

Connecting the learning environment to student motivation and identity in physics: The mediating role of learning burnout

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In introductory physics courses, which are foundational for many science, technology, engineering, and mathematics (STEM) disciplines, students' motivational beliefs, such as self-efficacy, interest, and identity, are critical for their success and persistence. However, the high academic demands of physics courses can lead to learning burnout, a detrimental psychological syndrome comprising exhaustion, cynicism, and inadequacy that threatens student development. Despite the recognized importance of a supportive learning environment, there is a lack of research on the role of learning burnout in physics. More specifically, the pathways linking the learning environment, burnout, and motivational beliefs, as well as the generalizability of these pathways across genders, have not been systematically investigated. This study addresses these gaps by testing a model where learning burnout mediates the relationship between students' perceived learning environment and their motivational beliefs and physics identity. The research employed a cross-sectional survey design with a sample of undergraduate students ($N = 1574$) from three universities in China. Data were analyzed using structural equation modeling (SEM) to test the hypothesized associations and multigroup SEM to examine gender invariance. The results revealed that a positive perceived learning environment, particularly a strong sense of belonging, was significantly associated with lower learning burnout. Furthermore, the study confirmed that learning burnout, specifically the dimensions of cynicism and inadequacy, partially mediated the relationship between the learning environment and students' motivational beliefs. Students' physics identity was most strongly and directly associated with perceived recognition, interest, and self-efficacy. Crucially, the structural model demonstrated invariance across genders, indicating that the identified psychological pathways are equivalent for male and female students. This study makes a significant contribution by integrating the concept of learning burnout into the physics education research framework and identifying its role as a key mediator. It provides a new perspective on gender equity, suggesting that disparities may arise from differing perceptions of the learning environment rather than from fundamentally different psychological processes.

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I. INTRODUCTION

Introductory physics courses provide the fundamental principles and analytical problem-solving skills that underpin science, technology, engineering, and mathematics

(STEM) disciplines [1–4]. However, the conceptual abstraction and mathematical sophistication of physics present significant academic challenges for many students [5–8]. Within this demanding learning context, students' motivational beliefs, particularly their self-efficacy, interest, and identity, are widely recognized as critical predictors of academic achievement, persistence, and future STEM career choices [9–19]. Research indicates that high self-efficacy is associated with proactive engagement with educational challenges and greater psychological resilience [20–28], while interest can drive deeper exploration and sustained engagement [29–35]. Concurrently, the extent to which students perceive themselves as a “physics person” (their physics identity) is deeply intertwined with

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their sense of belonging and long-term development in physics [9,36–39].

However, these positive motivational beliefs are dynamic and susceptible to decline, particularly when students undergo persistent negative learning experiences [40–45]. A primary concern among these experiences is learning burnout, a sustained negative psychological state arising from chronic academic stress or lack of interest [40,46–55]. Learning burnout is conceptualized across three core dimensions: exhaustion, cynicism, and inadequacy [52,54,55]. Although conceptually distinct, these dimensions are empirically shown to be highly correlated, collectively forming a syndrome that poses a significant threat to students' academic development [51,52,56–58]. The detrimental effects of learning burnout are well documented; it is significantly correlated with diminished academic achievement [47,48], linked to mental health issues such as anxiety and depression [59–62], and associated with a higher risk of attrition [62,63]. Given the academic challenge of physics courses, students may face an elevated risk of experiencing learning burnout, a possibility that warrants in-depth investigation.

The job demands-resources (JD-R) model [64–66] offers a framework for understanding how the perceived learning environment is closely linked to student learning experiences and psychological states [67–70]. According to the JD-R model, a positive learning environment provides crucial learning resources that help students buffer the negative consequences of high academic demands [64–66,71,72]. In the physics learning context, key resources include perceived recognition from instructors and peers [15,73–75], a strong sense of belonging within the learning community [74,76–80], and effective peer interactions [74,81–83]. Specifically, perceived recognition enhances a student's sense of value, a strong sense of belonging provides emotional support and security, and effective peer interactions can distribute cognitive load while facilitating the co-construction of knowledge. These psychological resources are essential for helping students navigate academic challenges and may be associated with a lower risk of learning burnout [72,84]. Furthermore, analyzing how access to these resources and their effects differ across student groups is a central concern in physics education research (PER), which emphasizes the importance of understanding the interplay between the learning environment and motivational beliefs for diverse groups of students [9,15,73,85–87].

However, the systematic investigation of learning burnout within the PER context remains nascent. While research has broadly emphasized the importance of a positive learning environment [67–70], the specific relationships between learning environment and learning burnout are unclear. More importantly, the potential mediating role of learning burnout in the relationship between the learning environment and students' motivational beliefs has not been empirically tested in physics. Moreover, while gender is a central area of inquiry in PER, it is unknown

whether the pathways linking the learning environment, burnout, and motivational beliefs are invariant across genders. Addressing these gaps is critical for understanding the challenges that diverse students face and for developing inclusive, evidence-based pedagogical interventions.

To address these gaps, this study proposes and empirically tests a model that positions learning burnout as a key mediator linking students' perceptions of their learning environment to their motivational beliefs and physics identity. Specifically, we extend prior physics identity frameworks [9,37] by theoretically “unpacking” the construct. Rather than modeling interest and perceived recognition as subcomponents of identity, we treat them as distinct motivational and environmental predictors. This approach enables us to empirically test the specific psychological pathways, including the novel mediating role of learning burnout, which links these environmental and motivational factors to the core self-categorization of being a “physics person.” Furthermore, we examine the invariance of this model across genders. Through this work, we aim to provide a more nuanced framework for understanding student challenges in introductory physics and to offer empirical evidence to inform the design of more supportive and equitable learning environments.

II. THEORETICAL AND EMPIRICAL BACKGROUND

A. Physics self-efficacy, interest, and identity

Motivational beliefs are key internal drivers influencing students' learning behaviors, academic achievement, and long-term development in a discipline [88–91]. This study focuses on three motivational beliefs known to profoundly impact student learning trajectories in STEM education: physics self-efficacy, interest, and identity [9–19].

The concept of self-efficacy originated from Bandura's social cognitive theory (SCT) [92–96], which posits that individuals, their behaviors, and the environment exist within a mutually determined dynamic framework [92–96]. Within this theory, self-efficacy is defined as an individual's belief in their capability to organize and execute the courses of action required to achieve specific goals [92–96]. Therefore, self-efficacy is not a measure of one's objective skills, but rather a subjective assessment of one's confidence in deploying those skills to meet specific challenges [94,97,98]. In PER, self-efficacy has been widely investigated as a critical factor in student success. For example, Sawtelle *et al.* [20] reported a positive relationship between self-efficacy and student retention in introductory physics, highlighting its role in persistence. The learning environment is a key factor in developing physics self-efficacy. For instance, Fencil and Scheel [99] found that instructional practices, such as cooperative learning and positive classroom interactions, significantly enhance students' physics self-efficacy. In terms of measurement, the Physics Self-Efficacy Scale

(PSES) developed by Çalışkan *et al.* [100] operationalizes the construct as an individual's confidence in completing specific physics tasks, including problem solving, experimental procedures, and conceptual applications. Subsequent research consistently shows that students with high physics self-efficacy are more likely to demonstrate greater engagement, persistence, and effective coping strategies when facing academic challenges [22,101–104]. Moreover, research also examines self-efficacy dynamics across different instructional modes [105,106] and its complex interplay with other motivational variables [15,107–110].

Interest is defined as the positive emotional and cognitive engagement an individual experiences when interacting with a specific object or activity, a core concept in the psychology of motivation [88,111–113]. It is closely related to and complementary to self-efficacy, as both constructs influence a student's willingness to engage with challenging material [88,111–113]. The highly influential four-phase model of interest development by Hidi and Renninger illustrates how interest can evolve from a transient, externally triggered situational interest to a stable and enduring individual interest [35]. Fostering physics interest has received significant attention in PER, as empirical research indicates that it is a critical factor in promoting deep learning, enhancing conceptual understanding, and facilitating knowledge transfer [9,114–116]. Furthermore, physics interest is also strongly linked to academic achievement, course selection, and career aspirations. For instance, Hazari *et al.* [9] identified it as a core predictor for high school students (particularly females) choosing to pursue physics-related careers. Pedagogically, connecting physics content to students' majors and daily life experiences has been shown to increase their interest and engagement [117].

Another motivational belief critical to long-term persistence in physics is physics identity. Drawing from the foundational work of Carlone and Johnson [118] and Hazari *et al.* [9,37], physics identity is defined as the extent to which an individual perceives themselves as a “physics person,” someone who feels others recognize them and possesses the traits necessary to belong to the physics community. This construct is typically understood through three core dimensions: interest, competence/performance, and recognition from others [9,119–121]. A robust physics identity is a key psychological factor associated with deeper learning engagement, greater resilience to challenges, and a higher likelihood of pursuing a career in physics [9,119–121]. Besides, physics identity is also instrumental in explaining group differences. For example, Bottomley *et al.* [15] confirmed its critical role in accounting for gender differences in academic performance. However, PER scholarship has highlighted how long-standing stereotypes of physics as “masculine” [86,122–126] and requiring innate “brilliance” [127–129] can create barriers to identity construction for female students and students from other underrepresented groups, leading to reduced engagement and sense of

belonging [38,119,130–133]. Therefore, investigating the factors associated with physics identity development across different student groups is paramount for advancing equity and inclusion in physics.

B. Physics learning burnout

The concept of burnout was first introduced by Freudenberger to describe the emotional and physical exhaustion caused by chronic occupational stress [134]. It was later systematically theorized and measured by Maslach and colleagues [135,136]. The construct was subsequently adapted to the educational context [47,52,58,137,138], where learning burnout is defined as a cumulative negative psychological state resulting from persistent academic pressure, a mismatch between learning demands and available resources, or a loss of interest in learning content [47,58]. Unlike transient fatigue, learning burnout is a more enduring and pervasive syndrome [139].

