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Relationships between students' attributions in chemistry and chemistry learning burnout: the chain mediating roles of chemistry self-efficacy and chemistry learning engagement

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Chemistry is frequently perceived as a challenging discipline, placing students at high risk of learning burnout, which significantly undermines their academic performance and well-being. However, a few studies have integrated behavioral (learning engagement) and cognitive (attributions and self-efficacy) perspectives to investigate the predictive relationships underlying chemistry learning burnout. Therefore, this study aims to explore the links between these variables and students' chemistry learning burnout. This research employed a sample of 1712 students (10th and 11th graders) from 8 high schools in China. After assessing all relevant variables, direct and indirect pathways were examined through structural equation modelling (SEM). The findings indicated that (1) internal/external attributions in chemistry, chemistry self-efficacy, and chemistry learning engagement all showed significant negative relationships with students' chemistry learning burnout; (2) both (a) chemistry self-efficacy and (b) chemistry learning engagement served as significant mediators in the relationship between internal/external attributions in chemistry and chemistry learning burnout; and (3) the chain mediating roles of (a) chemistry self-efficacy and (b) chemistry learning engagement were suggested in the link between internal/external attributions in chemistry and chemistry learning burnout. These findings advance the theoretical understanding of students' learning burnout in challenging science subjects by providing an integrated cognitive-behavioral framework. Practically, these findings provide a basis for chemistry educators and curriculum designers to implement targeted interventions that prioritize adaptive attributional training and the strengthening of psychological resources to mitigate burnout. Finally, we noted the study's limitations as well as future research directions.

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Introduction

As a scientific discipline, chemistry is essential for technological and scientific innovation (Avargil *et al.*, 2020). However, chemistry is also well-known as a challenging discipline due to its abstract and complex nature (Mangubat and Picardal, 2023). Students tend to develop negative perceptions of chemistry learning and experience feelings of pressure, helplessness and exhaustion, which usually contribute to learning burnout (Maslach *et al.*, 2001). Learning burnout is a chronic, harmful psychological state associated with studying (Schaufeli *et al.*, 2002); it discourages learning and is acknowledged as a significant negative indicator of students' well-being (Widlund *et al.*, 2021). Therefore, reducing chemistry learning burnout is crucial for promoting chemistry learning.

Previous studies have shown that factors affecting students' learning burnout can be examined at both behavioral and cognitive levels. The constructivist learning theory posits that learners need to develop a personalised concept of the world and assume greater learning responsibility through active participation (Aljohani, 2017), teamwork, and incorporation of prior knowledge into the learning process. Consistent with this theory, relevant research has found that, at the cognitive level, reasonable attributions and high self-efficacy can enhance students' positive emotional responses (Costa *et al.*, 2016; Guan *et al.*, 2024), which are important in reducing students' learning burnout (Maricuţoiu and Sulea, 2019; Sagone and Indiana, 2021); at the behavioral level, learning burnout is negatively correlated with students' learning engagement (Wickramasinghe *et al.*, 2021). Additionally, Hernandez *et al.* (2022) discovered that attributions play a significant role in shaping students' self-efficacy, and accumulated evidence indicates that higher self-efficacy is linked to increased learning engagement (Pajares and Valiante, 1999; Bruning *et al.*, 2013; Zumbrunn *et al.*, 2020), which means attributions may predict students' learning engagement. However, up to now, no study

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has adopted a systematic and complete model to test all relevant relationships. Therefore, this research developed a chain mediation model to thoroughly investigate how students' attributions in chemistry influence chemistry learning burnout. It examines the mediating roles of (a) chemistry self-efficacy and (b) chemistry learning engagement within these relationships.

Students' attributions in chemistry and chemistry learning burnout

Attribution was firstly introduced by Heider, which refers to the process of understanding why events occur or interpreting the causal relationships behind others' behaviors (Newcomb and Heider, 1958). On this basis, Weiner's attribution theory drew lessons from Rotter's locus of control theory and pointed out that individuals tend to attribute success and failure to factors like ability, effort, context, and luck. These causal factors used to explain the results can be further divided into three core dimensions: locus (*i.e.*, internal or external), stability, and controllability (Weiner, 1994; Weiner, 2000). Since the students' locus significantly predicts academic results (Phillips and Gully, 1997), this study will focus on students' descriptions of internal or external attributions for academic success and failure. Specifically, internal attributions refer to students ascribing their achievements or failures to internal factors (*i.e.*, ability and effort), which are perceived as relatively controllable (Weiner, 1985; Dweck, 2006). Conversely, external attributions refer to attributing learning outcomes to external factors (*i.e.*, luck and context), which are closely associated with the loss of a sense of control (Coffee and Rees, 2008). In this study, we define the students' attributions in chemistry as students' explanations for the reasons behind their success or failure in the process of learning chemistry, such as mastering complex concepts, solving chemical equations, or conducting experiments; the internal attributions in chemistry refer to students attributing the results of success or failure in the process of chemistry learning to their own factors. For instance, students attribute their failure to understand complex chemistry concepts to their own lack of effort; the external attributions in chemistry refer to students ascribing the outcomes of success or failure in the process of chemistry learning to external factors. For example, students attribute their experimental failures to instrument malfunctions.

Burnout was initially regarded as a work-related disorder (Maslach *et al.*, 2001). As schools can be seen as a place where students work, research gradually extended its scope to the educational field (Finn, 1989; Skinner *et al.*, 2008; Modin *et al.*, 2011) and defined learning burnout as a condition of emotional, physical, and cognitive depletion brought about by ongoing stress and unpleasant educational experiences (Salmela-Aro *et al.*, 2008). Evidence suggests that poor performances in learning related to burnout eventually culminate in school dropout (Bask and Salmela-Aro, 2012). Students are at a greater risk of learning burnout in chemistry, which can be regarded as one of the most difficult subjects (Partanen *et al.*, 2024). That is why the study of the chemistry learning burnout in students is vital in terms of its practical implications. The present research defines chemistry learning burnout as a condition caused by excessive chemistry coursework, leading to physical and mental exhaustion (Guo *et al.*, 2022), characterized by students losing interest, motivation, and confidence in learning chemistry and developing negative evaluations and attitudes towards chemistry teachers, peers, and the learning environment.

Attribution theory is widely used to provide a theoretical framework for the connection between attributions and learning burnout. The theory postulates that the trajectory dimension of causal relationships is related to self-esteem and self-esteem-related emotions (Graham, 2020). Students tend to have higher self-esteem and more positive emotions when they attribute success to internal causes and failure to external causes (Weiner, 1985; Zuidema *et al.*, 2023). Students with high self-esteem tend to believe they have the ability when facing academic setbacks and are more likely to maintain positive self-evaluations, thereby buffering feelings of burnout (Wang *et al.*, 2020; Jiang *et al.*, 2021). Additionally, Sagone and Indiana (2021) found that college students who adopt internal attributions report markedly lower anxiety than those who favor external attributions and students with lower anxiety levels show a corresponding decrease in learning burnout; Carr and Kurtz (1991) demonstrated that internal attributions are positively associated with students' metacognitive competence, and enhanced metacognition can substantially reduce negative psychological states, including learning burnout (Guo *et al.*, 2022). Drew and Watkins (1998) showed that students with internal attributions have a greater tendency to employ deep-learning strategies, which in turn reduces their likelihood of learning burnout (Partanen *et al.*, 2024). Conversely, Kahn *et al.* (2023) observed that college students exhibiting external attributions experience greater academic stress, and increased academic pressure can exacerbate fatigue symptoms, which are typical characteristics of learning burnout (Maslach *et al.*, 2001). Therefore, it can be inferred that students' attributions for learning achievements will have an impact on their learning burnout.

The potential influence of chemistry self-efficacy as a mediating factor

Chemistry self-efficacy is described as the belief a person holds in successfully completing specific tasks or resolving problems in chemistry (Qian *et al.*, 2023). When faced with difficulties, such a strong belief becomes a key determinant of their academic achievement in chemistry.

According to the attribution theory (Graham, 1991; Weiner, 2000), students' causal attributions in learning environments have an impact on their achievement-related beliefs and actions. Individuals who make internal attributions tend to believe there is a link between their own behaviour and academic performance, which helps them see their academic abilities more positively and increases their self-efficacy. Those who made external attributions are more likely to believe that their learning outcomes are determined by outside sources and are beyond their control (Rotter, 1966), and a lack of control and feelings of helplessness weaken their confidence in successfully achieving their goals. However, previous studies have only provided limited empirical support. Chang and Ho (2009) studied how attribution types affect students' self-efficacy in a network-based language learning environment. Research showed that internal attributions can positively predict students' sense of self-efficacy. Hsieh and Kang (2010) investigated the correlations between academic attribution and self-efficacy and found that learners who blame external factors for their learning results may be less in control of poor performance and have lower levels of self-efficacy.

