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Achievement emotions questionnaire for general chemistry (AEQ-GCHEM): development and psychometric evaluation

Alex Graves and Corina E. Brown *

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Chemical education literature suggests that General Chemistry, a required course for many STEM programs, is often perceived as difficult and stress-inducing. One measurable aspect of students' experiences in this course is achievement emotions, which both influence and are influenced by academic performance. To assess achievement emotions in the General Chemistry context, the General Chemistry Achievement Emotions Questionnaire (AEQ-GCHEM) was developed through a revision of the existing theory-based instrument established by Pekrun's group, the Short Version of the Achievement Emotions Questionnaire (AEQ-S). Additionally, a laboratory subscale was incorporated into this modified version. Evidence supporting the instrument was established through qualitative interviews, factor analysis, and analyses of the relationships between achievement emotions and academic contexts across multiple iterations. These findings indicate that the modifications made to the AEQ-S to develop the AEQ-GCHEM resulted in a psychometrically supported instrument for collecting data on the achievement emotions experienced by students in General Chemistry lecture and laboratory courses.

Introduction

Student success and retention in STEM disciplines remain a major concern for educators, institutions, and policymakers, prompting extensive research into why students struggle to persist and how to support their success (National Research Council, 2012; Seymour and Hunter, 2019; Leary *et al.*, 2020). Poor performance in first-year STEM courses is strongly linked to lower persistence in STEM majors (Matz *et al.*, 2017; Harris *et al.*, 2020). General Chemistry, a required gateway course for many science degrees, is frequently perceived as a difficult, stress-inducing ''weed-out'' course that contributes to student attrition (Gaiewski *et al.*, 2012; Koch, 2017; Harris *et al.*, 2020). Instructional approaches in General Chemistry, including reforms and evidence-based teaching practices, have been investigated to improve student outcomes and retention (Frey *et al.*, 2017; Cooper, 2019; Santos and Mooring, 2022). Beyond course structure, students' emotional experiences (affect) are increasingly recognized as central to learning, achievement, and persistence in STEM (Gómez *et al.*, 2020; Park, 2022; Brown and Nedungadi, 2024; Frost *et al.*, 2024). Achievement emotions, defined as emotions directly tied to achievement activities and outcomes, influence how students engage with learning tasks and regulate their motivation and thinking. According to Control-Value Theory (CVT), achievement emotions arise from students' perceptions of control over learning activities and the value they assign to those activities, and these emotions, in turn, shape cognitive engagement, motivation, and performance (Pekrun, 2006).

Achievement emotions have been studied across various STEM disciplines. For instance, Gómez *et al.* (2020) found that emotions such as enjoyment, pride, anxiety, and boredom can predict students' performance in mathematics. Their study emphasized the importance of considering both positive and negative emotions in educational contexts, highlighting their significant role in academic performance. Similarly, Park (2022) examined how achievement emotions relate to students' science identities in an inquiry-based physics classroom, finding that positive emotions, such as enjoyment and pride, were linked to higher motivation and improved academic performance. Brown and Nedungadi (2024) assessed the relationship between students' achievement emotions and academic performance in a General, Organic, and Biological Chemistry course. They found that positive activating emotions (*e.g.*, enjoyment, hope, pride) were positively correlated with final grades, whereas negative activating and deactivating emotions (*e.g.*, anxiety, shame, boredom) had negative correlations, except for anger. Frost *et al.* (2024) specifically explored the achievement emotion of shame in a first-semester organic chemistry course and reported a negative association with exam performance, indicating that students experiencing higher levels of shame

Department of Chemistry and Biochemistry, University of Northern Colorado, Greeley, CO 80639, USA. E-mail: Corina.Brown@unco.edu

performed worse. Collectively, these studies demonstrate that positive emotions, such as enjoyment and pride, are associated with deeper engagement, more effective learning strategies, and improved academic outcomes, while negative emotions such as anxiety, frustration, and boredom can hinder motivation and lead to disengagement and lower academic performance (Pekrun *et al.*, 2002; Pekrun, 2006; Eysenck *et al.*, 2007).

Affect is particularly important in gateway courses, which are courses that serve as prerequisites for other courses required in a degree program, such as the first semester of a two-semester General Chemistry sequence. These gateway courses often exhibit low retention rates, especially among underrepresented students, which can result in smaller student populations in subsequent courses (Cracolice and Busby, 2015; Seymour and Hunter, 2019; Hatfield *et al.*, 2022).

Learning is an emotional experience in which emotions influence academic performance and overall academic development (Pekrun, 1992; Pekrun *et al.*, 2009). The emotions that students experience in a classroom can be tied to a multitude of constructs, such as self-efficacy, learning attitudes, expectations, values, interests, motivation, and achievement, all of which have been studied in an attempt to understand factors influencing how students learn (Flaherty, 2020). Achievement emotions have been found to have strong relationships with factors that influence student retention (Respondek *et al.*, 2017; Turnquest *et al.*, 2024).

Despite substantial evidence linking achievement emotions to student learning and persistence in STEM, research examining these emotions in first-semester General Chemistry remains limited. There is a need for context-specific, theoretically grounded measures that capture the range of achievement emotions students experience in this gateway course. The present study addresses this need through the development and psychometric evaluation of an instrument specific to General Chemistry.