Among various theoretical models of burnout [52,54,64,140], the three-dimensional framework proposed by Maslach and colleagues has become the most widely applied due to its theoretical robustness and extensive empirical support [52,56,141–143]. This model conceptualizes learning burnout across three interrelated core dimensions: exhaustion, cynicism, and inadequacy [52]. In this study, we adopt this three-dimensional model, contextualizing its dimensions for physics learning. To ensure the ecological validity of our measurement instrument, we conducted in-depth interviews with introductory physics students, which revealed unique expressions of burnout, such as a “sense of powerlessness when facing difficult physics knowledge” and a “loss of interest due to persistent confusion.” Accordingly, we define the three dimensions in the physics learning context as (i) Exhaustion: A state of physical and mental fatigue resulting from the demands of the physics course. (ii) Cynicism: An indifferent or detached attitude toward the meaning and value of learning physics. (iii) Inadequacy: A diminished feeling of competence and accomplishment in meeting the challenges of physics learning. It is crucial to distinguish inadequacy from physics self-efficacy. The former is a state of depleted confidence stemming from a negative evaluation of past and present experiences with chronic stress [144–146], whereas the latter is a forward-looking assessment of one's capabilities for future tasks [100]. Furthermore, empirical research demonstrates that these three dimensions are not entirely separate but are highly correlated facets of a single, cohesive psychological syndrome [51,52,56–58]. This interconnectedness implies that statistical models must account for the shared variance among the dimensions to ensure accuracy.

The JD-R model provides a robust theoretical framework for investigating the correlates of learning burnout [64–66,71,72]. The JD-R model states that burnout occurs when the “demands” (e.g., academic stress and course

difficulty) consistently exceed a student's available learning "resources" [64–66,71,72]. Resources can be internal (e.g., self-efficacy) or external (e.g., instructor support and peer collaboration). This process is theorized to begin with exhaustion and may develop into cynicism and inadequacy [145,146]. With its high conceptual abstraction and mathematical rigor, physics poses a significant learning "demand" on students [5–8]. Consequently, the risk of burnout may increase if students perceive a deficit in learning "resources." For instance, Salanova *et al.* [58] found that academic hindrances (demand) predicted learning burnout, while academic facilitators (resources) predicted engagement. The adverse effects of learning burnout are well documented. A meta-analysis of over 100,000 students found that all dimensions of burnout are significantly and negatively correlated with academic achievement, with inadequacy showing the strongest negative relationship [47]. Furthermore, learning burnout is strongly associated with mental health issues, such as anxiety and depression, as well as with reduced motivation and engagement [47,52,147–151]. Despite its acknowledged harm, the connection between learning burnout and core motivational variables in physics education remains a topic that still requires systematic and in-depth research.

C. Physics perceived learning environment

Students construct learning experiences through subjective perceptions closely linked to their engagement, emotional state, and academic outcomes [67–70], rather than passively accepting the learning environment. Both SCT [92–96] and self-determination theory (SDT) [152] emphasize the profound connection between psychosocial factors in the learning environment and student motivation and persistence. Informed by these theories, this study focuses on three dimensions of the perceived environment that are critical in physics education: physics perceived recognition [15,73–75], sense of belonging [74,76–80], and peer interaction [74,81–83].

Perceived recognition in physics refers to students' perception of receiving positive feedback and affirmation from significant others (e.g., instructors and peers) regarding their competence, effort, and identity as a "physics person" [9,37]. This recognition serves as more than external feedback; it is a mechanism through which students construct their self-concept and disciplinary identity. In PER, perceived recognition is a key predictor of student learning outcomes and persistence. For example, Li and Singh [73] found that positive recognition from instructors significantly enhances the physics self-efficacy and interest of female students. Bottomley *et al.* [15] found that perceived recognition is positively associated with students' physics identity, self-efficacy, and academic performance. Notably, a study by Sundstrom and Holmes [75] highlights a key nuance: even without observable gender bias in peer evaluations, female students reported lower perceptions of being recognized. This

finding underscores that "perception" is a psychological variable influenced by internal beliefs and social stereotypes, not merely a direct reflection of external behaviors. Furthermore, a longitudinal study by Whitcomb *et al.* [74] demonstrated that students' perceptions of recognition are dynamic, suggesting the potential for intervention and improvement. In summary, perceived recognition is a critical psychosocial resource that is directly linked to positive motivational beliefs. Its potential role in helping students cope with academic challenges and mitigate learning burnout, possibly by enhancing their sense of value and confidence, warrants further exploration.

Sense of belonging refers to the feeling of being an accepted, respected, and supported member of a learning community [76,153,154]. From broader psychological and educational perspectives, belonging is considered a fundamental human need [152], essential for mental health [77,155] and academic success [76]. According to SDT [152,156,157], satisfying this need is crucial for fostering intrinsic motivation and maintaining psychological well-being. Fostering a sense of belonging is particularly critical in physics, a field some students perceive as having a high barrier to entry or an exclusive culture. The PER scholarship has emphasized the importance of an inclusive culture for fostering a sense of belonging, particularly for women [78]. It has provided strong empirical evidence linking a sense of belonging to academic outcomes. For instance, multiple studies have found that a sense of belonging significantly predicts course performance for introductory physics students, including those majoring in the biological sciences [73–79]. Such findings suggest that an environment fostering belonging provides students with emotional safety, thereby encouraging participation and help-seeking. Therefore, we hypothesize that a strong sense of belonging, acting as a protective resource, is associated with lower exhaustion and cynicism and positively correlated with physics identity.

Peer interaction refers to the communication and co-operation among students during the learning process [81,158] and is crucial for both cognitive and social development [82,158,159]. It is a significant predictor of student engagement across learning [82], with a particularly profound role in physics [83,160,161]. Productive peer interaction provides cognitive scaffolding, facilitates co-construction of complex concepts, and creates a collaborative atmosphere [83]. Moreover, the quality of these interactions is crucial. Research has found that negative peer evaluation experiences are associated with higher learning burnout, indicating that ineffective interactions can be a source of stress [162]. Similarly, Whitcomb *et al.* [74] highlighted the importance of effective peer interaction in their longitudinal study. Therefore, we aim to examine whether positive peer interactions as a potential learning resource are associated with lower learning burnout and more positive motivational beliefs.

In summary, physics perceived recognition, sense of belonging, and peer interaction are key psychosocial components that constitute a supportive physics learning environment. Li and Singh [107] previously integrated these three dimensions into a framework to examine the learning environment in introductory physics. Building on their work, this study expands this framework to systematically explore the relationships among these perceived environmental factors, learning burnout, and students' motivational beliefs and physics identity.

D. Gender differences

The persistent focus on gender within the PER community stems from the long-standing underrepresentation of women in physics and the pursuit of educational equity [9,123,163–168]. Within PER, gender is typically conceptualized not as a simple biological variable but as a complex sociocultural construct [9,102,123,163–166]. Research in this area typically focuses on how gender interacts with learning environments, stereotypes, and disciplinary cultures to shape students' learning trajectories [9,102,123,163–166].

A large body of empirical research has documented significant gender differences in both cognitive and affective domains of physics learning [123,163,164,166,167]. On standardized conceptual inventories such as the Force Concept Inventory (FCI), performance gaps between male and female students often persist even after instruction. They cannot be attributed solely to differences in mathematics preparation [163].

However, some of the most consistent and pronounced differences are found in students' motivational beliefs. Even when academic performance is comparable, female students typically report significantly lower physics self-efficacy than their male counterparts. Nissen and Shemwell [167] also found that high school physics experience had a more pronounced positive effect on the self-efficacy of male students. In contrast, the self-efficacy of female students was less impacted by prior experience. These differences in self-efficacy and disparities in physics identity correlate with students' course engagement and career aspirations. For example, research by Hazari *et al.* [9] found that different factors predict the choice to pursue a physics career for male and female students, with physics identity being particularly influential.

These gender differences cannot be attributed solely to individual variations in prior knowledge or ability [166]. A growing body of evidence suggests that the learning environment and disciplinary culture play a crucial role [102,105,167]. Notably, while interactive-engagement pedagogies can enhance learning for all students, they are not sufficient to eliminate the performance differences between females and males in FCI, suggesting that deeper environmental factors are at play [102]. In contrast, specific pedagogical interventions, such as the team-based project learning studied by Espinosa *et al.* [105], have been shown

to effectively reduce or even eliminate gender differences in physics self-efficacy. This suggests that the quality and inclusiveness of student interactions are more consequential than the mere presence of interaction, confirming the observation that male and female students may experience “his physics” and “her physics” within the same classroom [124].

E. The hypothesized theoretical model

Based on the theoretical and empirical foundations discussed above, we propose a structural model, as shown in Fig. 1, to systematically examine the association among perceived learning environment, physics learning burnout, and key motivational beliefs. To clearly operationalize the constructs discussed in the preceding sections (Secs. II A–II D) within this framework, Table I summarizes their conceptual definitions, specifies their distinct roles (e.g., distinguishing cynicism as a mediator from interest as an outcome), and provides the rationale for their placement in the model.

A core feature of this model is its statistical treatment of learning burnout. Theoretically, exhaustion, cynicism, and inadequacy are distinct but highly correlated facets of the burnout syndrome [51,52,54–58]. This strong intercorrelation suggests that even after accounting for their common antecedents, the residual variances of the three burnout dimensions may still covary. In structural equation modeling (SEM), neglecting to account for such residual covariances can lead to poor model fit and biased path estimates, a classic example of model misspecification [170–172]. Therefore, to more accurately reflect learning burnout as a cohesive psychological syndrome [52,54,55] and to avoid potential model misspecification, we specified correlations among the residual terms of the three burnout dimensions (as indicated by the curved arrows in Fig. 1). This theoretically grounded approach is critical for ensuring the statistical accuracy of the model.

Additionally, we recognize that while conceptually distinct, the dimensions of the perceived learning environment are often highly intertwined in students' real-world experiences [76–84]. For instance, according to SDT [152,156,157], students' needs for competence and relatedness are mutually reinforcing. A sense of belonging may facilitate positive peer interactions and the development of self-efficacy [76–84]. Therefore, it is plausible that some shared variance, not fully accounted for by their respective latent factors, exists among the measurement errors of items measuring perceived recognition, sense of belonging, and peer interaction. Accounting for these empirically and theoretically intertwined factors is critical for obtaining a well-fitting model without misspecification [171]. Therefore, we also specified correlations among the residual terms of the three environment dimensions (as shown by the curved arrows in Fig. 1).