As stated in social cognitive theory, self-efficacy shapes a person's emotional responses and thinking patterns (Bandura, 1986). Specifically, self-efficacy boosts the motivation and sense of accomplishment of the students. As a result, it encourages positive emotional experiences that serve as essential psychological resources to help combating learning burnout (Zhou *et al.*, 2022). Recent studies have also supported this perspective through empirical research. In an investigation that involved 1287 teenagers aged between 14 and 18, Martínez *et al.* (2021) discovered that students who have a high self-efficacy usually perceive academic demands as low-pressure opportunity to improve their skills, instead of being pressurizing. Likewise, the study conducted by Zhou *et al.* (2022) indicated that efficacious students display greater confidence in their ability to reach their goals and have greater levels of self-management that can negatively predict their learning burnout. More recently, Thi and Duong (2024) gave longitudinal evidence to support the fact that students' learning burnout is negatively impacted by self-efficacy over time. Taken together, self-efficacy is recognised to support students in effectively mitigating learning burnout, primarily by fostering their positive perception of academic stress and equipping them with adaptive coping strategies.

The potential influence of chemistry learning engagement as a mediating factor

Learning engagement refers to the state characterised by activity, effort, and intense concentration that students demonstrate during learning (Wong and Liem, 2022). It has three components: behavioural engagement, which is the focus and effort students dedicate to learning activities; emotional engagement, which is students' affective tendencies, perceptions of the school, and feelings of belonging; and cognitive engagement, which is students' willingness to actively address complex knowledge systems and acquire challenging skills in learning contexts (Fredricks *et al.*, 2004; Skinner and Pitzer, 2012). In this study, we define chemistry learning engagement as students' involvement in the chemistry course (Reid *et al.*, 2022), chemistry hands-on laboratory activities (Smith and Alonso, 2020; Pontigon and Talanquer, 2025) and chemistry enrichment activities (Brown, 2014).

Notably, learning engagement is considered a malleable construct that can be developed through cognitive processes (An *et al.*, 2024). Attribution is the cognitive process of recognising the causes of outcomes, which then influence emotional states, perseverance in tasks, and subsequent actions (Weiner, 1985; Graham, 2020). According to Rotter's (1954) locus of control structure, the distribution of attributions along the internal–external locus dimension is associated with individuals' perceived degree of their own responsibility for events. An external attribution reflects the denial of personal responsibility for events, whereas an internal attribution indicates the acknowledgement of responsibility for the outcome, whether it's positive or negative, which is also supported by neuroimaging studies (Blackwood *et al.*, 2003). The sense of responsibility encourages students to see themselves as active learners rather than passive recipients of information, making them more willing to participate in classroom interaction and absorbed at in-depth thinking. Chukwuorji *et al.* (2018) also provided evidence for the beneficial effects of internal attributions on students' sense of responsibility, which helps them achieve a state of high learning engagement, characterised by energy, enthusiasm, and deep absorption. In addition, Guan *et al.* (2024) investigated the relationships between attributions and learning engagement in a second language. They found that internal attributions promote a sense of interest, leading to active engagement, whereas external attributions could diminish one's motivation and involvement. Therefore, we can expect that when students ascribe outcomes to internal causes, like strategy use, they are more likely to persist. Conversely, attributions to external conditions, like the incompetence of teachers, can cause decreased learning engagement.

In terms of how learning engagement and learning burnout are related, learning engagement has a negative impact on learning burnout. The demand–resource model (Demerouti *et al.*, 2001) can shed light on this negative correlation. When learning resources, like teacher support and constructive feedback, are relatively insufficient, high learning demands from performance expectations and changes in the physical environment often tend to cause learning burnout. However, during the educational process, such key resources can serve effectively to enhance students' learning engagement and psychological resilience (Bakker *et al.*, 2014; Li *et al.*, 2025). Notably, the more the students are engaged in learning, the greater their motivation they have to generate more resources, leading to a "virtuous cycle" and therefore minimizing the incidence of learning burnout. Numerous studies have shown that learning engagement generally decreases learning burnout by triggering a range of positive effects. For example, Widlund *et al.* (2021) showed that students who show high levels of learning engagement tend to attain high levels of academic performance (Bae *et al.*, 2020). These students also tend to have positive motivational beliefs (Wang and Eccles, 2013), and they are more efficient in using a diversity of learning strategies and enforcing effective self-control systems, thus leading to a significant reduction of burnout in the learning process. Besides, it has also been found that learning engagement contributes to more satisfying learning experiences and academic performance (Lee and Shute, 2010; Bae *et al.*, 2020; Ulmanen *et al.*, 2024). Such benefits help mitigate learning burnout through the promotion of positive academic emotions (Fredricks *et al.*, 2004; Hyytinen *et al.*, 2022; Chen *et al.*, 2023). Therefore, in line with these discoveries, it is possible that certain attributions of students in chemistry might be a determinant towards reducing engagement in learning of chemistry, which in turn might be critical in increasing the experience of learning burnout in chemistry education.

The mediating influence of (a) chemistry self-efficacy and (b) chemistry learning engagement in a chain model

Drawing from Bandura's model of self-efficacy, self-efficacy is an important near-term variable that affects how much effort students devote to studying (Fredricks *et al.*, 2004). Students who possess high self-efficacy tend to set more ambitious goals, put in greater effort, and persist through challenges, leading to improved academic achievement (Liao *et al.*, 2024). For example, Zimmerman (2000a, 200b) noted that students with high self-efficacy are more likely to experience favourable emotions such as confidence and enjoyment during the learning process, which makes them engage more deeply in the learning activities. The same findings were shown in the study conducted by Ouweneel *et al.* (2013), in which they examined whether changes in students' self-efficacy correspond to synchronous changes in learning engagement and academic performance. The results showed that students with high efficacy were more likely to regulate their motivation by setting personal goals (Diseth, 2011), demonstrating better task engagement and deeper learning absorption (Ouweneel *et al.*, 2011). In analogy, Cai and Xing (2025) found that if students believe in their competence in learning, they can be more active in mobilising motivational and cognitive resources, thus continuously increasing the task engagement and finally acquiring the pre-set learning outcome (Bresó *et al.*, 2011; Liu *et al.*, 2024). In short, all these findings suggest that students with high self-efficacy are more willing to devote effort to the learning process and can maintain a positive attitude in the face of difficulties, thus being able to develop better coping ability, which comprehensively improves the level of learning engagement (Martin and Rimm-Kaufman, 2015).

Research questions and hypotheses

The purpose of this study is to explore the relationships among students' attributions in chemistry, chemistry self-efficacy, chemistry learning engagement, and chemistry learning burnout as well as to examine the chain mediating role of chemistry self-efficacy and chemistry learning engagement in these relationships. Thus, this research focuses on addressing the following questions:

(1) What relationships exist between students' attributions in chemistry (both internal and external) and their chemistry learning burnout within a chemistry learning context?

(2) Does chemistry self-efficacy mediate the relationship between attributions in chemistry and chemistry learning burnout?

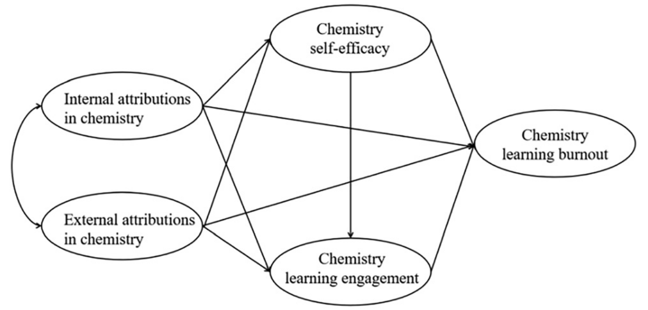

Fig. 1 The hypothesized pathways from attributions in chemistry to chemistry learning burnout through chemistry self-efficacy and chemistry learning engagement. Note. H1: IA → CLB; H2: EA → CLB; H3: IA → CSE → CLB; H4: EA → CSE → CLB; H5: IA → CLE → CLB; H6: EA → CLE → CLB; H7: IA → CSE → CLE → CLB; H8: EA → CSE → CLE → CLB (IA: internal attributions; EA: external attributions; CSE: chemistry self-efficacy; CLE: chemistry learning engagement; CLB: chemistry learning burnout).

(3) Does chemistry learning engagement mediate the relationship between attributions in chemistry and chemistry learning burnout?

(4) Do chemistry self-efficacy and chemistry learning engagement play a chain mediating role in the path from attributions in chemistry to chemistry learning burnout?

In pursuit of these research objectives, we clarified the theoretical underpinnings of attributions, self-efficacy, learning engagement, and learning burnout. By synthesizing the existing literature, we established the conceptual framework for the relationships between these variables and constructed the hypothesized model (Fig. 1). Based on this, the following hypotheses are proposed:

Hypothesis 1: internal attributions in chemistry are negatively associated with chemistry learning burnout.