Control-value theory

Pekrun proposed the control-value theory of achievement emotions (CVT) as a framework for explaining the interactions among, behavior, and achievement in academic settings (Pekrun 1992, 2000, 2006). According to this theory, students assess a learning situation based on the value they place on it and the degree of control they feel they have over it. This evaluation can trigger emotional responses, known as achievement emotions, which, in turn, influence the student's motivation and behavior in relation to learning and engagement (Pekrun, 2006). While CVT is not specific to chemistry education, an assumption of CVT is that affective, behavioral, and achievement relationships are disciplinarily, culturally, and demographically specific (Pekrun, 1992, 2006). Although evidence in support of this theory has been shown to be generalizable across educational settings, this hypothesis still warrants discipline-specific analysis and evaluation. This requires using discipline- or course-specific instruments that generate data supported by evidence of validity and reliability.

Achievement emotions, proposed in CVT, are emotions that influence a wide array of constructs, including attitudes and motivations (Pekrun, 1992, 2006). Pekrun identified nine achievement emotions that predominantly affect students: enjoyment, hope, pride, anger, anxiety, shame, hopelessness, boredom, and relief (Pekrun *et al.*, 2011; Pekrun and Linnenbrink-Garcia, 2014). Most academic emotions have not been studied in depth, except for anxiety, which has been widely shown to negatively impact academic performance across educational contexts, including the sciences (Eddy, 2000; Widanski and McCarthy, 2009; Rempel *et al.*, 2021, Gibbons *et al.*, 2019; Flaherty, 2022).

To measure achievement emotions, Pekrun *et al.* (2011) developed the Achievement Emotions Questionnaire (AEQ). This instrument has 24 subscales and measures nine achievement emotions across three settings: classroom, learning, and testing. Each subscale (*i.e.*, emotion-setting pairing) is composed of 6–12 items with an associated Likert-scale response; psychometric evaluation of this instrument revealed that it yields valid and reliable data. However, the AEQ's length (232 items) could make it difficult to administer in empirical studies in educational research. A shortened version of the AEQ, abbreviated as the AEQ-S (96 items), was created to solve the issue of the original survey's length (Bieleke *et al.*, 2021). The AEQ-S can assess students' achievement emotions and examine how these emotions relate to their motivation, values, and learning strategies.

According to Pekrun (2006) emotions can be classified by "valence" which refers to whether an emotion is positive (pleasant) or negative (unpleasant), and by arousal, as activating and deactivating. Based on the characteristics of valence and arousal of emotions, four categories of academic emotions can be distinguished as positive activating/deactivating emotions and negative activating/deactivating emotions as presented in Fig. 1.

Purpose of this study

Studies have shown that achievement emotions are domain-specific, meaning that a student's emotional experiences can vary depending on the context in which the emotion occurs (Goetz *et al.*, 2007; Gibbons *et al.*, 2018; Park, 2022; Brown and Nedungadi, 2024; Frost *et al.*, 2024). For example, the achievement emotions that a student experiences in a physics course may be entirely different constructs from the achievement emotions experienced by that same student in a chemistry course. Likewise, this applies to subdomains as well, *e.g.*, what a student experiences in a biochemistry course may be distinctly different from what that same student experiences in a General Chemistry course. Some discipline-specific versions of the AEQ have been developed, including the AEQ-OCHEM, which was derived to study achievement emotions in organic chemistry courses (Raker *et al.*, 2018). While the AEQ-OCHEM represents a validated adaptation of the AEQ for organic chemistry, it was specifically designed for the instructional structure and learning demands of this particular course.

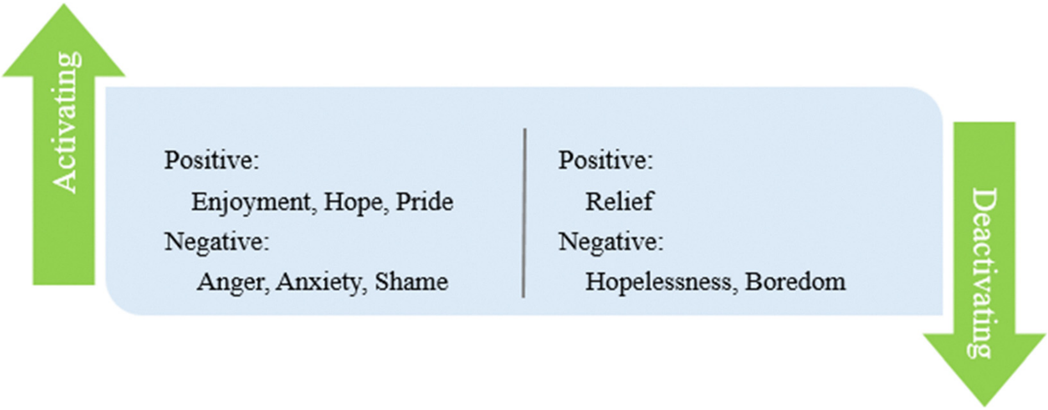

Fig. 1 Organization of achievement emotions by valence and activation.

The primary goal of this study was to develop a context-specific instrument to assess students' achievement emotions during the first semester of a General Chemistry course. Guided by these contextual and practical considerations, the AEQ-GCHEM was developed from the short version of the Achievement Emotions Questionnaire (AEQ-S). The AEQ-S was modified to align with the instructional structure of the general chemistry course, including the addition of a laboratory component. Evidence of response process and internal structure validity was then collected, including evaluation of factor structures that best represent the multi-dimensional nature of achievement emotions. This adapted instrument is referred to as AEQ-GCHEM.

This study was guided by the following two questions:

RQ1 What modifications of the AEQ-S are needed to produce a first-semester General Chemistry-specific Achievement Emotions Questionnaire (AEQ-GCHEM) that measures achievement emotions?