It is important to note that while our model specifies residual correlations among the dimensions of learning

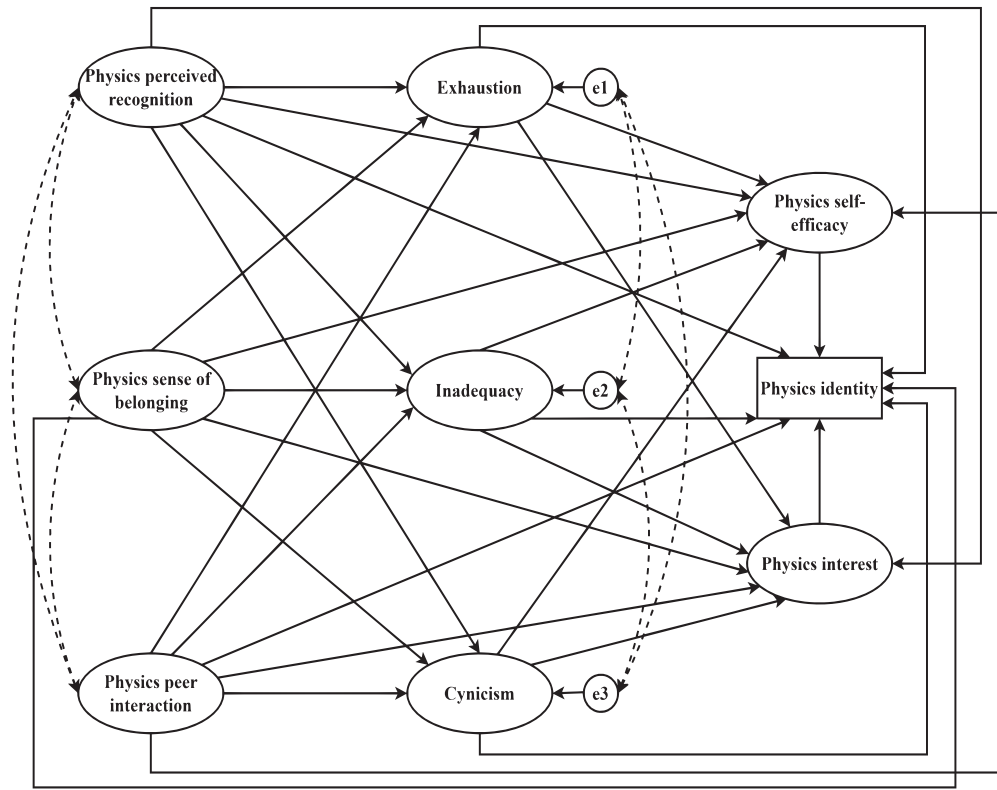


FIG. 1. The hypothesized theoretical model of the relationships between learning environment, burnout, motivational beliefs, and physics identity. Solid arrows represent hypothesized regression paths, while dashed curved arrows represent specified correlations among the residual terms of the latent factors within the environment and burnout blocks, respectively. The model also controls for student major and university type.

burnout and the perceived learning environment, we do not extend this treatment to the motivational beliefs (i.e., physics self-efficacy and interest). Self-efficacy (a belief about one's capability [92–96]) and interest (a feeling of curiosity or engagement [88,111–113]) are conceptually distinct cognitive and affective constructs. While they are theoretically and empirically correlated through their latent factors [28,97,98], there is no *a priori* theoretical basis to posit that their measurement errors would be directly correlated. Therefore, to maintain the parsimony and theoretical integrity of the model, we do not specify a correlation between the residual terms of these two constructs.

A second methodological consideration is the measurement of physics identity. Although physics identity is a multidimensional construct that includes interest, competence or performance, and recognition [9,37,118], measuring it as such in our model would create conceptual and statistical redundancy with our separate measures of interest and self-efficacy. Specifically, if the latent construct of “Physics Identity” were measured using items related to interest and recognition, it would conceptually overlap with “Physics Interest” and “Perceived Recognition,” which serve as independent predictors in the structural model. This operational

overlap would introduce severe multicollinearity (artificially high correlations), thereby compromising the stability and validity of the parameter estimates [171]. To disentangle these constructs and avoid such statistical artifacts, we follow the research paradigm of Li and Singh [107], who similarly modeled identity as an outcome distinct from its predictors and focused on its theoretical core: individual self-categorization [169]. Accordingly, we measure physics identity using the single item, “I see myself as a physics person.”

Therefore, as shown in Fig. 1, the hypothesized model tests a sequential process: students' perceptions of their learning environment are associated with their state of physics learning burnout; the burnout state is then associated with their immediate motivational beliefs; and these environmental, burnout, and immediate motivational factors are collectively related to their physics identity.

The model is based on the following interconnected theoretical premises. First, based on the JD-R model [64–66,71,72], we hypothesize that a positive perceived learning environment as a “learning resource” will be associated with lower learning burnout in physics. Concurrently, a large body of research supports the negative association between learning burnout and motivation [64,71,72]. Therefore, we expect learning burnout to

TABLE I. Conceptual definitions of key constructs, their specific roles in the hypothesized model, and rationales for their distinction.

Construct	Role in model	Conceptual definition	Key references	Rationale for distinction in this study
Physics interest	Motivational belief (outcome)	A positive emotional and cognitive engagement that an individual experiences when interacting with physics.	[88,111–113]	Distinction from cynicism: Interest represents the presence of positive engagement and curiosity, whereas Cynicism represents the loss of interest and the development of a detached, negative attitude arising from chronic stress [52,54].
Cynicism	Learning burnout dimension (mediator)	An indifferent or detached attitude toward the meaning and value of learning physics.	[52,54,55]	Distinction from interest: See above. Cynicism is explicitly conceptualized as a dimension of burnout syndrome, distinct from low motivation.
Perceived recognition	Learning environment (predictor)	The student's perception of receiving positive affirmation from significant others regarding their competence and identity.	[15,73–75]	Distinction from identity: Following Li and Singh [107], we model recognition as an external environmental resource (antecedent) rather than an internal component of identity. This allows us to test how external validation predicts internal self-categorization.
Physics identity	Final outcome	The core internal self-categorization of oneself as a “physics person” (reflecting the “Self” dimension).	[107,169]	Distinction from interest/recognition: To avoid statistical multicollinearity , we measure identity strictly as the outcome of self-categorization, distinct from its motivational (interest) and environmental (recognition) predictors. This aligns with the approach of isolating the “self” aspect from its sources [107].

have a negative association with immediate motivational beliefs. Combining these two paths, we hypothesize that learning burnout will statistically mediate the relationship between the perceived learning environment and immediate motivational beliefs (physics self-efficacy and interest). This implies that the positive association between the learning environment and motivational beliefs may be statistically mediated partly through an indirect pathway through the establishment of learning burnout states. We further hypothesize that the perceived learning environment, learning burnout, and immediate motivational beliefs will collectively predict the physics identity. To test for partial mediation, and consistent with prior research [107], we also include a direct path from the perceived learning environment to motivational beliefs. The present analysis focuses on first-year university students to examine these dynamics at an early stage of their physics learning. To account for potential confounding variables, we include students' majors (physics vs non-physics STEM) and universities as controls in all analyses.

Last but not least, given the critical role of gender in shaping environmental perceptions and motivational beliefs [9,102,123,163–167], we move beyond treating it as a control variable and instead examine it as a key grouping variable. We employ multigroup SEM to test the invariance of our proposed model across genders [173]. This analysis

follows established procedures to test for measurement and structural invariance, a prerequisite for meaningful cross-group comparisons [173]. This approach allows us to determine whether the identified psychological pathways are universal or differ significantly for male and female students.

In summary, this study aims to answer the following research questions:

RQ1. How do the three dimensions of the perceived learning environment (i.e., perceived recognition, sense of belonging, and peer interaction) relate to the three dimensions of physics learning burnout (i.e., exhaustion, cynicism, and inadequacy), and which environmental dimensions are the strongest predictors of lower burnout?

RQ2. To what extent does physics learning burnout mediate the relationship between the perceived learning environment and students' motivational beliefs (i.e., physics self-efficacy and interest)?

RQ3. What are the direct and indirect predictors of physics identity within the integrated model, considering the perceived learning environment, learning burnout, and motivational beliefs?

RQ4a. Is the hypothesized structural model invariant across genders?

RQ4b. Specifically, are the psychological pathways linking the learning environment, burnout, and motivational beliefs equivalent for male and female students?

III. METHODOLOGY

A. Participants and procedure

This study utilized a cross-sectional survey design, sampling undergraduate students from introductory calculus-based physics courses at four universities in mainland China. These courses are categorized into general physics for non-physics STEM majors and foundational physics for physics majors [174]. Given the systematic differences in the academic backgrounds and learning requirements between these two groups of students, these factors could act as potential confounding variables. Despite these differences, both course types serve as students' introductory and transitional experiences from secondary to university-level physics. Therefore, in order to test whether there is a generalized pattern of psychological associations across contexts, we included all students in the analytical framework and used the major category (physics vs non-physics STEM) as a key control variable in the SEM to statistically account for its effects.

The universities were selected to represent a diverse range of institutions within China's higher education system, thereby enhancing the external validity of the findings. The introductory calculus-based physics courses at all four participating universities followed a traditional, lecture-based instructional model during the data collection period. Data collection was conducted in two phases at the following universities: The pilot dataset for the exploratory factor analysis (EFA) [175] was collected from South China Normal University, a comprehensive research-intensive university with a strong tradition in teacher education. The main dataset for the confirmatory factor analysis (CFA) [170,171] and SEM was collected from three other universities: Shanghai Normal University, a comprehensive research-intensive university with a strong tradition in teacher education; Chengdu University of Information Technology, a specialized university with a distinct focus on atmospheric sciences and information technology; and Yibin University, a comprehensive university focusing on preservice teacher education. These universities represent a diverse cross section of Chinese higher education institutions. Shanghai Normal University and South China Normal University are comprehensive, research-intensive universities situated in major metropolitan areas, typically recruiting students with high scores on the National College Entrance Examination (Gaokao). Chengdu University of Information Technology is a specialized institution with a strong curriculum focus on engineering and atmospheric sciences. In contrast, Yibin University is a regional comprehensive university primarily serving students from the local province, with a core mission of preparing preservice teachers. This diversity ensures that the sample encompasses a broad range of student academic backgrounds and institutional learning environments.