Hypothesis 2: external attributions in chemistry are positively associated with chemistry learning burnout.

Hypothesis 3: the relationship between internal attributions in chemistry and chemistry learning burnout can be mediated by chemistry self-efficacy.

Hypothesis 4: the relationship between external attributions in chemistry and chemistry learning burnout can be mediated by chemistry self-efficacy.

Hypothesis 5: the relationship between internal attributions in chemistry and chemistry learning burnout can be mediated by chemistry learning engagement.

Hypothesis 6: the relationship between external attributions in chemistry and chemistry learning burnout can be mediated by chemistry learning engagement.

Hypothesis 7: there is a chained mediation effect of internal attributions in chemistry on chemistry learning burnout through (a) chemistry self-efficacy and (b) chemistry learning engagement.

Hypothesis 8: there is a chained mediation effect of external attributions in chemistry on chemistry learning burnout through (a) chemistry self-efficacy and (b) chemistry learning engagement.

Method

Participants

In this study, 1712 students from China, consisting of 45.62% males and 54.38% females in Grades 10 and 11, were selected through stratified purposive sampling. They were aged between 15 and 17, with a mean of 16.13 and a standard deviation of 0.58. First, Chinese cities were classified into first, second, third, and fourth-tier categories based on their economic strength, with first-tier cities being the most economically developed (Xu *et al.*, 2022). A total of eight schools were selected, with two from each tier. Second, within each school, students of the same grade were divided into high, medium, and low academic performance levels. Approximately 40 students were selected from each level. All of them had a fundamental understanding of chemistry, having studied the subject for at least two years starting in Grade 9.

Survey administration

We used an electronic questionnaire to conduct the investigation. It took a week to collect the questionnaires from the schools where the participants were enrolled at the end of the first semester of 2025. Before data collection, the study was approved by the parents of the students, the Academic Ethics Committee of Southwest University in China, and all relevant authorities. Prior to starting the research, all participants were also provided with an explanation of the study's purpose and how the data would be used, and they were assured that their personal information would remain completely confidential. Each student who participated voluntarily was given a ballpoint pen as a small token of appreciation.

Survey instruments

To measure the variables, we used established instruments and gathered evidence supporting the reliability and validity of score interpretations within the current sample. Besides, to improve the cultural adaptability and clarity of the scale items for Chinese high school students, we adapted the attribution scale (*e.g.*, adapting ''I feel that some of my good grades depend to a considerable extent on chance factors, such as having the right questions show up on an exam.'' to ''Sometimes my good chemistry grades were largely due to chance, such as when the questions were ones I happened to know.''), learning engagement scale (*e.g.*, adapting ''When doing schoolwork, I try to relate what I'm learning to what I already know.'' to ''When doing chemistry homework, I try to relate what I'm learning to what I already know.''), self-efficacy scale (*e.g.*, adapting ''How well can you use the equipment in the chemistry laboratory?'' to ''How well can you use common instruments, such as a separatory funnel and straight condenser, in the chemistry laboratory?''), and learning burnout scale (*e.g.*, adapting ''I often sleep badly because of matters related to my schoolwork.'' to ''I often have trouble sleeping because of chemistry study.'') to suit the specific context of high school chemistry courses in China. The complete set of adapted items is presented in Appendix A, and the reliability and validity of all the adapted scales have met the standards. As the original versions of the attributions scale, learning engagement scale, self-efficacy scale, and learning burnout scale were developed in English, the items were translated into Chinese to accommodate participants who are non-native English speakers. First, two bilingual researchers independently translated the items. They then discussed and agreed upon a final version.

Cognitive interviews. We also conducted cognitive interviews with twenty students from grades 10 and 11 to examine the response process validity of the survey items (Lewis, 2022). For the first round of cognitive interviews, we selected ten 10th and 11th grade students. Before the start of the interview, each participant was informed about the purpose of the study, the interview procedure, and the protocols for confidentiality. Semi-structured interviews were conducted, and each interview lasted about 40 minutes. At the beginning of each cognitive interview, students were provided with a copy of the survey items from four scales translated by bilingual researchers: the multidimensional–multiattributional causality scale, the learning engagement scale, the High School Chemistry Self-Efficacy Scale, and the School Burnout Inventory. Students read each question aloud and were asked by the researcher, following the interview protocol (in Appendix B), how they interpreted and decided to respond to items. Follow-up questions were asked for additional clarification as necessary. All interviews took place in a private interview room to ensure both participant confidentiality and audio quality. And all interviews were audio recorded, transcribed, and anonymized. For the sake of anonymity, participants are referred to as Student 1, Student 2, *etc.* (hereafter S1, S2...) throughout the reporting of the qualitative data.

This analysis was conducted by the first author (Q. H.) in collaboration with a secondary coder (Y. Y.). Based on Tourangeau's (2000) four-stage cognitive model (understanding, retrieval, judgement, and response) and tailored to the cognitive and linguistic characteristics of 10th and 11th-grade students, an initial codebook was developed by the first author (Q. H.) (see Appendix C). The first author (Q. H.) and the secondary coder (Y. Y.) performed the coding work independently. Following the completion of the first round of interviews, both coders reviewed and analyzed the transcripts of the ten interviews. To ensure the reliability of the analysis, interrater reliability was assessed; the two independent coders achieved high consistency on the first-round data, yielding a Cohen's kappa value of 0.855. After independent coding, the coders met, discussed and resolved differences in coding and came to a consensus. Through the discussion to achieve consensus, the coders agreed that no modifications to the codebook were needed. If students repeatedly report dissimilar interpretations of an item, then the item was flagged for modification. If students repeatedly report dissimilar interpretations of an item, then the item was flagged for modification. If students give a rationale that is aligned with the intended meaning, there is validity evidence that the item was being interpreted as intended and can be used in future implementations of the scale in the given context. We revised two items'

Table 1 Cognitive interview item revision examples

	Item 1	Item 2
Source	Attribution scale	Learning burnout scale
Original text	My academic low points in chemistry sometimes make me think I was just unlucky	I'm continually wondering whether my chemistry schoolwork has any meaning
Revised text	There was a period when my chemistry grades couldn't improve, and sometimes I thought it was due to bad luck	I constantly question the meaning of learning chemistry
Reason for revision	Term confusion	Ambiguity
Example student response	S1: The term 'low points' is too broad. I'm unsure if it refers to a decline in my chemistry grades or a period of low motivation. Without a specific definition, I cannot provide an accurate score	S3: When learning chemistry, I often wonder about the meaning of what I'm learning because I'm curious about its real-world applications. But I also see how it could mean someone is feeling discouraged and doubting the subject. So I don't know which one you're asking about
	S2: I interpreted 'low points' as an emotional state rather than academic performance. If the question specifically measures exam results, the current wording is misleading. I would have answered differently if the item had used 'grades' instead of 'low points'	S4: I'm not sure how to answer. For me, 'wondering about the meaning' is actually a good thing. It shows I'm thinking deeply about the lesson. But it could also sound like I'm losing interest and don't want to study anymore. It feels like a double-edged question
Discussion of items	Students discussed that the term 'low points' was conceptually underspecified, noting that they were inclined to interpret the item as an emotional state rather than a quantifiable academic performance, which hindered their ability to provide an accurate response based on their actual chemistry grades	Students discussed that wondering the meaning of their schoolwork did not necessarily signify a decline in interest, but could instead reflect intellectual curiosity, leading to confusion over whether the item intended to measure a negative attitude or a proactive inquiry

phrasing based on their feedback (shown in Table 1). To better understand the effect of these changes, we then conducted a second round of interviews with a new set of respondents (n = 10, Grades 10 and 11) to identify whether instrument modifications have resolved or exacerbated issues from the first round. The established codebook was subsequently applied to the transcripts from the second round of interviews. We treated the individual responses to each of the 41 items as discrete coding units (410 units in total). Two coders independently coded a randomly selected 30% of these item-response segments (n = 123). A Cohen's kappa coefficient of 0.903 was obtained, indicating a high level of inter-rater agreement. The results showed that after the revisions, all respondents in the second round understood each item as intended. Therefore, no further modifications were considered necessary, confirming the validity of the response process and ensuring good readability for the revised items (Deng *et al.*, 2021).