RQ2 What validity and reliability evidence support the use of the AEQ-GCHEM with students in a first-semester General Chemistry course?

Since achievement emotions have been shown to be domain-specific, the instrument needed to be crafted with language specific to a student's experience in a General Chemistry course. This included adding a component to the instrument to measure achievement emotions in a laboratory setting, since most students enrolled in a General Chemistry lecture course must concurrently be enrolled in a corresponding General Chemistry laboratory course.

Methods

All data collection procedures were approved by the Institutional Review Board (IRB) at the University of Northern Colorado, and informed consent was obtained from all student participants in accordance with IRB requirements. The voluntary nature of the data collection was emphasized to all potential participants. Participants who completed the survey received five extra credit points on an exam worth 80 points, within a course totaling 1000 points. Participants completed the survey *via* Qualtrics, an online survey data collection website. The survey was conducted after the participants received their first exam grade to allow them to have experience and reflected on all aspects of the course assessed by this survey, both prospectively and retrospectively. To ensure data quality, student responses were removed if participants did not complete one or more subscales or if responses exhibited patterned or incomplete answering (*e.g.*, identical ratings across all items or large sections left blank). The survey took about 20 minutes to complete. Response times and data patterns were monitored to identify random answering responding. Variation in item responses showed that students used the rating scale appropriately rather than giving the same response across items. Data were analyzed for each subscale when a student completed that subscale.

The last item of the survey contained a prompt that asks participants to indicate if they would participate in a brief interview regarding the survey. All interviews were conducted one-on-one *via* Zoom and recorded, with participants allowed to turn off their video if desired. Semi-structured interviews were scheduled at participants' convenience throughout the semester to gather feedback on the sources and causes of their achievement emotions and the clarity of the survey items. Students explained their responses, and the researcher asked follow-up questions as needed for clarification. Each interview lasted 20–30 minutes and followed a standardized protocol to ensure items were clearly understood and reflected emotions specific to the chemistry learning environment.

Interviews with six experts (chemistry educators with experience in chemical education research) were conducted to establish face validity of all four scales of the AEQ-GCHEM. Face validity refers to the extent to which items appear to measure the intended construct (Trochim and Donnelly, 2006). During the interviews, the experts evaluated each item for clarity and to ensure that it contained sufficient chemistry-specific language to evoke an achievement emotion that a student would experience in a chemistry learning context. Illustrative excerpts from expert interviews supporting the face validity of the instrument are provided in SI.11 in the Appendix.

Participants

Students were sampled for an initial pilot study across four academic semesters from Fall 2021 through Spring 2023, with additional students sampled for the main study using the finalized AEQ-GCHEM in Fall 2023 and Spring 2024. A total of 637 students participated in the pilot study, while 500 students participated in the main study, which included both surveys and interviews. Student participants were enrolled in the first-semester of General Chemistry at one of four universities with the following Carnegie classifications: one R2 institution in the Rocky Mountain region of the United States, one R1 in the Rocky Mountain region of the United States, one Doctoral Research University with Moderate Research Activity in the Midwest United States, and one R1 institution in the Southeastern United States. The summary of participants across semesters, instruments, and research phases is detailed in the Appendix, Table SI.1, with quantitative and qualitative sample sizes reported separately to provide a clear overview of the data collection for each phase.

Response process interview analysis

Interviews with students were analyzed to provide evidence of response process validity. All interviews were audio- and video-recorded with participants' consent, transcribed verbatim, and analyzed to provide evidence of response process validity. Two researchers independently reviewed the transcripts, noting instances of misinterpretation, or mismatched explanations. The two researchers then came together to discuss explanations that seemed unclear or not in alignment with the given response. The researchers then individually analyzed additional interviews before coming together to discuss the responses from those interviews. This cycle continued until all interviews were analyzed and discussed. The researchers then consolidated the findings for each item and assessed whether each item appeared to function well or was unclear or confusing to students. Information from the interviews was used to refine or remove unclear items prior to quantitative analysis, as well as to support the removal of items during quantitative analysis. Several statements were modified for clarity based on student feedback. Some items of the modified instrument (AEQ-S) also contain metaphorical language that students inconsistently interpreted; these items were modified accordingly based on qualitative interviews. Details about modifications are presented in the Appendix (see Tables SI.3 and SI.5 for summary).

Instrument modification

The AEQ-S was adapted to create the General Chemistry-specific Achievement Emotions Questionnaire (AEQ-GCHEM) through an iterative process of feedback from interviewing both experts and students. Broad or general tasks or references to a class were changed to specifically refer to General Chemistry (*e.g.*, "I enjoy being in class" was revised to "I enjoy being in my General Chemistry class") to help the respondents focus on their course-specific experiences.

For the AEQ-GCHEM, a laboratory setting was added in addition to the existing settings: classroom, learning, and testing. A mandatory laboratory course, in which students obtain practical experience working with chemicals and writing experimental reports, is taken concurrently with a General Chemistry lecture course (Reid and Shah, 2007). Because it is a different setting than the three settings included in the AEQ-S, the laboratory setting could induce separate achievement emotions than the other three settings.

The modifications to the AEQ-S were guided both by prior theory and research as well as empirical data collected in this study. Following the theoretical framework of the AEQ, we retained the established structure of settings and emotions (*e.g.*, the omission of boredom in the testing setting and inclusion of relief, as justified in prior work). Similarly, the decision to use sum-scoring aligns with conventions in earlier AEQ studies to facilitate comparison across instruments. At the same time, several modifications were based on empirical feedback gathered through interviews with students and experts, such as revising item wording for General Chemistry and determining that the laboratory setting aligned more closely with classroom and learning settings, warranting the inclusion of boredom rather than relief.