The pilot dataset was collected at the beginning of the spring 2025 semester, and the main dataset was collected midway through the same semester. All questionnaires were completed through the online survey platform "wjx.cn." We distributed the questionnaire links and QR codes to students through the assistance of course instructors, either in class or through course-related social media groups. The research protocol was reviewed and approved by the Academic and Ethics Committee of the School of Mathematics and Physics at Yibin University (referencing Project No. 2023PY11), and data collection was authorized by the course administration. The entire process strictly adhered to the principles of voluntariness and anonymity. The first page of the questionnaire was a detailed informed consent form, which clearly stated the study's purpose, data confidentiality protocols, and participants' rights to withdraw at any time. The questionnaire only proceeded to the items after students clicked "I agree to participate in this study." During the main data collection phase, which lasted one week, instructors sent a reminder three days after the initial distribution to increase the response rate.

During the pilot (EFA) phase, a total of 373 questionnaires were collected, resulting in 341 valid samples for EFA after data cleaning. In the main data collection phase, 2077 questionnaires were collected. After data cleaning, an adequate sample of 1574 was obtained for the main analysis, with an effective response rate of 75.8%. We performed rigorous data cleaning in both phases to ensure data quality, removing inattentive responses [176]. The exclusion criteria included: (i) excessively short completion times (less than 120 s, roughly equivalent to 3 s per item), (ii) responses showing obvious patterns (such as straight lining), and (iii) logically contradictory responses on reverse-coded items. The demographic characteristics of the main analysis sample are provided in Table II.

Regarding the measurement of gender, we used a binary "male/female" option in the questionnaire. This operationalization was chosen based on the sociocultural context of the participating universities and the feasibility of data collection. Providing a binary gender option was the most common and readily understood format for participants in this context. We acknowledge that this binary operationalization is a simplification of a complex social construct. As highlighted in discussions in PER [177,178], gender is a complex, fluid, and nonbinary construct, and future research requires a "more complex future beyond the binary" to understand gender issues comprehensively. Therefore, the findings of this study regarding gender differences must be interpreted within the limitations of this binary measurement.

B. Survey instruments

The survey instrument used in this study was a composite questionnaire designed to measure students' physics learning burnout, perceived learning environment,

TABLE II. Demographic characteristics of the main analysis sample ($N = 1574$).

Variable	Category	Count	Percentage (%)
Gender	Female	611	38.8
	Male	963	61.2
Major category	Physics	246	15.6
	Non-Physics STEM	1328	84.4
University	Yibin University	627	39.8
	Chengdu University of Information Technology	778	49.4
	Shanghai Normal University	169	10.8
Total		1574	

and motivational beliefs. The questionnaire comprised three sections: the first part is to collect the demographic characteristics of students; the second part is the physics learning burnout scale (PLBS), which we developed specifically for the context; and the third part is a perceived learning environment and motivational beliefs scale, which is directly adopted from the established literature. In total, the instrument was designed to measure latent constructs: three dimensions of physics learning burnout (exhaustion, cynicism, and inadequacy), three dimensions of the perceived learning environment (physics perceived recognition, sense of belonging, and peer interaction), and two motivational beliefs (self-efficacy and interest), as well as one single-item observed variable (physics identity). The development and psychometric properties of each scale are detailed below.

Given the lack of a suitable instrument for measuring physics learning burnout, we developed and validated the PLBS. The development followed a mixed-methods approach, combining theory-driven item generation with empirical validation [179]. First, to ensure content and ecological validity, we conducted semistructured interviews. We initially recruited 19 undergraduate students from the participating universities on a voluntary basis via their course social media groups (e.g., WeChat). To ensure a representative range of experiences, the sample included students from different academic years (freshmen to seniors), majors (physics and non-physics STEM), and self-reported performance levels (ranging from high-achieving to struggling). From this pool, we selected 12 representative transcripts for in-depth analysis. The interviews were guided by open-ended prompts designed to elicit authentic descriptions of academic stress, such as “Can you describe a time when you felt particularly frustrated or overwhelmed in your physics studies?” “How did you cope with these feelings?” and “What does the term ‘burnout’ mean to you in the context of learning physics?” We used thematic analysis to identify core recurring themes students used to describe their difficulties in learning physics, such as a sense of powerlessness (e.g., “no matter how hard I study, I cannot get it,” corresponding to inadequacy), a feeling of alienation (e.g., “physics has

nothing to do with me,” corresponding to cynicism), and mental fatigue (e.g., “thinking about physics problems gives me a headache,” corresponding to exhaustion), which provided critical contextual perspectives and material for our subsequent work. We then integrated these qualitative insights with Maslach’s three-dimensional burnout framework [52,54,55]. Drawing on established instruments, including the Maslach Burnout Inventory-Student Survey (MBI-SS) developed by Schaufeli *et al.* [52], the Study Burnout Inventory (SBI) by Salmela-Aro *et al.* [180], and other relevant scales adapted for the Chinese cultural context [181,182], we constructed an initial 24-item scale.

Then, we screened and structurally verified the 24 items through quantitative analysis. The EFA test was conducted in an independent exploratory sample ($N = 341$). The data demonstrated high suitability for factor analysis, with a Kaiser-Meyer-Olkin value of 0.942 (> 0.8) and a significant Bartlett’s test of sphericity [$\chi^2(136) = 5238.369$, $p < 0.001$] [175]. Meanwhile, we used maximum likelihood (ML) for factor extraction and chose oblimin with Kaiser normalization for rotation [183]. The EFA results strongly support a three-factor structure perfectly consistent with our theoretical framework, which explains 70.8% of the total variance. Based on eigenvalues greater than 1 and the scree plot [175], we removed seven items with factor loadings below 0.4 or significant cross loadings. The final PLBS contains 17 items across three subscales: exhaustion (six items), cynicism (four items), and inadequacy (seven items). All items were measured on a six-point Likert scale (1 = “Strongly Disagree” to 6 = “Strongly Agree”).

The scales measuring the perceived learning environment and motivational beliefs were adopted from the validated instrument developed by Li and Singh [107] to ensure comparability with foundational work in the field. Among these, the four items for physics self-efficacy were measured on a four-point Likert scale with the options “NO!, no, yes, YES!” coded from 1 to 4. The four items for physics interest employed a mixed-response format. For example, the option for the item “In general, I find physics:” is “Very boring, boring, interesting, very interesting,” while the option for the item “I wonder about how physics works” is the frequency of time: “Never, once a

month, once a week, every day.” In the data processing, all options were standardized to a scale of 1–4, with higher scores representing greater interest. At the same time, the three items for physics perceived recognition and the four for physics peer interaction were measured on a four-point Likert scale. The five items for physics sense of belonging were scored on a five-point Likert scale with options “not at all true, a little true, somewhat true, mostly true, and completely true.” Meanwhile, two negatively worded items (such as “I feel like an outsider in this class”) were reverse-coded before analysis. Besides, to avoid multicollinearity issues between the multidimensional measurement of identity and the core variables of physics self-efficacy and interest in the model, physics identity was measured with the single item: “I see myself as a physics person” on a four-point Likert scale (1 = “Strongly Disagree” to 4 = “Strongly Agree”).

C. Quantitative analysis of survey data

The quantitative analysis followed a two-step SEM strategy to test the hypothesized theoretical model. First, we conducted a CFA to validate the measurement model. This crucial first step ensures that all scales are reliable and valid before testing the theoretical relationships among them. After establishing the psychometric properties of the measurement model, we proceeded to test the complete structural model using SEM. Data preprocessing and descriptive statistics were performed in SPSS 26.0, and CFA and SEM were conducted using AMOS 28.0. We evaluated model fit using multiple indices: the comparative fit index (CFI), Tucker-Lewis index (TLI), the root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR) [170,171]. We then assessed the psychometric properties of the scales. Internal consistency was evaluated using Cronbach’s alpha (α) and composite reliability (CR). Convergent validity was evaluated using the average variance extracted (AVE), and discriminant validity was established by comparing the square root of the AVE for each construct to its correlations with other constructs [170,171].

After validating the measurement model, we tested the complete structural model using SEM, controlling for students’ majors and university. This approach allows for the simultaneous estimation of all hypothesized path coefficients, providing a robust test of our research questions [171]. We tested the mediation effects (RQ2) using a bias-corrected bootstrapping procedure (5000 resamples) to generate 95% confidence intervals for the indirect effects [184]. Moreover, to address gender differences (RQ4), we conducted a multigroup SEM analysis, following established procedures for hierarchical invariance testing [171,173]. We sequentially tested for configural, metric, and structural invariance to determine whether the model’s pathways were equivalent for male and female students.

IV. RESULTS

This section presents the results of the quantitative analysis, beginning with the evaluation of the measurement model, followed by the structural model tests used to address the four research questions.

A. Measurement model evaluation and descriptive statistics

Before testing the hypothesized theoretical model, we conducted a CFA on the measurement model comprising all latent variables: exhaustion, cynicism, inadequacy, physics self-efficacy, interest, perceived recognition, sense of belonging, and peer interaction.

The CFA results indicated that the measurement model fit the data well: $\chi^2(630) = 3082.30$, $p < 0.001$; $\chi^2/\text{d.o.f.} = 4.893$, CFI = 0.953, TLI = 0.948, RMSEA = 0.050, SRMR = 0.0343. Although the $\chi^2/\text{d.o.f.}$ ratio was slightly elevated due to the large sample size, this is a common phenomenon with this index in large samples [171]. However, the other key fit indices [comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR)] all met or exceeded criteria for good model fit [185]. Collectively, these results support the construct validity of our measurement model.

As shown in Table III, all scales demonstrated excellent internal consistency. The Cronbach’s alpha (α) values ranged from 0.812 (for physics self-efficacy) to 0.956 (for inadequacy), and composite reliability (CR) values were all above 0.81 (ranging from 0.817 to 0.956), exceeding the recommended 0.70 threshold [186]. The model also showed strong convergent validity. The average variance extracted (AVE) for all constructs was above the 0.50 threshold (ranging from 0.528 to 0.795), and all standardized factor loadings were significant and substantial ($\lambda > 0.691$, $p < 0.001$) [187], which collectively provide evidence of good convergent validity of the model in Appendix A (see Table VII).