Students' attributions in chemistry. The measurement instrument for students' attributions to their chemistry achievements was adapted based on the multidimensional-multiattributional causality scale (MMCS) (Lefcourt *et al.*, 1979). The scale includes four sub-dimensions: ability (4 items, *e.g.*, "When I get good chemistry grades, it is because of my learning competence."), effort (4 items, *e.g.*, "Whenever I receive good chemistry grades, it is always because I have studied hard for that course."), context (4 items, *e.g.*, "Some of the times that I have gotten a good chemistry grade, it was due to the teacher's easy grading scheme.") and luck (4 items, *e.g.*, "Some of my low chemistry grades have seemed to be partially due to bad breaks."). All items were measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The score for internal attribution is calculated by adding the scores for ability and effort, while the score for external attribution is the sum of the scores for context and luck. A higher internal attribution score indicates that students are more inclined to attribute their chemistry academic achievements to internal factors; a higher external attribution score suggests that students are more likely to attribute their chemistry academic achievements to external factors. To ensure the structural independence of these two dimensions, a competitive model analysis was conducted, supporting the discriminant validity of the proposed structure (Table 2).

Chemistry learning engagement. The learning engagement scale was devised and verified by Reeve and Tseng (2011). The adapted scale included three dimensions of students' learning engagement: behavioural, emotional, and cognitive. The behavioural engagements included 3 items (*e.g.*, "I work hard when we start something new in chemistry class."). The emotional engagements also included 3 items (*e.g.*, "I enjoy learning new things in chemistry class.") and the cognitive engagements included 4 items (*e.g.*, "I make up my own examples to help me understand the important chemistry concepts I study.").

Table 2 Models fit indices for competitive second-order CFA models of the attribution scale

Fit index	Accept value	Model A: two-dimensional structure	Model B: unidimensional structure
χ^2	—	362.046	525.557
df	—	99	100
χ^2/df	<5.0	3.66	5.26
CFI	>0.90	0.952	0.922
TLI	>0.90	0.941	0.906
RMSEA	<0.08	0.056	0.070

Note: Model A: two-factor model; model B: single-factor model. $\Delta\chi_{(1)}^2$ = 163.511, p < 0.001, supporting the discriminant validity of the two-dimensional construct.

The Likert scale included five points, where one meant "strongly disagree" and five meant "strongly agree". Higher ratings reflected greater chemistry learning engagement.

Chemistry self-efficacy. The self-efficacy scale was derived from the High School Chemistry Self-Efficacy Scale (HCSS) (Aydin and Uzuntiryaki, 2009). This scale includes two dimensions: self-efficacy in chemistry cognitive skills and self-efficacy in chemistry laboratory procedures. Among them, chemistry self-efficacy for cognitive skills included 4 items (*e.g.*, "How well can you describe the properties of elements by using periodic table?") and self-efficacy for the chemistry laboratory included 3 items (*e.g.*, "How well can you interpret data during the chemistry laboratory sessions?"). All items are rated on a 5-point Likert scale, from 1 (very poor) to 5 (very well). Higher scores on the scale reflected a greater level of chemistry self-efficacy.

Chemistry learning burnout. The tool used to measure chemistry learning burnout was adapted from the School Burnout Inventory (Salmela-Aro *et al.*, 2009), which includes three subscales: exhaustion related to school (3 items, *e.g.*, "I often have trouble sleeping because of chemistry study."), cynicism about the purpose of school (3 items, *e.g.*, "I constantly question the meaning of learning chemistry."), and feelings of inadequacy as a student (2 items, *e.g.*, "I used to have higher expectations of my chemistry learning than I do now."). A 5-point Likert scale was employed. The scale ranged from 1 (strongly disagree) to 5 (strongly agree), with a higher total score suggesting a higher level of chemistry learning burnout.

Data analysis procedures and tools

This study used SPSS (version 27.0), AMOS (version 26.0) and R (version 4.5.2) for data analysis. The analytical methods included:

(1) Examining the measuring devices: before the official test, the validity and reliability of the data collected from the current sample were assessed because the measuring instruments used in this study were translated and adapted from well-known scales.

The four scales were tested using the exploratory factor analysis (EFA) and the confirmatory factor analysis (CFA). We first employed EFA in SPSS 27.0 on a randomly divided half of the pretest data, Part 1 (n = 260), in order to examine whether the scale's factor structure corresponded to the original dimensions (Lee *et al.*, 2008). Specifically, principal component analysis was used to quantify the number of factors retrieved, and the maximum variance approach was used to analyze the factor matrix. The number of factors was determined by combining the Kaiser criterion (eigenvalues > 1.0) and the inspection of the scree plot. The reliability of the data collected using the adapted scales was then assessed using AMOS 26.0 after we adjusted the questionnaires in accordance with the EFA results and applied CFA on the other half of the pretest data, Part 2 (n = 260) (Velayutham and Aldridge, 2013). The Maximum Likelihood (ML) estimator was employed for the CFA as it provides consistent and efficient parameter estimates when the data exhibit approximate multivariate normality (Costello and Osborne, 2005). Lastly, supported by previous research (Dunn *et al.*, 2014), the omega coefficient (ω) (McDonald, 2013) is considered superior to the alpha coefficient (α) (Cronbach and Shavelson, 2004) for assessing reliability. Consequently, using the same Part 2 sample (n = 260) as for the CFA, we employed the omega coefficient (ω) *via* the MBESS package in *R* as a more reliable measure of internal consistency in the third phase (Komperda *et al.*, 2018; McNeish, 2018).

To ensure the suitability of data for exploratory factor analysis (EFA), the Kaiser–Meyer–Olkin (KMO) measure should be above 0.6, and Bartlett's test of sphericity must produce a statistically significant result ($p < 0.05$) (Bartlett, 1951). When assessing individual items, those with factor loadings greater than 0.4 and without significant cross-loadings (below 0.32) are deemed acceptable for inclusion in the scale (Tabachnick and Fidell, 2007; Wei *et al.*, 2021). For CFA fit indices, the recommended thresholds are: χ^2/df less than 5, RMSEA below 0.08, SRMR below 0.08, CFI above 0.9, and TLI above 0.9 (Hair, 2006; Opperman *et al.*, 2013). Lastly, the reliability of the measurement data is considered acceptable if its omega coefficient (ω) exceeds 0.7 (Green and Yang, 2015).

(2) Validation of model hypotheses: using the formal test data (n = 1712), common method bias was first assessed using Harman' s single-factor test (Podsakoff *et al.*, 2003) prior to hypothesis testing. According to the conventional criterion, the absence of significant common method variance was indicated if the first factor explained less than 40% of the total variance and half of the total variance (Mo *et al.*, 2019). Following this preliminary check, structural equation modeling (SEM) was conducted on this formal sample in AMOS 26.0 to examine direct and mediating effects. Similarly, the maximum likelihood (ML) estimator was used in the SEM to examine the structural relationships among the latent variables. The mediation effect can be either partial or full. A partially mediated relationship features significant direct and indirect effects, while a fully mediated relationship is indicated by a nonsignificant direct effect alongside a significant indirect effect (González and Paoloni, 2015).

The bias-corrected percentile Bootstrap method is widely considered a gold standard in mediation analysis because of its strong statistical features. This method does not rely on data normality assumptions or large sample sizes. Additionally, it provides a way to directly calculate confidence intervals for the mediation effect without depending on standard error estimates (Preacher and Hayes, 2008). We used this method to assess the significance of the mediating effect by conducting 5000 bootstrap samples on the original data at a 95% confidence level (Guo *et al.*, 2022). If zero is excluded from the 95% bootstrap confidence interval, the mediating impact is considered significant (Hayes, 2015). Model fit was evaluated using metrics such as χ^2/df, RMSEA, SRMR, GFI, CFI, and TLI.

Suitability for measurement instruments. The results reported below were derived exclusively from the pretest sample (N = 520). Specifically, EFA was performed using Part 1 (n = 260), while CFA and omega coefficients were calculated based on Part 2 (n = 260).

Students' attributions in chemistry. Following the EFA analysis, all items on our scale had factor loadings above 0.4, which led to retaining all items. The KMO value was 0.841 (>0.6), and Bartlett's test statistic was 5527.528 ($p < 0.001$). The factors explained 66.092% of the variance, with factor loadings for all items ranging from 0.716 to 0.845 (Appendix D). Based on this, to validate the hierarchical structure of "Internal Attributions" and "External Attributions", a second-order confirmatory factor analysis (CFA) was conducted. The results indicated a good model fit: χ^2/df = 3.66 [<5], RMSEA = 0.056 [<0.08], CFI = 0.952 [>0.9], TLI = 0.941 [>0.9], SRMR = 0.039 [<0.08]. This supports the use of composite scores representing the broader latent constructs of internal and external attributions. Internal consistency measured by McDonald's omega was 0.835 (95% CI = [0.809, 0.860]) for the internal attribution subscale and 0.842 (95% CI = [0.820, 0.862]) for the external attribution subscale, with values of 0.824 (95% CI = [0.796, 0.848]), 0.824 (95% CI = [0.793, 0.850]), 0.817 (95% CI = [0.783, 0.846]), and 0.831 (95% CI = [0.806, 0.854]) for the four subdimensions. These results, all above 0.70, provide evidence of good internal consistency reliability for the measures in the present sample.