AEQ-GCHEM items

The AEQ-GCHEM contains 128 items across 32 subscales. Items are grouped based on the four settings and then the achievement emotions. Each item is evaluated on a 5-point Likert scale: strongly disagree (1) to strongly agree (5). The score from each subscale (*i.e.*, each setting-emotion pairing) was obtained by averaging the item scores within the particular subscale. No items were reverse scored. Higher values consistently reflect stronger experiences of the respective emotions, whether positive or negative. Although averaging (sum-scoring) Likert-like values can lead to inaccurate assumptions and conclusions from data when compared to factor-based scoring in some scenarios (Widaman and Revelle, 2022), the method used in this study allows the data and results to be compared more easily to previous studies (also using sum-scoring methods) while still maintaining relatively similar levels of reliability.

Although a total of nine achievement emotions were measured with this instrument, only eight were measured in each setting; the testing setting did not measure boredom but instead measured relief, which was only measured in the testing setting. The original AEQ study justified these omissions of setting-emotion pairings based on prior exploratory studies in which it was determined that boredom is not significantly experienced in the testing setting; however relief, which is not experienced significantly in the classroom or learning setting, is experienced significantly in the testing setting (Spangler *et al.*, 2002; Pekrun, 2006). When designing the laboratory setting for the AEQ-GCHEM, the setting aligned more with the classroom and learning settings based on interviews with students and experts. Therefore, the boredom emotion was included in the laboratory setting and the relief emotion omitted.

AEQ-GCHEM iterations

The AEQ-GCHEM was modified at several points over the course of this study. The first four academic semesters of data collection were considered part of the pilot study (n = 607). The final two academic semesters of collecting data used the finalized version of the instrument (n = 484). The results and discussion in this article used data collected with the finalized version of the instrument, with some psychometric analyses of the data collected from the previous iterations of the AEQ-GCHEM being given in the Appendix (Tables SI.1–SI.4).

Results and discussion

Before using an instrument, it is important to examine its psychometrics, or the characteristics of the instrument itself. Since instruments are designed to measure people's attributes, evaluating the instrument's properties ensures it will function as intended by the researcher (Furr and Bacharach, 2013). The two psychometric attributes of the AEQ-GCHEM assessed were validity and reliability of the data collected with the instrument. These attributes are important because instruments should produce data that can be interpreted both accurately (validity) and consistently (reliability) (Knekta *et al.*, 2019).

Validity evidence

The validity of the data collected with the AEQ-GCHEM has been investigated for evidence based on test content (through expert evaluation and student interviews), response process (through student interviews), internal structure (through factor analysis), and relationships among variables (through emotion-emotion correlations).

Interviews were conducted with experts (n = 6) and students enrolled in first-semester General Chemistry (n = 30) to evaluate if the achievement emotions being measured by the instrument are achievement emotions that students in a first-semester General Chemistry course experience. Interview participants read each instrument item and discussed whether the prompt elicited an emotion they could relate to from their first-semester General Chemistry experience. In these interviews, emphasis was placed on whether the achievement emotions between settings are separate constructs (*i.e.*, if students experience anxiety differently in the classroom *versus* when taking a test) and whether the achievement emotions experienced in a first-semester General Chemistry course are different than achievement emotions experienced in other academic courses. All experts and students agreed that achievement emotions in a first-semester General Chemistry course are separate constructs from achievement emotions in other courses, and that achievement emotions between settings are separate constructs. Response process interviews were conducted with students to evaluate whether each item was interpreted consistently and as intended by the researchers. Through this process, several items in the survey were altered due to inconsistent interpretations by students. One example is that the item on the classroom-pride subscale "When I do well in my general chemistry class, my heart throbs with pride." was altered to be "When I do well in my general chemistry class, I am proud of myself." Students were not interpreting this item consistently due to the phrase "my heart throbs with pride"; the reasons being that many students either did not relate to the phrase, indicating that it is too strong of a feeling, or did not understand what was being conveyed by the phrase. The students were also asked how they would change an item to result in less misinterpretations, and several variations of the items were read to the students to assist in determining what the language of the new item should be. A full list of altered items can be found in the Appendix (Tables SI.3 and SI.5).

Exploratory factor analysis (EFA) with oblimin rotation was conducted on the laboratory portion of the AEQ-GCHEM (Table 1). Oblimin rotation was chosen as an oblique rotation method because achievement emotions are theoretically expected to be correlated. Items are presented according to the emotion they were intended to measure and are grouped by the factors on which they loaded, with factor loadings reported for each item; bolded values indicate the primary factor loading for each item. Some items (*e.g.*, JOY4 and SHA1) exhibited relatively low primary factor loadings and non-zero secondary loadings on other factors. Such loading patterns are consistent with the conceptual overlap among related achievement emotions (*e.g.*, joy and pride; shame and anxiety), which has been reported in prior achievement emotion research and can result in cross-loadings or lower loadings for certain items.