Table III presents the descriptive statistics, correlation matrix, and an assessment of discriminant validity for all variables. The overall pattern of correlations was consistent with our theoretical framework. As expected, the three dimensions of perceived learning environment (physics perceived recognition, sense of belonging, and peer interaction) showed significant moderate to strong positive correlations with the positive motivational beliefs (physics self-efficacy and interest), with r values ranging from 0.503 to 0.641 ($p < 0.001$). Concurrently, these three environmental dimensions were significantly negatively correlated with the three dimensions of physics learning burnout (exhaustion, cynicism, and inadequacy), with r values ranging from -0.297 to -0.597 ($p < 0.001$). In contrast, the three physics learning burnout dimensions were negatively correlated with physics self-efficacy and interest,

TABLE III. Descriptive statistics, reliability, and correlations for latent variables. *Note.* $N = 1574$. M , mean; SD, standard deviation; α , Cronbach's alpha; CR, composite reliability; AVE, average variance extracted. Values on the diagonal in bold are the square root of the AVE. All correlation coefficients are significant at $p < 0.001$.

Observed variable	M	SD	α	CR	AVE	1	2	3	4	5	6	7	8	9
1. Exhaustion	3.564	1.005	0.949	0.949	0.757	0.870								
2. Cynicism	3.064	0.957	0.910	0.912	0.722	0.685	0.850							
3. Inadequacy	3.508	0.986	0.956	0.956	0.757	0.785	0.713	0.870						
4. Self-efficacy	2.795	0.424	0.812	0.817	0.528	-0.545	-0.556	-0.579	0.727					
5. Interest	2.604	0.541	0.859	0.865	0.617	-0.572	-0.579	-0.581	0.709	0.785				
6. Perceived recognition	2.247	0.626	0.919	0.921	0.795	-0.348	-0.297	-0.376	0.503	0.632	0.892			
7. Sense of belonging	3.337	0.662	0.908	0.908	0.664	-0.528	-0.597	-0.559	0.641	0.601	0.449	0.815		
8. Peer interaction	2.816	0.521	0.930	0.932	0.774	-0.454	-0.507	-0.436	0.600	0.561	0.403	0.635	0.880	
9. Physics identity														

with r values ranging from -0.545 to -0.581 ($p < 0.001$). These results align with our theoretical framework: a supportive learning environment is associated with lower learning burnout and higher motivation. As shown on the diagonal in Table III, the square root of each construct's AVE was greater than its correlation with any other construct, satisfying the Fornell-Larcker criterion [187] and establishing discriminant validity.

In summary, the measurement model demonstrated excellent reliability and validity, providing a solid foundation for the subsequent structural model testing.

B. Structural model testing

Having established the validity and reliability of the measurement model, we proceeded to test the hypothesized structural model depicted in Fig. 1. This model explicitly includes the theoretically grounded residual correlations among the three learning burnout dimensions and the perceived learning environment dimensions, as hypothesized. The analysis was conducted using SEM, controlling for students' major and university. The structural model demonstrated an acceptable fit to the data: $\chi^2(730) = 5452.719$, $p < 0.001$; $\chi^2/\text{d.o.f.} = 7.469$; CFI = 0.914; TLI = 0.903; RMSEA = 0.064; SRMR = 0.0584. When evaluating the model, an important consideration is the large sample size of this study ($N > 1500$). Methodological literature has widely noted that the chi-square (χ^2) test is extremely sensitive to large samples, where even trivial discrepancies between the model and the data may result in a significant p value, thus inflating the $\chi^2/\text{d.o.f.}$ ratio [171,188]. Therefore, it is common practice to emphasize relative fit indices like CFI, TLI, RMSEA, and SRMR in large samples [185]. In the hypothesized theoretical model, the CFI of 0.914 and TLI of 0.903 meet the acceptable threshold of > 0.90 . The RMSEA (0.064) and SRMR (0.058) were below the benchmark for good fit (< 0.08). In summary, these indices indicate that the hypothesized structural model provides an acceptable fit to the data and is suitable for path analysis [171,188].

The standardized path coefficients for the model are shown in Fig. 2, with detailed results, including standard errors and p values, provided in Table IV. The model accounted for a substantial portion of the variance in the key outcome variables: 58.1% of the variance (R^2) in physics self-efficacy, 65.1% in physics interest, 45.1% in physics identity, 33.6% of the variance (R^2) in exhaustion, 40.9% in cynicism, and 39.0% in inadequacy. As shown in Table IV, the control variables (major and university) also had significant associations with several endogenous variables. The implications of these contextual effects are reserved for the Discussion section.

C. Associations of perceived learning environment with physics learning burnout (RQ1)

To answer the first research question (RQ1), we examined the direct paths from the three dimensions of the perceived learning environment to the three dimensions of physics learning burnout. As shown in Fig. 2 and detailed in Table IV, the perceived learning environment dimensions were overall significantly and negatively associated with the burnout dimensions.

Specifically, sense of belonging had significant negative associations with exhaustion ($\beta = -0.362$, $p < 0.001$), cynicism ($\beta = -0.460$, $p < 0.001$), and a sense of inadequacy ($\beta = -0.421$, $p < 0.001$). These were the strongest predictive paths from any environmental factor to the burnout dimensions. Peer interaction also significantly predicted exhaustion ($\beta = -0.169$, $p < 0.001$), cynicism ($\beta = -0.204$, $p < 0.001$), and inadequacy ($\beta = -0.098$, $p < 0.001$). The associations for perceived recognition were more specific. It was a significant predictor of exhaustion ($\beta = -0.145$, $p < 0.001$) and a sense of inadequacy ($\beta = -0.192$, $p < 0.001$), but its path to cynicism was not statistically significant ($\beta = -0.037$, $p = 0.147$).

D. The indirect role of physics learning burnout (RQ2)

To address the second research question (RQ2) concerning the mediating role of learning burnout, we tested the

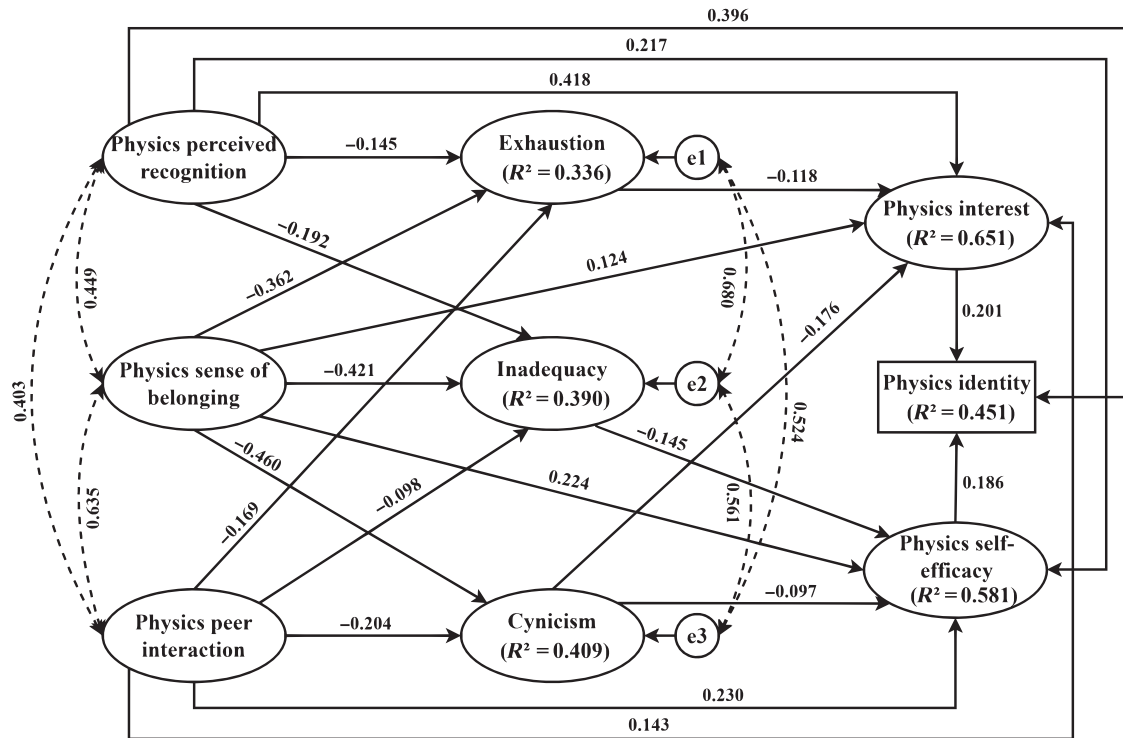


FIG. 2. The structural model with standardized path coefficients. *Note.* Standardized coefficients (β) are shown. For clarity, only statistically significant paths ($p < 0.05$) are displayed. The model controls for student major and university type. R^2 values indicate the percentage of variance explained for each endogenous variable.

indirect effects of the perceived learning environment on motivational beliefs through the three burnout dimensions. A significant indirect effect requires a significant path from the predictor to the mediator and a significant path from the mediator to the outcome.

As the previous section (RQ1) established, the paths from the learning environment to burnout were largely significant. Therefore, we examined the second segment of the mediation chain: the paths from the burnout dimensions to the motivational beliefs. As shown in Fig. 2 and Table V, these paths varied in strength and significance. Cynicism was the strongest predictor, with significant negative paths to both physics interest ($\beta = -0.176$, $p < 0.001$) and self-efficacy ($\beta = -0.097$, $p = 0.009$). Meanwhile, inadequacy significantly predicted lower self-efficacy ($\beta = -0.145$, $p < 0.001$) but was not significantly related to interest ($\beta = -0.060$, $p = 0.100$). Exhaustion significantly predicted lower interest ($\beta = -0.118$, $p < 0.001$) but was not significantly related to self-efficacy ($\beta = -0.062$, $p = 0.104$). The presence of these significant “b1” paths provides the basis for testing the full indirect effects.

Based on these constituent paths, we employed the bias-corrected bootstrapping procedure (with 5000 resamples) to formally test the significance of the indirect effects [184,189]. As shown in Table V, the results revealed multiple significant indirect pathways. For example, a significant indirect effect of sense of belonging on physics

interest was mediated by cynicism (standardized indirect effect $\beta = 0.081$, 95% CI = [0.045, 0.121]). Similarly, a significant indirect effect of sense of belonging on self-efficacy was mediated by a sense of inadequacy (standardized indirect effect $\beta = 0.061$, 95% CI = [0.023, 0.101]). These results confirm that cynicism and a sense of inadequacy, in particular, function as key mediators linking the learning environment to students’ motivational beliefs. Moreover, the direct paths from the perceived learning environment to motivational beliefs remained significant after accounting for these indirect effects, as shown in Fig. 2 and Table IV. For instance, the direct path from perceived recognition to physics interest remained strong ($\beta = 0.418$, $p < 0.001$). This pattern indicates partial mediation, whereby the learning environment directly and indirectly influences motivational beliefs through the pathway of learning burnout [190].