Chemistry learning engagement. All of the question items were kept after the EFA analysis since their factor loadings were higher than 0.4. The KMO value was 0.831 (>0.6), and Bartlett's test of sphericity revealed a statistic of 2873.582 ($p < 0.001$). Three factors were derived from the EFA, which together represented 67.464% of the total variance; individual item loadings were observed within the range of 0.756 to 0.855 (Appendix D). Subsequently, we performed a CFA on a second-order model. The results suggest a well-fitting model: χ^2/df = 2.357 [<5]; RMSEA = 0.040 [<0.08]; CFI = 0.985 [>0.9]; TLI = 0.979 [>0.9]; SRMR = 0.029 [<0.08]. The omega coefficient for the entire measurement tool was 0.818 (95% CI = [0.791, 0.841]), with the three dimensions having omega coefficients of 0.774 (95% CI = [0.730, 0.810]), 0.776 (95% CI = [0.734, 0.809]), and 0.818 (95% CI = [0.786, 0.844]). The values all exceeded 0.70, indicating strong reliability.

Chemistry self-efficacy. The EFA analysis revealed a Bartlett's test value of 2279.625 ($p < 0.001$) and a KMO statistic of 0.802 (above 0.6). The EFA resulted in two factors that accounted for 69.303% of the total variance, with factor loadings ranging from 0.782 to 0.885 (above 0.4, shown in Appendix D). Following the EFA, a CFA was conducted. Notably, since the chemistry self-efficacy scale comprises only two dimensions, a second-order factor model could not be identified (Rindskopf and Rose, 1988). Consequently, a correlated two-factor model was employed to examine the structural validity. The CFA results were: χ^2/df = 2.357 [<5]; RMSEA = 0.040 [<0.08]; CFI = 0.985 [>0.9]; TLI = 0.979 [>0.9]; SRMR = 0.029 [<0.08]. The data collected using the scale showed high reliability, as the omega coefficient for the entire scale was 0.812 [>0.7] (95% CI = [0.779, 0.838]), while that of the two dimensions was 0.822 (95% CI = [0.791, 0.849]) and 0.835 (95% CI = [0.806, 0.857]).

Chemistry learning burnout. As previously stated, eight items were assessed in total. All items were retained following the EFA as evidenced by a KMO value of 0.767 and a Bartlett's test statistic of 2013.095 ($p < 0.001$). Results showed that the EFA successfully extracted three factors, with factor loadings ranging from 0.723 to 0.872 (Appendix D) and a cumulative explained variance of 71.847%. Based on the EFA results, a second-order model was constructed and tested using CFA. The CFA findings showed χ^2/df = 3.225[<5], RMSEA = 0.051 [<0.08], CFI = 0.981 [>0.9], TLI = 0.969 [>0.9], and SRMR = 0.039[<0.08]. Reliability analyses indicated acceptable internal consistency for the obtained data, with the omega coefficient being 0.779 [>0.7] (95% CI = [0.749, 0.806]) for the whole scale and 0.774 (95% CI = [0.739, 0.804]) and 0.777 (95% CI = [0.738, 0.809]) for exhaustion and cynicism, respectively. As there are only 2 items in the feelings of inadequacy dimension, its reliability was not calculated (Naibert *et al.*, 2024).

Results

Preliminary analysis

In accordance with the methodological guidance of Podsakoff *et al.* (2003), a Harman single-factor test was conducted to assess common method bias. The results confirmed the absence of significant bias in our measurement instruments, as the first factor accounted for only 20.456% of the variance, which is well below the 40% threshold. Furthermore, the factor solution revealed twelve factors with initial eigenvalues greater than 1, and the total variance explained reached 68.656%, meeting the recommended standard of 60% and thereby suggesting that the twelve elements of reservation are suitable (Mo *et al.*, 2019).

As illustrated in Table 3 the skewness values [−0.191 to 0.285] and kurtosis values [0.010 to 0.947] for all variables are within the acceptable range for a normal distribution (Kline and Santor, 1999). The means and standard deviations of each variable are also shown. Moreover, the bivariate correlations analyzed *via* Pearson's product–moment method and

Table 3 Descriptive statistics and variables' correlation analysis

Variable	*M*	SD	Skewness	Kurtosis	1	2	3	4	5
1. Internal attributions in chemistry	3.344	0.634	−0.152	0.604	1.000				
2. External attributions in chemistry	2.630	0.678	0.099	0.059	−0.176***	1.000			
3. Chemistry self-efficacy	3.149	0.566	−0.001	0.947	0.297***	−0.250***	1.000		
4. Chemistry learning engagement	3.489	0.555	−0.191	0.756	0.350***	−0.279***	0.346***	1.000	
5. Chemistry learning burnout	2.488	0.671	0.285	0.010	−0.457***	0.155***	−0.455***	−0.531***	1.000

Note: ***$p < 0.001$.

displayed in Table 3 indicated significant relationships both within and between the underlying structures. Specifically, internal attributions in chemistry were found to be positively and significantly related to chemistry self-efficacy (r = 0.297, $p < 0.001$) and chemistry learning engagement (r = 0.350, $p < 0.001$); internal attributions in chemistry were shown to be negatively correlated with chemistry learning burnout (r = −0.457, $p < 0.001$). For external attributions in chemistry, they were significantly and negatively associated with chemistry self-efficacy (r = −0.250, $p < 0.001$) and chemistry learning engagement (r = −0.279, $p < 0.001$), but positively linked to chemistry learning burnout (r = 0.155, $p < 0.001$). Chemistry self-efficacy was significantly and positively correlated with chemistry learning engagement (r = 0.346, $p < 0.001$), while showing a significant negative relationship with chemistry learning burnout (r = −0.455, $p < 0.001$). Ultimately, chemistry learning engagement showed a strong and negative correlation with chemistry learning burnout (r = −0.531, $p < 0.001$).

Analyzing the chain mediation model

AMOS 26.0 was used in this study to examine the hypothesized model. The model fit indices indicated that the model in this research provided a satisfactory match to the findings: χ^2/df = 1.704, GFI = 0.931, AGFI = 0.921, CFI = 0.960, TLI = 0.957, RMSEA = 0.029, and SRMR = 0.036. Besides, as indicated in Fig. 2, the findings showed that internal and external attributions in chemistry, chemistry self-efficacy, and chemistry learning engagement were all directly and negatively associated with chemistry learning burnout (internal attributions: β = −0.323, $p < 0.001$; external attributions: β = −0.254, $p < 0.001$; chemistry self-efficacy: β = −0.440, $p < 0.001$; and chemistry learning engagement: β = −0.556, $p < 0.001$). Besides, it revealed that internal attributions in chemistry held a positive and direct relationship with chemistry self-efficacy (β = 0.428, $p < 0.001$) and chemistry learning engagement (β = 0.326, $p < 0.001$); external attributions in chemistry held a negative and direct relationship with chemistry self-efficacy (β = −0.305, $p < 0.001$) and chemistry learning engagement (β = −0.215, $p < 0.001$). Moreover, chemistry self-efficacy showed a positive and significant predictive relationship with chemistry learning engagement (β = 0.328, $p < 0.001$).

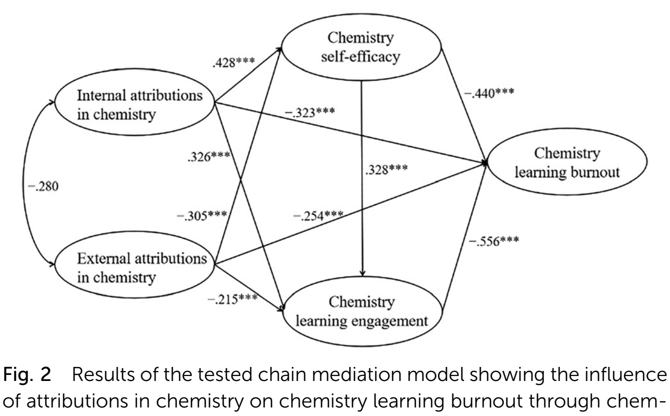

Fig. 2 Results of the tested chain mediation model showing the influence of attributions in chemistry on chemistry learning burnout through chemistry self-efficacy and chemistry learning engagement. Note: all beta coefficients are significant at the 0.001 level.

As suggested by Hayes (2015), we examined the mediating roles within the model using the bootstrap method. Table 4 shows that the 95% confidence intervals (CI) for both the direct and indirect path estimates do not include 0, indicating that these relationships are statistically significant (Hayes, 2015). Specifically, the direct path coefficients from internal and external attributions in chemistry to chemistry learning burnout were −0.323 (95% CI = [−0.548, −0.107]) and −0.254 (95% CI = [−0.417, −0.114]), respectively. This result supports Hypothesis 1 but is inconsistent with Hypothesis 2. The mediation analysis revealed significant total path relationships for internal attributions, which were negatively linked to chemistry learning burnout (β = −0.771, 95% CI = [−0.933, −0.607]). In contrast, external attributions indicated no significant overall relationship (β = 0.056, 95% CI = [−0.097, 0.199]).