Factor analyses were conducted on data collected using the final version of the AEQ-GCHEM. Confirmatory factor analyses (CFAs) were performed using summed subscale scores, which were treated as continuous variables (McNeish and Wolf, 2020). Examination of the distributions of the survey's subscale scores through analysis of skewness and kurtosis values indicated approximate univariate normality. Therefore, a maximum likelihood estimator (ML) was used for CFA of the individual survey subscales. However, the summed subscale scores showed a lack of normality, suggesting that the use of the maximum likelihood estimator with mean and variance adjustment (MLM) was more appropriate for the factor analytic models (Yuan and Bentler, 2000). The original AEQ-S was designed to support interpretation of both the full instrument and individual subscales; therefore, the 32 subscales of the AEQ-GCHEM were evaluated in the same manner. The internal structure of each subscale was assessed using CFA, which is appropriate when an *a priori* factor structure is hypothesized (Brown, 2015). All CFAs were conducted using the *lavaan* package (version 0.6–14) in *R* (version 4.1.1). Model fit was evaluated using the comparative fit index (CFI $>$ 0.94), standardized root-mean-square residual (SRMR $<$ 0.09), and root-mean-square error of approximation (RMSEA $<$ 0.09). All subscales met these fit criteria (Table 2).

Confirmatory factor analysis using the MLM estimator was also conducted on summed subscale scores to evaluate the internal structure of the complete AEQ-GCHEM using four theoretically motivated models (Table 3). These models have been previously used to examine relationships between achievement emotions and the settings in which they are experienced (Pekrun, 2006; Bieleke *et al.*, 2023). The fourth model, which specifies nine emotion factors with correlated residuals associated with instructional settings, demonstrated adequate fit to the data (CFI = 0.964, SRMR = 0.093, RMSEA = 0.056).

Table 1 Factor loadings for exploratory factor analysis conducted on the laboratory section of the AEQ-GCHEM

	Factor loadings								
Items	1 (8)[a]	2 (7)[a]	3	4	5	6	7 (1)[a]	8 (2)[a]	Emotions
JOY1	**0.49**	0.24	0.03	−0.31	0.02	−0.15	0.10	−0.11	Enjoyment
JOY2	**0.63**	0.13	0.11	−0.17	0.08	−0.07	−0.05	−0.11	
JOY3	**0.47**	0.04	0.30	−0.11	−0.12	0.10	−0.15	−0.12	
JOY4	**0.21**	−0.08	0.68	0.03	0.02	−0.04	−0.01	0.03	
HOP1	0.18	**0.68**	−0.01	0.01	−0.21	−0.01	−0.04	0.02	Hope
HOP2	0.03	**0.69**	0.07	0.03	−0.05	0.06	−0.20	−0.03	
HOP3	0.00	**0.46**	0.16	−0.10	−0.21	−0.09	−0.03	−0.01	
HOP4	0.09	**0.45**	0.31	−0.01	0.02	−0.14	−0.01	−0.09	
PRI1	−0.18	0.33	**0.45**	−0.09	0.08	−0.25	−0.02	−0.02	Pride
PRI2	−0.04	0.11	**0.60**	−0.12	−0.15	0.05	−0.03	0.00	
PRI3	−0.01	0.14	**0.72**	−0.10	0.02	−0.03	−0.09	−0.02	
PRI4	0.04	−0.04	**0.77**	0.11	0.01	0.05	0.05	−0.06	
ANG1	−0.06	0.01	0.03	**0.65**	0.13	0.03	0.03	0.02	Anger
ANG2	−0.02	0.03	0.00	**0.73**	−0.01	0.05	0.01	0.05	
ANG3	−0.14	−0.02	−0.02	**0.74**	−0.05	−0.06	0.16	0.06	
ANG4	−0.03	0.03	−0.11	**0.48**	0.23	−0.03	−0.06	0.19	
ANX1	−0.03	−0.14	0.05	0.02	**0.63**	0.09	0.04	−0.01	Anxiety
ANX2	0.06	−0.15	−0.09	0.00	**0.71**	0.00	0.03	−0.02	
ANX3	−0.15	0.06	−0.05	−0.05	**0.34**	0.19	0.32	0.12	
ANX4	−0.01	−0.03	0.13	0.12	**0.57**	0.23	−0.02	0.03	
SHA1	0.06	0.03	−0.13	0.18	0.37	**0.28**	0.25	0.03	Shame
SHA2	0.02	−0.10	−0.01	0.03	0.24	**0.50**	0.06	0.06	
SHA3	−0.03	−0.04	0.05	−0.03	0.06	**0.58**	0.10	0.12	
SHA4	−0.07	0.05	−0.05	0.01	0.10	**0.68**	0.23	−0.03	
HPL1	−0.01	−0.08	−0.03	0.14	0.13	0.29	**0.40**	0.05	Hopelessness
HPL2	0.07	−0.05	0.02	0.15	−0.04	0.14	**0.76**	0.02	
HPL3	−0.02	−0.06	0.00	−0.03	0.03	0.01	**0.80**	0.01	
HPL4	−0.06	−0.01	−0.03	−0.01	0.01	−0.01	**0.79**	0.02	
BOR1	−0.03	0.06	−0.02	−0.10	0.01	0.00	0.01	**0.95**	Boredom
BOR2	0.01	−0.03	0.02	0.03	−0.09	0.10	−0.05	**0.87**	
BOR3	0.03	−0.04	−0.01	0.15	0.05	−0.13	0.08	**0.74**	
BOR4	−0.07	−0.08	0.03	0.21	0.14	−0.07	0.03	**0.55**	

[a] Note. Factors were reordered after rotation based on interpretability and conceptual alignment with the achievement emotion framework. Original factor numbers from the exploratory factor analysis output are shown in parentheses.