Beyond the specific indirect pathways, we also examined the total effects of the perceived learning environment on motivational beliefs by summing the direct and indirect effects. The results revealed that each environmental dimension has a significant impact on both physics self-efficacy and interest. Specifically, perceived recognition demonstrated a strong total effect on physics interest ($\beta = 0.453$) and a moderate total effect on physics self-efficacy ($\beta = 0.258$). Similarly, sense of belonging showed substantial total effects on physics interest ($\beta = 0.273$) and

TABLE IV. Standardized path coefficients for the full structural model. *Note.* D1, D2, and U1 are dummy-coded variables representing Yibin University, Chengdu University of Information Technology, and Shanghai Normal University, respectively. Shanghai Normal University (U1) served as the reference group.

Predictor	Outcome	β	S.E.	t value	p value
A. Predicting physics learning burnout					
<i>From perceived learning environment</i>					
Physics perceived recognition	Exhaustion	−0.145	0.041	−5.596	< 0.001
Physics perceived recognition	Cynicism	−0.145	0.040	−1.449	0.147
Physics perceived recognition	Inadequacy	−0.037	0.042	−7.699	< 0.001
Physics sense of belonging	Exhaustion	−0.362	0.054	−10.941	< 0.001
Physics sense of belonging	Cynicism	−0.460	0.054	−13.908	< 0.001
Physics sense of belonging	Inadequacy	−0.421	0.056	−13.155	< 0.001
Physics peer interaction	Exhaustion	−0.169	0.064	−5.503	< 0.001
Physics peer interaction	Cynicism	−0.204	0.063	−6.708	< 0.001
Physics peer interaction	Inadequacy	−0.098	0.066	−3.326	< 0.001
B. Predicting motivational beliefs					
<i>From physics learning burnout</i>					
Exhaustion	Physics interest	−0.118	0.018	−3.453	< 0.001
Exhaustion	Physics self-efficacy	−0.062	0.016	−1.625	0.104
Cynicism	Physics interest	−0.176	0.017	−5.298	< 0.001
Cynicism	Physics self-efficacy	−0.097	0.016	−2.602	0.009
Inadequacy	Physics interest	−0.060	0.018	−1.643	0.100
Inadequacy	Physics self-efficacy	−0.145	0.016	−3.496	< 0.001
<i>From perceived learning environment</i>					
Physics perceived recognition	Physics interest	0.418	0.021	16.669	< 0.001
Physics perceived recognition	Physics self-efficacy	0.217	0.017	8.396	< 0.001
Physics sense of belonging	Physics interest	0.124	0.026	4.117	< 0.001
Physics sense of belonging	Physics self-efficacy	0.224	0.024	6.485	< 0.001
Physics peer interaction	Physics interest	0.143	0.029	5.421	< 0.001
Physics peer interaction	Physics self-efficacy	0.230	0.026	7.580	< 0.001
C. Predicting physics identity					
<i>From perceived learning environment</i>					
Physics perceived recognition	Physics identity	0.396	0.032	12.864	< 0.001
Physics sense of belonging	Physics identity	0.055	0.036	1.639	0.101
Physics peer interaction	Physics identity	−0.046	0.041	−1.563	0.118
<i>From physics learning burnout</i>					
Exhaustion	Physics identity	0.001	0.024	0.026	0.980
Cynicism	Physics identity	−0.005	0.024	−0.134	0.893
Inadequacy	Physics identity	0.032	0.024	0.804	0.421
<i>From motivational beliefs</i>					
Physics interest	Physics identity	0.201	0.050	5.116	< 0.001
Physics self-efficacy	Physics identity	0.186	0.059	5.010	< 0.001
D. Effects of control variables					
<i>Major</i>					
Major: Physics = 1	Inadequacy	0.126	0.060	6.096	< 0.001
Major: Physics = 1	Cynicism	0.100	0.057	4.735	< 0.001
Major: Physics = 1	Exhaustion	0.076	0.058	3.515	< 0.001
Major: Physics = 1	Physics interest	−0.062	0.026	−3.415	< 0.001
Major: Physics = 1	Physics self-efficacy	0.011	0.023	0.512	0.609
Major: Physics = 1	Physics identity	0.078	0.035	3.979	< 0.001
<i>University type</i>					
University: D1 vs U1	Inadequacy	0.094	0.044	4.552	< 0.001
University: D1 vs U1	Cynicism	0.021	0.042	1.005	0.315
University: D1 vs U1	Exhaustion	0.060	0.043	2.771	0.006
University: D1 vs U1	Physics interest	−0.050	0.019	−2.738	0.006
University: D1 vs U1	Physics self-efficacy	−0.088	0.017	−4.251	< 0.001

(Table continued)

TABLE IV. (Continued)

Predictor	Outcome	β	S.E.	t value	p value
University: D1 vs U1	Physics identity	0.026	0.026	1.332	0.183
University: D2 vs U1	Inadequacy	0.046	0.043	2.239	0.025
University: D2 vs U1	Cynicism	0.053	0.042	2.504	0.012
University: D2 vs U1	Exhaustion	0.030	0.042	1.403	0.161
University: D2 vs U1	Physics interest	-0.032	0.019	-1.764	0.078
University: D2 vs U1	Physics self-efficacy	0.001	0.017	0.056	0.955
University: D2 vs U1	Physics identity	0.024	0.025	1.229	0.219

self-efficacy ($\beta = 0.353$). At the same time, peer interaction had a total impact of $\beta = 0.205$ on physics interest and $\beta = 0.275$ on self-efficacy. These total effects provide a comprehensive view of how a supportive learning environment, directly and indirectly influencing burnout, fosters students' motivational beliefs.

E. Analysis of associations with physics identity (RQ3)

The path analysis related to physics identity revealed its key correlates. As shown in Fig. 2 and Table IV, physics identity was strongly and positively predicted by both physics interest ($\beta = 0.201$, $p < 0.001$) and physics self-efficacy ($\beta = 0.186$, $p < 0.001$). Among the perceived learning environment dimensions, only perceived recognition had a significant and strong direct positive association with physics identity ($\beta = 0.396$, $p < 0.001$). The

direct paths from sense of belonging ($\beta = 0.055$, $p = 0.101$) and peer interaction ($\beta = -0.046$, $p = 0.118$) to physics identity were not statistically significant. Notably, none of the three burnout dimensions had a significant direct association with physics identity (all $p > 0.40$). In summary, the strongest direct predictors of physics identity in the model were perceived recognition, interest, and self-efficacy.

F. Multigroup analysis: Testing for gender invariance

To investigate whether the structural association model constructed in this study exhibits gender differences, we tested for gender differences in the structural model by conducting a hierarchical multigroup analysis to establish measurement and structural invariance [171,173].

TABLE V. Standardized indirect effects of perceived learning environment on motivational beliefs through burnout. *Note.* Estimates are from a bias-corrected bootstrap procedure with 5000 resamples. Significant indirect effects (where the 95% CI does not contain zero) are marked in bold and with asterisks (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). This table summarizes all tested indirect paths.

Indirect path (Predictor → Mediator → Outcome)	Standardized β	95% CI
Via cynicism		
Physics sense of belonging → Cynicism → Physics interests	0.081***	[0.045, 0.121]
Physics sense of belonging → Cynicism → Physics self-efficacy	0.045*	[0.008, 0.086]
Physics peer interaction → Cynicism → Physics interest	0.036***	[0.019, 0.058]
Physics peer interaction → Cynicism → Physics self-efficacy	0.020*	[0.004, 0.041]
Physics perceived recognition → Cynicism → Physics interest	0.006	[-0.004, 0.022]
Physics perceived recognition → Cynicism → Physics self-efficacy	0.004	[-0.001, 0.015]
Via inadequacy		
Physics sense of belonging → Inadequacy → Physics self-efficacy	0.061**	[0.023, 0.101]
Physics peer interaction → Inadequacy → Physics self-efficacy	0.014**	[0.004, 0.032]
Physics perceived recognition → Inadequacy → Physics self-efficacy	0.028**	[0.010, 0.051]
Physics sense of belonging → Inadequacy → Physics interest	0.025	[-0.008, 0.059]
Physics peer interaction → Inadequacy → Physics interest	0.006	[-0.001, 0.019]
Physics perceived recognition → Inadequacy → Physics interest	0.012	[-0.003, 0.028]
Via exhaustion		
Physics sense of belonging → Exhaustion → Physics interest	0.043**	[0.017, 0.072]
Physics peer interaction → Exhaustion → Physics interest	0.020**	[0.008, 0.038]
Physics perceived recognition → Exhaustion → Physics interest	0.017**	[0.006, 0.032]
Physics sense of belonging → Exhaustion → Physics self-efficacy	0.023	[-0.007, 0.052]
Physics peer interaction → Exhaustion → Physics self-efficacy	0.011	[-0.002, 0.026]
Physics perceived recognition → Exhaustion → Physics self-efficacy	0.009	[-0.002, 0.024]

TABLE VI. Measurement invariance tests across gender.

Model	χ^2	d.o.f.	$\Delta\chi^2$	Δ d.o.f.	p value	CFI	Δ CFI
Configural	6345.339	1460				0.910	
Metric	6387.835	1489	42.496	29	0.066	0.910	0.000
Scalar	6555.389	1526	167.554	37	< 0.001	0.907	-0.003

As shown in Table VI, we evaluated changes in model fit using the χ^2 difference test, supplemented by the change in CFI (Δ CFI), with a value greater than -0.01 considered supportive of invariance in large samples [191]. The results supported both configural invariance (the baseline model, CFI = 0.910) and metric (weak) invariance [$\Delta\chi^2(29) = 42.496$, $p = 0.066$; Δ CFI = 0.000]. This indicates that the factor structure and item loadings were equivalent across the male and female student groups. Establishing metric invariance is the necessary prerequisite for meaningfully comparing structural path coefficients across groups, providing a valid basis for the next stage of analysis [173]. The model did not achieve scalar (strong) invariance. Although the change in CFI was minimal (Δ CFI = -0.003), the chi-square difference test was highly significant [$\Delta\chi^2(37) = 167.554$, $p < 0.001$]. This suggests that direct comparisons of latent means across gender may not be valid for this sample.