Furthermore, the findings showed three indirect pathways between both internal and external attributions in chemistry and chemistry learning burnout: (a) attributions → chemistry self-efficacy → chemistry learning burnout; (b) attributions → chemistry learning engagement → chemistry learning burnout; and (c) attributions → chemistry self-efficacy → chemistry learning engagement → chemistry learning burnout. Specifically, the relationships between both internal and external attributions and chemistry learning burnout were mediated by chemistry self-efficacy at −0.188 (95% CI = [−0.329, −0.097]) and 0.134 (95% CI = [0.056, 0.268]), respectively. This provided support for Hypotheses 3 and 4, suggesting that chemistry self-efficacy plays a mediating role in the relationship between internal and external attributions and chemistry learning burnout. The relationships of both internal and external attributions to chemistry learning burnout were mediated by chemistry learning engagement in the following ways: −0.181 (95% CI = [−0.358, −0.070]) and 0.120 (95% CI = [0.026, 0.280]), supporting Hypotheses 5 and 6 by indicating that chemistry learning engagement serves as a mediator in these relationships. Regarding the links between internal and external attributions and chemistry learning burnout, the chain mediation pathways involving chemistry self-efficacy and chemistry learning engagement were 0.056 (95% CI = [0.018, 0.130]) and −0.078 (95% CI = [−0.173, −0.031]), respectively. These results suggested that the relationships between both internal and external attributions and chemistry learning burnout are sequentially linked through chemistry self-efficacy and chemistry learning engagement, supporting Hypotheses 7 and 8.

Discussion

The relationships of internal and external attributions with chemistry learning burnout

In line with Hypothesis 1, the findings showed that in the field of chemistry education, internal attributions were significantly and negatively associated with chemistry learning burnout. If we employ the self-regulation theory to understand learning

Table 4 Results of bootstrapping the direct and indirect effects of internal and external attributions in chemistry on chemistry learning burnout through chemistry learning engagement and chemistry self-efficacy

Path	Effect	SE	95% Bootstrap LLCI	95% Bootstrap ULCI	p	Ratio (%)
Direct effects						
Internal attribution → chemistry learning burnout	−0.323	0.113	−0.548	−0.107	0.006	41.89
External attribution → chemistry learning burnout	−0.254	0.078	−0.417	−0.114	< 0.001	—
Indirect effects						
Internal attribution → chemistry self-efficacy → chemistry learning burnout	−0.188	−0.329	−0.329	−0.097	< 0.001	24.38
Internal attribution → chemistry learning engagement → chemistry learning burnout	−0.181	−0.358	−0.358	−0.070	0.001	23.48
Internal attribution → chemistry self-efficacy → chemistry learning engagement → chemistry learning burnout	−0.078	−0.173	−0.173	−0.031	0.002	10.12
External attribution → chemistry self-efficacy → chemistry learning burnout	0.134	0.056	0.056	0.268	< 0.001	—
External attribution → chemistry learning engagement → chemistry learning burnout	0.120	0.026	0.026	0.280	0.012	—
External attribution → chemistry self-efficacy → chemistry learning engagement → chemistry learning burnout	0.056	0.018	0.018	0.130	0.003	—
Total effects						
Internal attribution → chemistry learning burnout	−0.771	0.082	−0.933	−0.607	< 0.001	100
External attribution → chemistry learning burnout	0.056	0.075	−0.097	0.199	0.488	—

Note: 5000 bootstrap samples. CI = confidence interval. Ratio refers to the proportion of the specific effect to the total effect. For external attribution, ratios are not reported because the direct and indirect effects have opposite signs (competitive mediation effect), making the total effect non-significant and the proportion calculation statistically uninterpretable.

burnout, it can be seen as a consequence of the interplay between demanding learning conditions and insufficient self-regulation (Bakker and de Vries, 2021). Internal attributions promote the development of higher-level metacognitive self-regulation skills (Zimmerman, 2000a, 2000b). These skills trigger the use of adaptive self-regulation strategies (Kljajic *et al.*, 2017), which contribute to psychological adjustment and enhance the learning experience. Ultimately, this process reduces learning burnout.

However, the findings of this study indicated that chemistry learning burnout had a significantly negative relationship with external attributions. This finding contradicts hypothesis 2 of this study and the previous study (Duncan *et al.*, 2023). The negative correlation between these two variables suggested that the more external attributions students made towards their failure in chemistry learning, the less chemistry learning burnout they would experience. External attributions for failure is considered a core manifestation of self-serving attributional bias (Zuckerman, 1979; Skaalvik, 1994), an adaptive cognitive component widely observed in Chinese adolescents. This bias is linked to the preservation of self-esteem and is positively related to mental health outcomes (Blackwood *et al.*, 2003; Hu *et al.*, 2016). High school students care about how others think about them very much. In order to maintain their self-image and not to be labeled as underachievers, when they perform poorly in chemistry tests, students tend to blame external variables for the failure, such as too much difficulty (Masi *et al.*, 2000). As a self-protection strategy, external attributions for negative events protect one's self-image and facilitate the construction of a positive self-concept (Hu *et al.*, 2016). This process generates positive emotions, thereby reducing negative mental states such as learning burnout.

This study suggests that, within chemistry education, internal attributions show a stronger direct relationship with chemistry learning burnout than external attributions. According to the Conservation of Resources theory, internal attributions trigger learners to develop a sense of control and conscientiousness, which are two new personal resources. These resources can initiate a positive gain cycle and then reduce learning burnout effectively (Akirmak and Ayla, 2021). While external attributions protect self-esteem and prevent immediate resource depletion, this effect is purely defensive. It fails to initiate a positive gain cycle for acquiring new resources (Alarcon *et al.*, 2011). Consequently, the direct path between external attributions and the mitigation of chemistry learning burnout is relatively weaker. This provides a possible explanation for why internal attributions exhibit a more robust predictive relationship with chemistry learning burnout in this empirical study.

Mediation of chemistry self-efficacy and learning engagement

The study's findings demonstrated that both (a) chemistry self-efficacy and (b) chemistry learning engagement acted as mediators in the links between internal and external attributions in chemistry and chemistry learning burnout. To be specific, this study showed that chemistry self-efficacy mediated the relationship between internal attributions in chemistry and chemistry learning burnout (β = −0.188); it also mediated the relationship between external attributions in chemistry and chemistry learning burnout (β = 0.134), supporting Hypotheses 3 and 4.

Within the framework of attribution theory, Weiner (2010) emphasized that attributions of success or failure significantly shape subsequent behaviors and expectations, such as self-efficacy. Previous studies also found that attributions of success and failure have an important influence on students' perception of their ability to finish learning tasks. For instance, Li *et al.* (2024) discovered that internal attributions encourage deep task engagement and the use of effective strategies, thus boosting students' cognitive abilities and self-efficacy.; In contrast, external attributions result in diminished confidence and slowed task progression, adversely impacting cognitive performance and reducing self-efficacy. According to Pekrun's (2006) control-value theory, fostering favorable views of learning capacity and control, while accurately assessing academic value, can effectively promote positive emotions. Consistent with this theory, students with high self-efficacy would see difficult tasks as opportunities to practice and develop abilities to be acquired and gained, which would not be avoided (Alqurashi, 2019). Such a positive cognitive orientation promotes learning and performance while increasing satisfaction with learning outcomes, thereby effectively alleviating learning burnout. One explanation is that self-efficacy motivates students to employ metacognitive strategies and resources (Komarraju and Nadler, 2013). Furthermore, it enables them to adopt more flexible self-control mechanisms when facing challenges (Gebauer *et al.*, 2020; Blackmore *et al.*, 2021). Thus, students with high self-efficacy are more likely to be motivated to participate in challenges and tend to report fewer negative emotional reactions, such as learning burnout, compared to students with low self-efficacy. Additionally, research indicates that a decline in self-efficacy is associated with increased emotional distress (*e.g.*, depression and anxiety) and self-limiting behaviors (*e.g.*, avoidance and low self-control) (Huang *et al.*, 2023), which are further linked to higher levels of learning burnout. Some scholars even go further to suggest that burnout is essentially a crisis of self-efficacy (Leiter, 1992). In brief, students with lower self-efficacy show a higher propensity toward experiencing learning burnout.