Table 2 CFI, SRMR, and RMSEA values for each emotion, separated by setting

	Fit indices											
	Classroom			Learning			Testing			Laboratory		
Emotion	CFI	SRMR	RMSEA	CFI	SRMR	RMSEA	CFI	SRMR	RMSEA	CFI	SRMR	RMSEA
Enjoyment	1	0.03	0	0.997	0.04	0.05	0.984	0.06	0.11	1	0.03	0
Hope	1	0.01	0	1	0.02	0	1	0.02	0	1	0.03	0
Pride	1	0.03	0	0.984	0.06	0.08	1	0.01	0	0.997	0.04	0.05
Anger	0.996	0.03	0.05	0.992	0.04	0.08	0.997	0.03	0.05	1	0.02	0
Anxiety	1	0.02	0	1	0.01	0	1	0.02	0	1	0.02	0
Shame	0.999	0.03	0.03	1	0.01	0	0.999	0.03	0.04	1	0.03	0
Hopelessness	1	0.02	0	1	0.01	0	1	0.02	0	1	0.02	0
Boredom	0.998	0.03	0.06	1	0	0	—	0.998	0.03	0.05		
Relief	—	—	0.995	0.05	0.08	—						

The fourth model assumes that achievement emotions are related both across emotions and within instructional settings, consistent with a multitrait–multimethod (MTMM) framework in which emotions represent traits and instructional settings represent methods. Within this framework, the CFA model allows examination of the extent to which emotions are distinguishable across settings while accounting for shared method variance associated with the setting (Campbell and Fiske, 1959; Kline, 2016). Factor correlations reported in Table 3 were obtained directly from the CFA model; because these

Table 3 Comparative fit indices for confirmatory factor analysis models tested for the complete AEQ-GCHEM

Model	CFI	SRMR	RMSEA
Model 1	0.556	0.140	0.166
Model 2	0.723	0.114	0.137
Model 3	0.677	0.101	0.143
Model 4	0.964	0.093	0.056

Table 4 Spearman's correlations between AEQ-GCHEM subscales in the classroom setting

Variables	Emotion	1	2	3	4	5	6	7	8
1	Enjoyment	1							
2	Hope	0.60	1						
3	Pride	0.60	0.65	1					
4	Anger	−0.61	−0.54	−0.44	1				
5	Anxiety	−0.40	−0.66	−0.42	0.54	1			
6	Shame	−0.31	−0.50	−0.37	0.43	0.67	1		
7	Hopelessness	−0.50	−0.72	−0.55	0.64	0.74	0.66	1	
8	Boredom	−0.60	−0.28	−0.37	0.53	0.26	0.26	0.32	1

correlations are model-derived estimates rather than results of independent correlation tests, no p-value adjustment was applied (Fig. 2).

To evaluate relationships among variables for additional evidence of validity, associations among subscales within the classroom setting were examined using Spearman rank-order correlations (Table 3). In contrast to the subscale scores used in the CFA, item-level response distributions and some subscale distributions violated normality assumptions. Therefore, Spearman correlations were used in place of Pearson correlations. The resulting correlations ranged from −0.72 to +0.67 and were consistent with theoretically expected relationships among achievement emotions (all $p < 0.05$). As Pekrun postulated, and can be seen in Table 4, the positive emotions (enjoyment, hope, and pride) have positively correlating relationships among each other, and the negative emotions (anger, anxiety, shame, hopelessness, and boredom) show a similar relationship to other negative emotions (Pekrun, 2006). Furthermore, positive and negative emotions have negatively correlating relationships to each other. The Spearman rank-order correlations for the subscales in the other settings showed similar relationships, and these data can be found in the Appendix (Tables SI.5–SI.7). The factor loadings for each item in the survey to their respective emotion-setting pairing and item variance (Table SI.8), as well as the covariance between each achievement emotion (Table SI.9), can also be found in the Appendix.

Associations between the settings for each individual emotion were evaluated with Spearman rank-order correlation (Table 5). Correlations range from 0.21 (testing/laboratory – pride) to 0.84 (classroom/learning – hopelessness). The associations between settings suggest that some emotions are generalized across learning contexts while others are more context-specific. This distinction is important because it informs both measurement and intervention: generalized emotions may require course-wide strategies, whereas context-specific emotions may be addressed through targeted instructional changes.

Reliability evidence

The internal consistency reliability of the AEQ-GCHEM subscales was evaluated using McDonald's omega (ω). McDonald's omega is recommended for instrument development and evaluation because it is based on the underlying factor model and provides a more robust estimate of internal consistency than Cronbach's alpha, particularly when item factor loadings are unequal (Hayes and Coutts, 2020). Omega values were calculated for each AEQ-GCHEM subscale, and all subscales demonstrated acceptable internal consistency reliability ($\omega \geq 0.70$; Table 6), consistent with commonly accepted thresholds for research instruments (Nunnally and Bernstein, 1994). Confirmatory factor analyses

