into the generalizability of these results, we recommend more versatile samples with more even gender distributions, as well as students from different age-groups, disciplines, learning contexts, institutions and cultures.

4.2 | Implications for Practice

As mistakes occur frequently in the chemistry laboratory, students should be comfortable with encountering them. We argue that learning to deal with scientific mistakes ought to be an explicit learning goal of laboratory education, and this should be clearly established in the curriculum and articulated to students. Therefore, it is crucial to help students embrace mistakes as a part of the learning process, encouraging affective goal setting that frames mistakes not as failure but as opportunities for learning and growth (Galloway et al. 2016; Miller and Krajcik 2019; Nunes et al. 2024). For example, highlighting how common and inevitable mistakes are in the laboratory (in this study, they occurred in 28.5% of the situations), preferably at the beginning of laboratory courses, could plausibly reduce students' negative attitudes, frustration and anxiety toward mistakes (Wan et al. 2023; Käfer et al. 2019). In the moments of mistakes, students could be reminded of the broader learning goals, distinguishing the mistake from failure, which may help regulate their levels of anxiety, reflecting the fear of prospective failure (Pekrun 2024). Also, sharing one's own experiences of

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mistakes could alleviate students' feelings of isolation (Nunes et al. 2024; Schechtel and Bongers 2026). These shifts in perspective can help students engage in integrative emotional regulation and reappraisal of the negative emotions, fostering their positive affect toward the learning process and supporting meta-affective learning (Sharabi and Roth 2025; Pekrun et al. 2018; Radoff et al. 2019).

Second, teachers might want to devote extra attention to students' affective needs when guiding them through mistakes. This may come across as simply acknowledging and affirming students' emotional experiences in mistake situations (see also Keen and Sevian 2022; Sharabi and Roth 2025), but also approaching the situation with humor (see also Lamminpää and Vesterinen 2018) or encouraging the student to continue and praising them for what they are doing well. Students could be reminded that mistakes are not necessarily indications of their capabilities as learners but are unavoidable for all (Tulis and Dresel 2025). In contrast, teachers should avoid rushing the situation, focusing only on correcting the mistake, or ignoring or belittling their emotional struggles (Keen and Sevian 2022). This is crucial, as perceived emotional support from a teacher has been associated with lower anxiety (Rach et al. 2012). Emotional support can also play a significant role in students' integrative emotional regulation, which can promote adaptive coping practices in mistake situations (Lamminpää and Vesterinen 2018; Sharabi and Roth 2025). Additionally, we propose that dialog as well as collaboration among peers can contribute to an emotionally supportive learning environment and promote meaningful learning, while also training skills important for students' prospective careers (Seery et al. 2024; Ippolito and Kingsbury 2024). Thus, students should be encouraged to solve problems collaboratively.

Finally, our findings call for targeted support in regulating emotions during mistake situations, particularly for students who are more prone to frustration and anxiety in mistake situations, that is, lower-performing students and those who perceive learning stressful and burdensome. Students with high emotional costs may be specifically prone to excessive anxiety and fear of failure in the laboratory courses, as they not only tend to experience higher levels of anxiety compared to other students in general, but their levels of anxiety also diligently elevate when they make mistakes. We propose that these students, in particular, could benefit from the emotional support actions recommended above.

4.3 | Implications for Research

There is a need to understand students' on-task emotional reactions in the chemistry laboratory (Smith and Alonso 2020), and the direct associations between students' state emotions and making mistakes (Schmid et al. 2025; Sharabi and Roth 2025). In this study, we were able to respond to these calls and capture students' on-task emotions in mistake situations, as well as identify trait-like emotions based on situational measures. Using the MSEM with random slopes, we were able to identify groups of students who might need encouragement or help in regulating their emotions. Our findings support the framing of mistakes as a situational phenomenon, associated with a variety of emotional responses. Thus, we propose the need for more research that approaches mistakes on-task and in ecologically authentic contexts.

On that note, more in-depth research is still required to capture students' emotional trajectories in navigating mistakes. For a more comprehensive understanding, the phenomenon should be approached using various methodologies, including, for example, interviews, observation, and diary reflections. This could enlighten, particularly the role of sociocultural factors, like peer- and teacher-interaction and feedback, in shaping students' emotional responses to mistakes, specifically in the chemistry laboratory context. Such methods could also be utilized to recognize other emotions that arise in mistake situations, such as doubt, curiosity, or confusion. Moreover, in this study, we connected students' potential control and value appraisals to emotions solely based on the theoretical assumptions. Future research could empirically measure these appraisals to connect them to mistake-related emotions. Finally, in this study, students' emotional responses to mistakes were not linked to further achievement outcomes, and we recommend considering this in future studies for better capturing the learning potential that lies within.

5 | Conclusions

We investigated students' emotional responses to mistakes in the undergraduate chemistry laboratory using the CVT as a theoretical lens. In more detail, we examined the role of individual factors, that is, gender, performance level, and STVs of laboratory activities (utility and cost), as well as mistake situation factors, that is, type of mistake and support in solving the mistake, in predicting students' emotional reactions. The results support the conceptualization of mistakes as a situational phenomenon and suggest that they likely trigger negative activating emotions in students. We propose that well-performing students tend to get less anxious and frustrated, remaining more relaxed in mistake situations, while students with high perceived costs of laboratory activities are more prone to anxiety in mistake situations. Careless mistakes were associated with more positive emotions, while mistakes caused by lack of skills or knowledge decreased positive emotions and increased anxiety and particularly frustration. Students experienced heightened anxiety and frustration in situations where they received teacher support, whereas peer support was not associated with any of the studied emotions at a statistically significant level. Meaningful learning could thus be enhanced by supporting students' integrative emotional regulation in situations involving mistakes, particularly for lower-performing students or those with high perceived emotional costs of laboratory work. This is especially important when the mistake stems from a skill or knowledge gap.

Author Contributions

Reetta Kyynäräinen: conceptualization, investigation, writing – original draft, methodology, visualization, writing – review and editing, formal analysis, data curation. **Elisa Vilhunen:** conceptualization, writing – review and editing, supervision. **Pei-Hsin Li:** conceptualization, writing – review and editing. **Mikko-Jussi Laakso:** writing –

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review and editing, supervision, funding acquisition. **Veli-Matti Vesterinen:** conceptualization, writing – review and editing, supervision, investigation, project administration, data curation, methodology.

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Ethics Statement

This research was conducted according to the ethics requirements for research involving human subjects, and it followed the ethical guidelines of the Finnish National Board on Research Integrity TENK. Participation in the study did not pose any risks and was not associated with high physical or emotional stress. The participants were informed about the absolute voluntariness of participation, the study objective, the protection of data privacy, as well as the no-risk character of the study and contact information was provided for any questions or problems.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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