The findings indicated that the relationship between internal attributions in chemistry and chemistry learning burnout was mediated by chemistry learning engagement (β = −0.181). Meanwhile, chemistry learning engagement served as a mediating factor in the relationship between external attributions in chemistry and chemistry learning burnout (β = 0.120), confirming Hypotheses 5 and 6. According to self-determination theory (Deci and Ryan, 2000), perceived autonomy and control over events significantly influence students' intrinsic motivation and willingness to engage. In other words, when students develop a sense of ownership of their learning process, they tend to exhibit higher persistence in the presence of challenges and show increased effort in their studying. This finding supported Swinton *et al.* (2011), who suggested that when students attribute success to internal factors, they are more likely to be motivated to engage in future learning. Because they believed they had the ability to achieve change through their own efforts, they can perceive a stronger sense of subjective control, and thus show a higher level of learning engagement. Conversely, external attributions are positively correlated with self-handicapping (Stewart and De George-Walker, 2014). This behavior frequently impairs academic performance, leading to diminished engagement and even potential dropout (Núñez *et al.*, 2023; Qian *et al.*, 2024). Additionally, the broaden-and-build theory of positive emotions (Fredrickson, 2001) suggests that the positive emotions generated by learning engagement build students' social and cognitive resources and strengthen their sense of belonging. (Denovan *et al.*, 2020). Studies indicate that learning engagement imparts students with a sense of purpose and accomplishment, enhances learning satisfaction, and bolsters emotional resilience and cognitive resourcefulness, thereby mitigating learning-related stress and burnout (Romano *et al.*, 2021). Specifically, students who report higher effort in their studies tend to be more resilient when things don't go their way, which is linked to better stress management and a lower likelihood of experiencing learning burnout.

However, both the direct and indirect relationships between external attribution and chemistry learning burnout were significant but manifested in opposite directions, indicating a competitive mediation model (Zhao *et al.*, 2010). This finding unveils a complex mechanism characterized by dual pathways. On the one hand, external attribution was associated with a decrease in direct burnout levels, reflecting the self-protective function of self-handicapping. Drawing from self-handicapping theory (Urdan and Midgley, 2001), students often proactively manage the attributional implications of their academic performance by strategically identifying or creating external obstacles, such as perceived task difficulty. In the short term, they mitigate the impact of failure by shielding students' self-worth from low-ability inferences, consequently buffering immediate burnout (Ferradás *et al.*, 2017). On the other hand, external attribution showed a significant negative relationship with both chemistry self-efficacy and learning engagement. Frequent reliance on external attributions reflects a perceived lack of control over academic outcomes. As noted by Gadbois and Sturgeon (2011), such self-handicapping tendencies are longitudinal predictors of diminished self-efficacy and reduced academic engagement. Consequently, although external attributions offer a temporary buffer against distress through self-protection, they indirectly exacerbate learning burnout over time by eroding the core motivational resources, which are necessary for sustained chemistry learning.

The chain mediation of (a) chemistry self-efficacy and (b) learning engagement

This study found that both (a) chemistry self-efficacy and (b) chemistry learning engagement served as chain mediators between internal (β = −0.078) and external attributions (β = 0.056) in chemistry and chemistry learning burnout. This supports Hypotheses 7 and 8. Based on the demands–resources model (Salmela-Aro and Upadyaya, 2014), self-efficacy serves as a critical personal resource that directly promotes students' learning engagement, thereby effectively curbing the occurrence of learning burnout (Bakker *et al.*, 2014). Current studies suggest that students who ascribe their learning performance more to internal or external factors have significantly different levels of self-efficacy (Graham, 2006). Students with higher self-efficacy are more willing to employ more varied learning strategies and develop their cognitive skills, thus having higher learning engagement (Price *et al.*, 2011; Tsao, 2021; Xu *et al.*, 2024). In addition, highly learning-engaged students can also feel the satisfaction of completing the work and build self-worth, which can help diminish their learning burnout (Demerouti *et al.*, 2001).

Implications for practice

The research findings of this study provided practical implications for educators to reduce high school students' chemistry learning burnout. First, our research findings revealed that internal attributions in chemistry negatively predicted students' chemistry learning burnout, whereas no similar relationships were found for external attributions due to their countervailing direct and indirect pathways. Thus, teachers should encourage students to make positive internal attributions, especially about effort attributions. For instance, when a student successfully predicts reaction products, teachers should attribute this success to the students' chemical thinking skills, specifically their command of core concepts like periodic trends. Such feedback may raise higher expectations for future success and achievement as well as enhance student agency (Hsieh and Kang, 2010) and further reduce the possibility of chemistry learning burnout. Research has shown that rigid and teacher-centered instruction will cause an authoritarian climate (Richardson and Mishra, 2018). Adolescents in such climate tend to think that most of the learning responsibility lies in their teachers (Mameli *et al.*, 2019) and make external achievement attributions. Therefore, to move toward a truly student-centered instruction, chemistry teachers should prioritize inquiry-based experiments over traditional verification-based labs, encouraging students to take active ownership of their chemistry learning. Regarding external attributions, on the one hand, schools should actively build a more equitable and friendly chemistry learning environment, such as upgrading lab equipment and implementing formative assessment practices (Ural, 2016), to lessen objective grounds for external attribution. Building on these institutional improvements, chemistry curriculum designers' evaluation methods should shift from a binary outcome-based results to a process-oriented assessment. By focusing on the nuances of the scientific inquiry process rather than just the final outcome, designers can help students perceive their progress as a continuous journey of growth, thereby fostering a more resilient mindset toward challenges. Consequently, students will devote more energy to sustainable growth and adjustment. On the other hand, teachers and parents should not make black-and-white judgments about students' external attributions for their chemistry achievement and should recognize their protective psychological function. Accordingly, teachers and parents should express comprehension and acceptance of students' legitimate external attributions and offer timely and active support—both emotional and material. Jue and Kim (2023) stated that recognition and respect from significant others are also of great importance in preventing psychological burnout.

In addition, the research findings further revealed that students' chemistry learning burnout can be reduced by considering the independent and chain mediating roles of (a) chemistry self-efficacy and (b) chemistry learning engagement. A constructivist learning environment gives students more responsibility to choose the activities that they will undertake in the process of learning. This will enhance students' self-efficacy beliefs (Wang *et al.*, 2024). For instance, teachers can implement project-based learning (PBL) by designing tasks rooted in real-world chemical challenges. Specifically, in a lesson centered on "developing a DIY sodium hypochlorite generator for household disinfection *via* brine electrolysis", teachers can facilitate student-led knowledge construction by organizing attributional discussions regarding experimental outcomes. If students fail to observe the expected evolution of gas at the electrodes, instead of letting them blame the failure on a lack of talent, instructors should guide them to investigate modifiable technical variables, such as unstable electrode connections or inadequate electrolyte concentration. By analyzing these modifiable technical variables, students can maintain their confidence and self-efficacy even in the face of setbacks. Beyond classroom-level interventions, such mastery experiences should be systematically reinforced through curriculum design. To be specific, chemistry curriculum developers should implement a clear difficulty gradient, moving from fundamental chemical concepts to complex reaction systems. This structured progression ensures that students experience a series of "small wins", providing a solid foundation for their self-efficacy before they encounter more challenging inquiries. Similarly, teachers can employ contextualized storytelling methods (Ho *et al.*, 2026). By linking chemical content with students' personal experiences, students not only achieve a more profound mastery of chemical reaction mechanisms but also learn to regulate anxiety when encountering difficult knowledge points through emotional resonance, thereby strengthening their confidence in overcoming chemistry hurdles. Furthermore, teachers should focus on cultivating students' growth mindset (Qian *et al.*, 2025). By explicitly affirming the cognitive effort and persistence students invest in challenging chemistry-related topics and teachers enable students to directly perceive the advancement of their chemical literacy. This sense of accomplishment is subsequently transformed into sustained chemistry self-efficacy.

According to self-determination theory, students' learning engagement will be enhanced when their fundamental psychological needs—autonomy, competence, and relatedness—are met (Deci and Ryan, 2000; Van den Berghe *et al.*, 2016). Therefore, chemistry teaching practices should be targeted at meeting these student needs. To enhance students' autonomy, an autonomy-supportive learning environment should be established. By integrating socio-scientific issues (SSI) into the chemistry curriculum, teachers can help students perceive the practical value of the chemistry discipline, thereby stimulating intrinsic interest and facilitating a transition from passive learning to autonomous exploration (Hsu *et al.*, 2019). Teachers' structured support, such as clear pre-lab guidelines and timely assistance during challenging exercises, could cultivate students' feelings of growth and mastery of the topics being studied, thereby enhancing their active participation in course activities (Cents-Boonstra *et al.*, 2021). Besides, teachers should emphasize peer interaction and collaborative learning in chemistry classes to create a supportive and interactive learning environment (Adlakha *et al.*, 2026), which may promote a sense of mutually supportive connections, thus exhibiting greater learning engagement.

Limitations and further research

Although this study constructed and verified the chain mediation model of the influence of students' attributions in chemistry on students' chemistry learning burnout, future studies should pay more attention to a few remaining limitations that should be addressed.