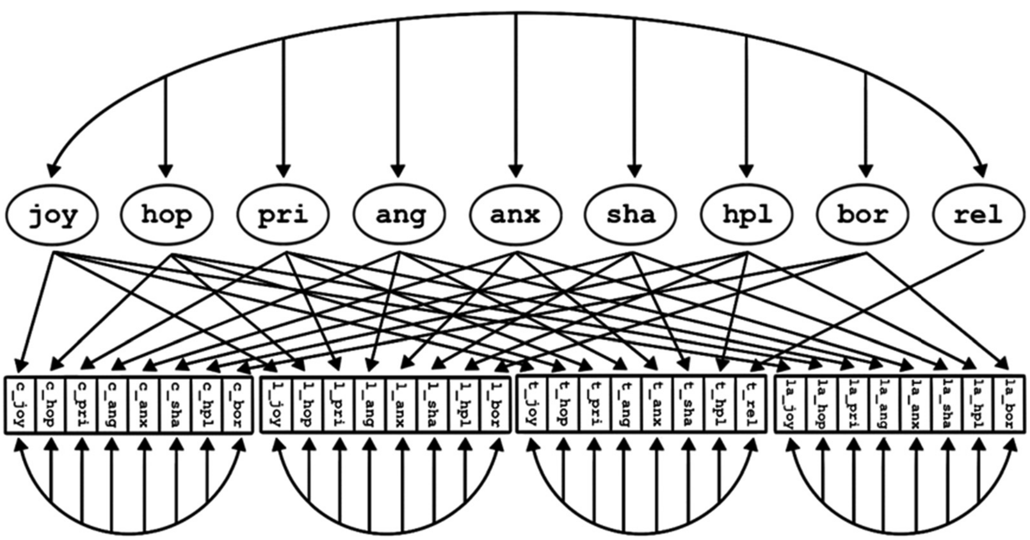

Fig. 2 The model for relationships between achievement emotions. Note: c, l, t, and la prefixes denote the settings classroom, learning, testing, and laboratory, respectively. The emotions are abbreviated: joy = enjoyment, hop = hope, pri = pride, ang = anger, anx = anxiety, sha = shame, hpl = hopelessness, bor = boredom, rel = relief.

Table 5 Spearman's correlations between settings for each emotion

	Classroom/learning	Classroom/testing	Classroom/laboratory	Learning/testing	Learning/laboratory	Testing/laboratory
Enjoyment	0.74	0.57	0.38	0.65	0.36	0.24
Hope	0.75	0.72	0.29	0.78	0.32	0.29
Pride	0.64	0.58	0.41	0.58	0.40	0.21
Anger	0.64	0.62	0.34	0.61	0.42	0.30
Anxiety	0.78	0.68	0.34	0.67	0.36	0.39
Shame	0.66	0.63	0.43	0.79	0.39	0.39
Hopelessness	0.84	0.76	0.34	0.81	0.41	0.37
Boredom	0.75	—	0.50	—	0.45	—

Table 6 McDonald's omega values for each AEQ-GCHEM subscale

	Setting			
Emotion	Classroom	Learning	Testing	Laboratory
Enjoyment	0.85	0.90	0.80	0.88
Hope	0.83	0.86	0.89	0.88
Pride	0.79	0.76	0.94	0.83
Anger	0.75	0.83	0.83	0.86
Anxiety	0.83	0.85	0.86	0.83
Shame	0.90	0.88	0.93	0.87
Hopelessness	0.86	0.92	0.94	0.91
Boredom	0.90	0.89	—	0.90
Relief	—	—	0.91	—

conducted at the subscale level indicated unidimensionality for each AEQ-GCHEM subscale (Table 2), supporting the appropriateness of using McDonald's omega as a reliability estimate.

To address Research Question 1: "What modifications of the AEQ-S are needed to produce a first-semester General Chemistry-specific Achievement Emotions Questionnaire (AEQ-GCHEM) that measures achievement emotions?" several modifications were required to develop the instrument. First, chemistry-specific language needed to be present in each item of the instrument. Through the process of obtaining test content validity, both experts and students agreed that achievement emotions relating to General Chemistry were separate constructs from achievement emotions relating to other academic subjects or general academics. Second, several items needed further alterations to provide support for response process validity. Most commonly, many metaphors and idioms were replaced with more straightforward language to help participants interpret the items consistently. For example, the item "After the chemistry exam, I wish I could tell the teacher off." was altered to be "I resent having to take exams in my General Chemistry class." Students did not respond to the original item as they did other items on the testing-anger subscale, indicating that the anger felt towards the instructor of the chemistry course is not necessarily related to the anger felt towards the course subject.

To address Research Question 2: "What validity and reliability evidence supports the use of the AEQ-GCHEM with students in a first-semester General Chemistry course?", the internal reliability and validity evaluations presented in this study support the AEQ-GCHEM and its subscale measures. All McDonald's omega reliability values are within acceptable ranges, indicating strong internal consistency for each AEQ-GCHEM subscale. Confirmatory factor analyses of the AEQ-GCHEM and its subscales yielded acceptable goodness-of-fit values, supporting the internal structure of the instrument and each subscale. When considering the relationships between each AEQ-GCHEM subscale, our results reflect those proposed in CVT (Pekrun *et al.*, 2011). Although some of the associations between subscales (such as hopelessness and shame in learning and testing contexts) approach collinearity (>0.80) indicating that these subscales would be measuring the same constructs (Kline, 2016), the overarching conclusion for these results supports the model that the nine achievement emotions in four contexts are distinct constructs. Additionally, the correlations between the achievement emotions in each setting show the relationships that are expected from CVT, wherein the positive emotions positively correlate with each other and negatively correlate with the negative emotions. Qualitative interviews with experts and students provided evidence for both test content validity and response process validity, showing that participants interpreted the constructs the instrument was designed to measure consistently and as intended.

When comparing fit indices with those reported for the Achievement Emotions Questionnaire–Short Version (AEQ-S), AEQ-GCHEM Model 4 demonstrates similar psychometric performance. Prior validation work on the AEQ-S found that its best-fitting model achieved CFI = 0.96, SRMR = 0.05, and RMSEA $\approx$ 0.063–0.069, supporting the structural validity of the short-form AEQ scales. Our AEQ-GCHEM Model 4 results (CFI = 0.957, SRMR = 0.080, RMSEA = 0.062) are comparable to the AEQ-S measures, indicating that AEQ-GCHEM provides a similarly acceptable representation of discrete achievement emotions within a discipline-specific context.