Having established metric invariance, we proceeded to test for the invariance of the structural paths by comparing each constrained single-path model with the metric invariance model [173]. As shown in Table VI, the results indicated that constraining each path coefficient to be equal across the male and female groups did not significantly worsen the model fit (all $p > 0.05$). This indicates no statistically significant differences in the individual path coefficients between male and female students. This result supports the invariance of the structural pathways, suggesting that the entire psychological model—from the perceived learning environment through burnout to motivational outcomes and physics identity—operates equivalently for male and female students in our sample. Detailed results of the path constraint tests are available in Appendix B (see Table VIII).

V. DISCUSSION

This study systematically investigated the relationships among the perceived learning environment, physics learning burnout, and students' motivational beliefs and identity within introductory university physics, testing a hypothesized structural model and its invariance across genders. The findings reveal that learning burnout is a critical mediator linking the learning environment to motivational beliefs, and that this psychological model is invariant across genders. This section discusses the theoretical contributions and practical implications of these findings.

A. Learning environment as a key psychological resource in relation to lower learning burnout

A central finding of this study is that a positive perceived learning environment as an important “learning resource” is strongly associated with lower physics learning burnout. This is highly consistent with the JD-R model [64–66,71,72]. Among the environmental factors, sense of belonging was the strongest and most consistent predictor of lower burnout across all three dimensions. This finding resonates with research on the importance of school belonging [192]. It suggests a key insight: an internalized, emotional connection of “I belong here” may provide a more fundamental form of psychological safety than external validation (recognition) or functional support (peer interaction) [193]. In the high-challenge context of physics, a strong sense of belonging can create a learning space where students feel safe to make mistakes and seek help without fear of judgment. This may mitigate the emotional drain and alienation characteristic of burnout, freeing cognitive resources for learning. This interpretation aligns with the central role of relatedness in SDT [152,156,157]. When students feel accepted and respected, their fundamental need for relatedness is met, which provides a psychological support system that buffers them against the challenges that can trigger burnout.

A particularly nuanced finding was the differential effect of perceived recognition: it was associated with lower exhaustion and a sense of inadequacy but was not significantly linked to cynicism. This pattern suggests that recognition and belonging may fulfill distinct psychological needs, a distinction that can be framed using expectancy-value theory (EVT) [194]. Specifically, recognition from instructors or peers directly addresses the expectancy for success component of EVT. This external validation can counteract feelings of incompetence (inadequacy) and the fatigue accompanying struggle (exhaustion). Cynicism, however, relates more to the task value component of EVT, an internal skepticism about the meaning and worth of physics [194]. Affirming a student's capability may not be sufficient to answer their internal question of “Why should I learn this?” In contrast, the community connection from a sense of belonging may be more effective at addressing cynicism by allowing students to co-construct and internalize the value of physics with their peers.

In essence, the key implication of these findings is a shift in focus for addressing student burnout. Rather than concentrating solely on fostering individual resilience,

our results highlight the critical and actionable role of shaping the learning environment to cultivate a supportive and inclusive classroom culture.

B. Physics learning burnout:

The “indirect pathway” of motivational depletion

A significant contribution of this study is that it empirically establishes learning burnout as a key mediator in the relationship between the perceived learning environment and students’ motivational beliefs. The results demonstrate that a positive learning environment is associated with higher student self-efficacy and interest, and this statistical association can be partly understood through an indirect pathway linked to lower learning burnout.

Specifically, cynicism and inadequacy emerged as key mediating variables associated with lower physics interest and self-efficacy. When students begin to doubt the value of physics and become emotionally detached (cynicism), learning is demoted from an exploratory intellectual activity to a series of meaningless tasks. This process reflects a thwarting of the basic psychological needs for autonomy and purpose central to SDT [152,156,157]. In other words, when the intrinsic value of learning is eroded, the foundation for high-quality motivation (particularly interest) is undermined. Similarly, a negative feedback cycle can form around inadequacy, a concept consistent with SCT [92–96]. The expectation of failure leads to reduced cognitive investment and effort, resulting in increased frustration, which further confirms the belief “I cannot do this” and thus directly correlates with a decrease in self-efficacy. These results collectively indicate that burnout is not merely a negative outcome but a critical intermediate link associated with the further erosion of motivation, a finding consistent with previous research [195–197].

Moreover, a particularly noteworthy finding is that while the learning environment predicted exhaustion, exhaustion did not significantly predict a decline in physics self-efficacy. This may suggest that, consistent with cognitive appraisal theories of stress [198], fatigue is not directly linked to a significant decrease in students’ beliefs about their abilities. Instead, the key factors associated with diminished confidence are the accompanying doubt about the value of learning (cynicism) and the negative evaluation of personal competence (inadequacy). This distinction provides a basis for more precisely targeting educational interventions, and the underlying logic aligns perfectly with the dual-pathway mechanism of the JD-R model [64–66,71,72]. These findings suggest that supporting student motivation requires a two-pronged approach: not only adding supportive resources to the environment but also actively subtracting the conditions that lead to burnout. In other words, if the internal states of cynicism and inadequacy are not addressed, simply providing more external resources or incentives may prove ineffective.

C. Associated factors of physics identity

Consistent with the third research question (RQ3), our findings highlight three key factors associated with physics identity, and among the various predictors in the model, perceived recognition, interest, and self-efficacy emerged as the strongest and only significant direct predictors. Perceived recognition was the strongest direct predictor of physics identity ($\beta = 0.396$, $p < 0.001$). This finding is highly consistent with the identity frameworks of Carlone and Johnson [118] and Hazari *et al.* [9,37], which emphasize the fundamental importance of “being seen” for identity construction. Identity is a social self-concept. When students perceive that significant others (e.g., instructors and peers) recognize them as a “physics person,” they are more likely to internalize this label. This result provides empirical support for social identity theory [199], which posits that identity is constructed and maintained through social interaction and external validation.

The prominence of perceived recognition, especially in contrast to the nonsignificant effects of belonging and peer interaction, warrants interpretation. This pattern may reveal a specific mechanism of identity formation: while belonging and peer interaction contribute to a comfortable and supportive classroom climate, perceived recognition provides direct, personalized social evidence that explicitly addresses the question, “Am I a physics person?” It may be that this explicit, personalized confirmation is more critical for the act of identity construction than a general sense of environmental comfort is. Alongside this external factor, our findings confirm that interest and self-efficacy constitute the internal psychological bedrock for identity. The significant predictive roles of interest (related to task value) and self-efficacy (related to expectancy for success) align directly with the core tenets of EVT [194]. Furthermore, the strong path from self-efficacy to identity is consistent with SCT, which emphasizes the central role of efficacy beliefs in shaping personal and career trajectories [92–96].

Interestingly, none of the burnout dimensions directly predicted physics identity. This suggests that physics identity, as a relatively stable self-concept [200], may be insulated from the direct effects of burnout, unlike the more immediate and fluctuating states of interest and self-efficacy. Instead, the model suggests an indirect negative relationship: burnout erodes interest and self-efficacy, which are the primary building blocks of physics identity. This finding has important practical implications. Because interest and self-efficacy are the key pathways through which burnout affects identity indirectly, interventions that support these motivational beliefs may be the most effective strategy. Such interventions could buffer students against the downstream negative effects of burnout on identity, preventing a transient state of stress from solidifying into a long-term identity issue.

D. Psychological association models behind gender invariance

Another key finding of this study is the structural invariance of the psychological model across genders. The multigroup analysis indicates that the pathways linking the learning environment, burnout, motivational beliefs, and identity are statistically equivalent for the male and female students in our sample. This finding offers a new perspective for understanding gender issues in physics education.

This result does not imply an absence of gender differences in physics learning. On the contrary, it provides a deeper explanation for their origins. The well-documented gender gaps in outcomes like self-efficacy [9,201–204] may not stem from male and female students having fundamentally different psychological processes or needing different motivational support. Instead, our results point to a more constructive interpretation: the root of these disparities may not be in the psychological pathways themselves, but rather at the starting point of the model, in systematic differences in how male and female students perceive the learning environment. In other words, the problem is not that male and female students are psychologically constructed differently, but that they may be experiencing learning environments of different quality. This interpretation aligns with research on stereotype threat [205] and implicit bias [206]. Even within the same objective classroom setting, sociocultural stereotypes about “who belongs in physics” may mean that female students must exert more effort to be recognized or are less likely to interpret ambiguous feedback as positive.

This finding has clear implications for promoting educational equity. Rather than designing gender-specific interventions, the goal should be to create high-quality, supportive learning environments universally beneficial for all students. In other words, while male and female students may differ in the mean levels of certain variables (as suggested by the lack of scalar invariance), the psychological processes that govern the relationships between these variables are the same. This suggests that interventions aimed at improving the learning environment are likely to be effective for all students and may help to close existing gender gaps in motivational outcomes by providing equitable access to these psychological resources. This finding also contributes to the dialogue calling for moving beyond a binary view of gender [177], suggesting that a critical focus for future research is understanding how environmental features are perceived and experienced differently by students of various gender identities [178].

Furthermore, this failure to establish scalar invariance is a highly illuminating finding. In psychometrics, a lack of scalar invariance can indicate differential item functioning, which means that students from different groups with the same underlying level of a trait (e.g., self-efficacy) may respond to a survey item differently [207]. Such systematic differences provide microlevel, quantitative evidence for the theoretical position that gender as a sociocultural

construct profoundly influences how individuals interpret and report their internal experiences [208].

E. The role of contextual factors: Differences by major and university

Beyond our primary hypotheses, the analysis of the control variables revealed significant differences related to students’ academic major and university type. These findings offer valuable insights into the heterogeneity of physics education. A striking finding was the “double-edged sword” experienced by physics majors. As shown in Table IV, physics majors reported significantly higher exhaustion, cynicism, and inadequacy compared to their nonphysics STEM peers. This is unsurprising, as their foundational physics courses are more theoretically deep and mathematically rigorous [64,93,157], corresponding to higher “demands” within the JD-R model [64–66,71,72]. However, physics majors also exhibited a significantly stronger physics identity. This coexistence of higher burnout and stronger identity may reveal a potential tension inherent in professional identity formation. The intense academic challenges may deplete psychological resources and increase burnout. However, precisely this high-threshold, demanding process may foster a stronger sense of in-group identity and commitment. This finding suggests that for physics majors, stress and burnout should not be viewed in isolation but instead require a more holistic assessment that incorporates the dynamics of identity formation.