Firstly, a limitation of this study is its dependence on self-reported data for all constructs. As a result, the data might be affected by social expectations or self-report bias. Therefore, future research should incorporate complementary measurement techniques, such as eye-tracking and electroencephalography (EEG), to minimize subjective bias. Secondly, this study only employed cross-sectional data from China, which limits the cross-cultural generalizability of the results and can only suggest potential relationships, making it difficult to confirm causal relationships. Thus, future research should employ longitudinal data from different cultures to strengthen the robustness and generalizability of the results. Thirdly, this study does not account for potential gender effects. Since prior research suggests gender differences in attribution patterns and self-efficacy (Huang, 2013; Reschke *et al.*, 2024), future work should use multi-group analysis to investigate whether gender moderates the relationships in our model. Finally, this study did not differentiate between specific dimensions of internal attribution, such as effort *versus* ability. While some literature suggested that excessive internal attribution for failure can lead to learned helplessness and may exacerbate learning burnout, this phenomenon was not observed in our findings. This discrepancy may be attributed to the possibility that our participants generally possessed a growth mindset. Future research should therefore refine the measurement of internal attributions to investigate whether their protective effect against burnout diminishes when students focus primarily on ability-based explanations.

Conflicts of interest

There are no conflicts to declare.

Data availability

To safeguard participants' sensitive information, the data supporting this study are not publicly available. However, anonymized and de-identified datasets can be requested from the corresponding author *via* email upon reasonable request. A data access agreement that outlines the data's permitted uses and guarantees participant confidentiality must be signed by researchers who want to use the data.

Appendices

Appendix A Adapted research instruments

Tables 5–8.

Table 5 Adapted multidimensional-multiattributional causality scale

Items
1. When I get good chemistry grades, it is because of my learning competence.
2. When I get good chemistry grades, it's because the course content is easy to understand.
3. If I were to fail the chemistry exam, it would probably be because I lacked skill in chemistry area.
4. If I were to get poor chemistry grades, I would assume that I lacked ability to succeed in chemistry.
5. Whenever I receive good chemistry grades, it is always because I have studied hard for that course.
6. I can overcome all obstacles in the path of chemistry learning if I work hard enough.
7. When I fail to do as well as expected in chemistry class, it is often due to a lack of effort on my part.
8. Poor chemistry grades inform me that I haven't worked hard enough.
9. Some of the times that I have gotten a good chemistry grade in chemistry, it was due to the teacher's easy grading scheme.
10. Sometimes I get good chemistry grades only because the course material was easy to learn.
11. Often my poor chemistry grades are obtained in courses that the teacher has failed to make interesting.
12. Some low chemistry grades I've received were due to the teacher's strict marking.
13. Sometimes my good chemistry grades were largely due to chance, such as when the questions were ones I happened to know.
14. Sometimes I feel that I have to consider myself lucky for the good chemistry grades I get.
15. Some of my low chemistry grades have seemed to be partially due to bad breaks.
16. There was a period when my chemistry grades couldn't improve, and sometimes I thought it was due to bad luck.

Table 6 Adapted learning engagement scale

Items
1. I listen carefully in chemistry class.
2. The first time my chemistry teacher talks about a new topic, I listen very carefully.
3. I work hard when we start something new in chemistry class.
4. I enjoy learning new things in chemistry class.
5. When we work on something in chemistry class, I feel interested.
6. When I am in chemistry class, I feel curious about what we are learning.
7. When doing chemistry homework, I try to relate what I'm learning to what I already know.
8. I make up my own examples to help me understand the important chemistry concepts I study.
9. When I'm learning chemistry, I try to connect what I am learning with my own experiences.
10. I try to make all the different ideas fit together and make sense when I'm learning chemistry.

Table 7 Adapted high school chemistry self-efficacy scale

Items
1. To what extent can you explain chemical laws and theories?
2. How well can you choose an appropriate formula to solve a chemistry problem?
3. How well can you describe the properties of elements by using periodic table?
4. How well can you interpret graphs/charts related to chemistry?
5. How well can you carry out experimental procedures in the chemistry laboratory?
6. How well can you use common instruments, such as a separatory funnel and straight condenser, in the chemistry laboratory?
7. How well can you interpret data during the laboratory chemistry sessions?

Table 8 Adapted learning burnout scale

Items
1. I feel overwhelmed by my chemistry learning.
2. I often have trouble sleeping because of chemistry study.
3. The pressure of my chemistry learning causes me problems in my close relationships with others.
4. I feel a lack of motivation in my chemistry learning and often want to give up.
5. I feel that I am losing interest in chemistry learning.
6. I constantly question the meaning of learning chemistry.
7. I often have feelings of inadequacy in my chemistry learning.
8. I used to have higher expectations of my chemistry learning than I do now.

Appendix B Cognitive interview protocol

1. Introductory aspects [read to interviewee]

We are testing an instrument that has questions that may be difficult to understand, hard to answer, or that make little sense. Your task is to read each item aloud from the provided questionnaire and then verbalize your interpretation of the item and your reasoning for selecting a particular response.

We are not looking for correct answers; we just want to listen to your comments. So your honest feedback is crucial for identifying any items that are unclear, confusing, or interpreted differently than intended. This will help us validate and improve the instrument.

Please note that this session is strictly confidential. Your identity will be anonymized, and the audio recording will be used solely for transcription and analysis by the research team. You are free to pause, skip any question, or end the interview at any time without penalty.

We very much appreciate your taking the time for this conversation. We will start with some general background information, and then we will move on to aspects related to the instrument. Do you have any questions before we proceed?

2. Background [use these to strengthen rapport with the interviewee and set a comfortable environment]

(a) Did you have a chemistry class today?

(b) Have you ever filled out a similar questionnaire before?

3. Think-aloud training exercise:

"Think of a familiar place where you often study, like a library or a coffee shop. In your mind, describe the route you take from the entrance to your usual seat. As you do this, please verbalize everything you are visualizing and thinking about."

4. Instrument assessment [use prompts and follow-ups as necessary]

Semi-structured interview questions:

(a) Is there anything confusing about the wording of the question?

(b) What were you thinking about when you responded to the question?

(c) How did you decide to pick ⟨response option selected⟩?

Possible follow-ups:

(a) Could you elaborate on what you mean by ⟨respondent's words⟩?

(b) When responding to this item, how do you interpret ⟨the key term⟩?

(c) When you were deciding on your answer, was there a specific event or situation you had in mind?

Open-ended suggestion collection:

(a) Do you have any other additional suggestions for this questionnaire (such as the overall layout, length, or relevance of the content)?

5. Wrap up

Thank you again for your valuable collaboration. Once more, this interview is confidential, you will not be identified by name and only the transcriber will listen to this tape. The transcriber is bound to confidentiality, as well.

Appendix C Codebook

Table 9.

Table 9 Codebook for cognitive interview analysis

Code	Definition	Representative quote
Term confusion	Misinterpretation due to a lack of familiarity with technical or academic vocabulary	"I found the term 'low points' quite vague. I wasn't sure if it meant my chemistry grades were dropping or if I was just feeling unmotivated in class. I didn't know which situation I should be thinking about when picking a score"
Ambiguity	Uncertainty arising from phrases or items that allow for multiple reasonable interpretations	"I'm not sure if 'wondering' means I'm interested in the application of chemistry or if I'm doubting its value. The direction is unclear"
Calibration	Difficulty in mapping internal states onto fixed numerical response options	"I understand the question, but I'm struggling to choose a score. I can describe most periodic trends, but since I still make mistakes on transition metals, I don't know if I should pick 4 or 5. The gap between these two options is hard to judge"
Logic gap	Misalignment between verbal reasoning and the selected score	"I chose '5 (Strongly Agree)' because I always study very hard before exams, so I feel lucky that my efforts paid off. But I just realized the question is asking if it was just luck, which contradicts what I just said about my hard work"

Appendix D Standard factor loadings of items

Table 10.

Table 10 Standard factor loadings of items (EFA results)

Variables	Item	Standard loading
Internal attributions in chemistry	1	0.785
	2	0.823
	3	0.761
	4	0.787
	5	0.735
	6	0.818
	7	0.749
	8	0.845

Table 10 (continued)

Variables	Item	Standard loading
External attributions in chemistry	1	0.772
	2	0.751
	3	0.780
	4	0.814
	5	0.817
	6	0.716
	7	0.827
	8	0.806
Chemistry self-efficacy	1	0.782
	2	0.791
	3	0.797
	4	0.802
	5	0.830
	6	0.885
	7	0.840
Chemistry learning engagement	1	0.771
	2	0.855
	3	0.795
	4	0.756
	5	0.825
	6	0.811
	7	0.792
	8	0.757
	9	0.778
	10	0.808
Chemistry learning burnout	1	0.723
	2	0.849
	3	0.857
	4	0.803
	5	0.820
	6	0.809
	7	0.872
	8	0.854

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