Limitations

A few aspects of this study need to be addressed in order to better understand the extent to which our findings may be generalized in varying contexts. There are two key limitations of our research. One of the limitations of this study is due to the fact that the sample selection was collected from a first-semester General Chemistry course at four universities. While each course possessed a similar structure and curriculum, there are several factors, such as classroom environments, the instructor's teaching style, and course difficulty, that could affect the students' achievement emotions. In our study, data were collected from first-semester General Chemistry courses that had a traditional course format, which incorporated lecture, online homework, and quizzes/exams which constituted the majority of the students' overall course grade. Other course formats, such as flipped, peer-led team learning (PLTL), or Process Oriented Guided-Inquiry Learning (POGIL), may generate different achievement emotions. Additionally, teaching style has been documented to affect student learning experience and students' attitudes and behavior. In their role, teachers can motivate, manage, and engage students in the process of learning. Research shows a relationship between various teaching styles and student engagement levels in higher education (Pekrun, 2014; Amoura *et al.*, 2015; Inayat, 2020). Other factors, such as each student's personality traits, could also influence the achievement emotions in an unknown manner. The role of individual characteristics and resources may underlie students' performance in college and may provide variation of achievement emotions among different groups of students. Research has examined factors such as self-efficacy, locus of control, self-esteem, emotional intelligence, cognitive test anxiety, and coping strategies, revealing variations in students' performance and perceptions of the course across different student groups (Ramos-Sánchez and Nichols, 2007; Aspelmeier *et al.*, 2012; Thomas *et al.*, 2017; Shankland *et al.*, 2019). The interaction between instructor effects and student personality may create a complex dynamic that shapes academic outcomes and impacts the achievement emotions differently. Therefore, without further study, it is unknown if the AEQ-GCHEM measure will function similarly in a different in-person active learning environment.

Conclusions

The AEQ-GCHEM is a 128-item instrument comprising 32 subscales designed to measure the achievement emotions experienced by students in a first-semester General Chemistry course. Data collected from students at four universities demonstrated that the AEQ-GCHEM has acceptable validity and reliability. Associations between the achievement emotions within contexts suggest that each subscale measures a separate, distinct construct. Our results support the use of the AEQ-GCHEM and its subscales for measuring achievement emotions in a first-semester context.

While instruments have been developed to measure achievement emotions in many contexts, including other chemistry contexts (Raker *et al.*, 2018), this is the first instrument designed to measure achievement emotions experienced by students enrolled in a first-semester General Chemistry course. These results do not indicate that similar modifications can be made to the AEQ-S for the measurement of achievement emotions in other contexts; whenever an instrument is modified, data should be gathered to assess its reliability and validity, ensuring the instrument still produces accurate and consistent measurements (Arjoon *et al.*, 2013).

Future research implications

The AEQ-GCHEM enables further research on achievement emotions in general chemistry, including their relationship to learning and how targeting these emotions to improve academic success and retention can inform evidence-based teaching practices. Although many studies link affect to achievement in chemistry (Reardon *et al.*, 2010; Xu and Lewis, 2011; Chan and Bauer, 2014), few have examined how achievement emotions influence student performance in chemistry (Brown and Nedungadi, 2024; Frost *et al.*, 2024), and none have focused specifically on a first-semester general chemistry context.

The instrument could be used in its entirety or just selected subscales. Also, the instrument can be used to explore how achievement emotions are impacted by novel teaching practices and equitable and inclusive instructional methodologies. An inclusive and equitable course creates a welcoming environment for diverse learners. The instructor is sensitive to, aware of, and responsive to the differences and individual needs of students, adapting instruction to support their academic goals (Dewsbury and Brame, 2019; Addy *et al.*, 2021). If chemistry instructors are seeking equitable practices in their teaching, they should be seeking to customize their practices to meet the individual needs of each student (White *et al.*, 2020), which would include addressing the achievement emotions that each student experiences and that could be identified by using the AEQ-GCHEM. From a broader educational perspective, the instrument can be used by researchers and practitioners alike facilitating a focused attention on an array of achievement emotions as an important aspect of academic achievement. This instrument could enable more experimental research in first-semester General Chemistry courses, which is perceived as a course that permits or prohibits access to many STEM professions. It could provide instructors with insights into the emotions students experience in various contexts of the course, helping to identify potential interventions that could alleviate negative emotions and enhance positive achievement emotions. A comprehensive exploration of the full spectrum of emotions experienced by students is necessary to better understand the emotional diversity within academic settings. Additionally, the instrument could help examine the relationship between achievement emotions and the sense of belonging (Fink *et al.*, 2020; Edwards *et al.*, 2022). Future research could focus on identifying specific academic emotions that significantly influence the connection between sense of belonging and academic achievement.

Ethical considerations

Institutional Review Board approval was obtained before data collection (Protocol # 2110030582) of University of Northern Colorado.

Author contributions

The authors contributed to the following roles during manuscript preparation. Conceptualization: AG, CB; data curation: AG; formal analysis: AG, CB; investigation: AG, CB; methodology: AG, CB;

project administration: AG, CB; supervision: CB; writing original draft: AG and CB.

Conflicts of interest

There are no conflicts of interest to declare.

Data availability

The coded dataset supporting this study is available from the authors upon reasonable request.

The supplementary information (SI) includes the Appendix. See DOI: https://doi.org/10.1039/d6rp00050a.

Appendix

The Appendix contains supporting information that pertains to the modified instrument AEQ-GCHEM, preliminary survey item modifications, and survey subscale and item modifications.

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