Differences across university types further highlight the role of the broader educational context. Our data show systematic differences in burnout and motivational beliefs among students of different kinds of institutions. This can be interpreted through the JD-R framework [64–66,71,72], as different universities likely present students with distinct constellations of demands and resources [64–66,71,72]. For example, a top research university may offer abundant research opportunities (high resources) but also foster more intense academic competition (high demands). In contrast, a regional university may have lower academic pressures (lower demands) but also fewer institutional resources (lower resources). The results suggest a need for future research to measure the specific demands (e.g., academic pressure) and resources (e.g., instructor support) that students perceive within different institutional contexts. Such research could inform more targeted recommendations for institutional and instructional improvement.

This analysis of contextual factors reveals that the psychological model operates within specific and heterogeneous educational contexts. This finding enhances the external validity of our study and provides a foundation for future research to move from examining universal psychological patterns toward understanding their contextualized manifestations.

VI. CONCLUSION AND IMPLICATIONS

This study provides empirical support for a model wherein a supportive physics learning environment is associated with lower learning burnout, which is linked to stronger motivational beliefs and physics identity. Specifically, a positive perceived learning environment, particularly a strong sense of belonging, is a critical psychological resource associated with lower burnout. Meanwhile, burnout partially mediates the relationship between the environment and motivation; a supportive environment is linked to lower cynicism and inadequacy, which are associated with higher interest and self-efficacy. Furthermore, physics identity was most strongly and directly predicted by perceived recognition, interest, and self-efficacy. Besides, this entire structural model was invariant across genders, suggesting that these psychological pathways are robust and operate equivalently for male and female students.

The theoretical contribution of this study is to systematically integrate the construct of learning burnout into the framework of motivation research in physics education and to empirically test its role as a key mediator connecting environment and motivation. This deepens our understanding of how negative psychological experiences are linked to positive motivational beliefs in the context of physics learning. In addition, this study offers a new perspective for discussing equity in physics education, shifting the focus toward environmental experiences rather than inherent group differences by revealing the model's invariance across genders.

Meanwhile, the findings also offer practical implications for physics instruction. Instructors should move beyond a sole focus on content transmission to consciously cultivate a supportive learning environment. This includes implementing pedagogical strategies that foster a sense of belonging (e.g., collaborative group work and positive instructor-student rapport) and recognition (e.g., offering specific, timely affirmation of student effort and progress). Instructors should also be trained to recognize signs of burnout (e.g., disengagement and self-deprecation) as signals requiring intervention rather than as indicators of low ability. The results suggest that such interventions should focus on alleviating cynicism and inadequacy. By proactively increasing these “learning resources” (such as clear guidance, meaningful peer interaction, and emotional support), instructors can create conditions that promote motivation directly and buffer students against burnout.

Despite the theoretical and practical value of this study's findings, some limitations point the way to future research. First, the cross-sectional design cannot make causal inferences [209]. Although our model is theoretically grounded, future research should use longitudinal designs to track these relationships over time or experimental designs (e.g., an intervention to enhance instructor recognition) to test the causal pathways proposed. Second, this study used a single item to measure physics identity to avoid conceptual

overlap, which ensured the statistical robustness of the model but also limited the capture of the rich construct of physics identity. Specifically, from a psychometric perspective, single-item measures are more susceptible to random measurement error than multi-item scales. Furthermore, they may not fully capture the nuanced subdimensions (e.g., specific beliefs about competence or performance) inherent in multidimensional identity frameworks. A key challenge and opportunity for future research is the development of novel, multidimensional identity instruments that can be used in complex path models without introducing multicollinearity. Third, our sample was drawn exclusively from calculus-based introductory physics courses. Students in algebra-based courses may represent a different population in terms of academic background and STEM identity formation. Therefore, future research should investigate whether the psychological pathways identified here are generalizable to noncalculus physics learning contexts. In addition, this study relied on self-reported data from students, which may pose a risk of common methodological bias [210] and could be cross-validated in the future with more objective data, such as classroom observations and academic records. Moreover, the “variable-centered” approach revealed general psychological patterns but may have masked heterogeneity within the sample. Future research could adopt a “person-centered” approach, such as latent profile analysis [211], to identify subgroups of students with different environment-burnout-motivation profiles, thereby providing more precise empirical evidence for differentiated interventions.

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DATA AVAILABILITY

The data that support the findings of this article are not publicly available because they contain sensitive personal information. The data are available from the authors upon reasonable request.

APPENDIX A

TABLE VII. Standardized factor loadings (λ) of all items in the questionnaire.

Construct and item	λ	p value
Exhaustion		
I feel exhausted by physics studies.	0.838	< 0.001
I feel emotionally drained by physics studies.	0.886	< 0.001
I find it hard to fully concentrate when I study physics.	0.880	< 0.001
I find studying physics to be a real struggle.	0.916	< 0.001
I have to spend a lot of energy studying physics.	0.832	< 0.001
I feel a lot of pressure from my studies in physics.	0.864	< 0.001
Cynicism		
I doubt the significance of my physics studies.	0.864	< 0.001
I don't feel like paying attention in physics class.	0.846	< 0.001
I don't feel like talking about physics with my instructors or peers.	0.873	< 0.001
I have become less interested in my physics studies since my enrollment at the university.	0.814	< 0.001
Inadequacy		
I often feel inadequate when studying physics.	0.887	< 0.001
I doubt whether I can learn physics well.	0.915	< 0.001
I find most of the material in physics hard to understand.	0.898	< 0.001
Learning physics often freaks me out.	0.902	< 0.001
I often get frustrated when I don't understand the material in physics.	0.838	< 0.001
I tend to put off studying physics.	0.823	< 0.001
Even when I ask for help, I still find it hard to understand physics.	0.821	< 0.001
Physics identity		
I see myself as physics person.	1.000	< 0.001
Physics self-efficacy		
I am able to help my classmates with physics in the laboratory or in recitation.	0.699	< 0.001
I understand concepts I have studied in physics.	0.713	< 0.001
If I study, I will do well on a physics test.	0.735	< 0.001
If I encounter a setback in a physics exam, I can overcome it.	0.758	< 0.001
Physics interest		
I wonder about how physics works.	0.691	< 0.001
In general, I find physics.	0.800	< 0.001
I want to know everything I can about physics.	0.828	< 0.001
I am curious about recent physics discoveries.	0.815	< 0.001
Physics perceived recognition		
My family sees me as physics person.	0.913	< 0.001
My friends see me as physics person.	0.926	< 0.001
My physics TA and/or instructor see me as physics person.	0.833	< 0.001
Physics sense of belonging		
I feel like I belong in this class.	0.791	< 0.001
I feel like an outsider in this class.	0.767	< 0.001
I feel comfortable in this class.	0.876	< 0.001
I feel like I can be myself in this class.	0.875	< 0.001
Sometimes I worry that I do not belong in this physics class.	0.756	< 0.001
Physics peer interaction		
My experience and interaction with other students in this class ...		
Made me feel more relaxed about learning physics.	0.799	< 0.001
Increased my confidence in my ability to do physics.	0.913	< 0.001
Increased my confidence that I can succeed in physics.	0.924	< 0.001
Increased my confidence in my ability to handle difficult physics problems.	0.877	< 0.001

APPENDIX B

TABLE VIII. Detailed results of structural path invariance tests.

Path name	χ^2	d.o.f.	$\Delta\chi^2$	Δ d.o.f.	p value
Exhaustion $\rightarrow$ Physics interest	6388.446	1490	0.611	1	0.434
Exhaustion $\rightarrow$ Physics self-efficacy	6387.989	1490	0.154	1	0.695
Exhaustion $\rightarrow$ Physics identity	6388.653	1490	0.818	1	0.366
Cynicism $\rightarrow$ Physics interest	6387.835	1490	0.000	1	1.000
Cynicism $\rightarrow$ Physics self-efficacy	6389.292	1490	1.457	1	0.227
Cynicism $\rightarrow$ Physics identity	6388.634	1490	0.799	1	0.371
Inadequacy $\rightarrow$ Physics interest	6388.001	1490	0.166	1	0.684
Inadequacy $\rightarrow$ Physics self-efficacy	6387.856	1490	0.021	1	0.885
Inadequacy $\rightarrow$ Physics identity	6387.842	1490	0.007	1	0.933
Physics perceived recognition $\rightarrow$ Exhaustion	6387.949	1490	0.114	1	0.736
Physics perceived recognition $\rightarrow$ Cynicism	6388.067	1490	0.232	1	0.630
Physics perceived recognition $\rightarrow$ Inadequacy	6387.836	1490	0.001	1	0.975
Physics perceived recognition $\rightarrow$ Physics interest	6388.812	1490	0.977	1	0.323
Physics perceived recognition $\rightarrow$ Physics self-efficacy	6388.895	1490	1.060	1	0.303
Physics perceived recognition $\rightarrow$ Physics identity	6389.689	1490	1.854	1	0.173
Physics sense of belonging $\rightarrow$ Exhaustion	6388.393	1490	0.558	1	0.455
Physics sense of belonging $\rightarrow$ Cynicism	6387.849	1490	0.014	1	0.906
Physics sense of belonging $\rightarrow$ Inadequacy	6388.806	1490	0.971	1	0.324
Physics sense of belonging $\rightarrow$ Physics interest	6390.673	1490	2.838	1	0.092
Physics sense of belonging $\rightarrow$ Physics self-efficacy	6387.880	1490	0.045	1	0.832
Physics sense of belonging $\rightarrow$ Physics identity	6388.967	1490	1.132	1	0.287
Physics peer interaction $\rightarrow$ Exhaustion	6388.074	1490	0.239	1	0.625
Physics peer interaction $\rightarrow$ Cynicism	6389.728	1490	1.893	1	0.169
Physics peer interaction $\rightarrow$ Inadequacy	6388.646	1490	0.811	1	0.368
Physics peer interaction $\rightarrow$ Physics interest	6388.032	1490	0.197	1	0.657
Physics peer interaction $\rightarrow$ Physics self-efficacy	6389.484	1490	1.649	1	0.199
Physics peer interaction $\rightarrow$ Physics identity	6387.876	1490	0.041	1	0.840
Physics interest $\rightarrow$ Physics identity	6387.928	1490	0.093	1	0.760
Physics self-efficacy $\rightarrow$ Physics identity	6387.989	1490	0.154	1	0.695

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Correction: Typographical errors in the sixth and seventh sentences of the third paragraph of Sec. III B have been fixed.