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Students' attitudes and beliefs toward physics learning: Evidence from secondary schools

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Abstract
Students' attitudes and epistemological beliefs about physics play a critical role in shaping their learning engagement and academic performance. This study investigates secondary school students' attitudes and beliefs toward physics learning and examines the influence of demographic variables, including grade level, gender, and school background. The Colorado learning attitudes about science survey (CLASS) was employed as the primary research instrument. Data were collected from secondary school students and analyzed using descriptive statistics, independent-samples t-tests, and multivariate analysis of variance. The results reveal that students' attitudes and beliefs toward physics learning are influenced by multiple factors, including personal interest, family support, instructional approaches, and conceptual understanding abilities. Significant differences were identified across grade levels, gender groups, and school contexts. Students with more positive attitudes toward physics learning and stronger epistemological beliefs tend to demonstrate higher levels of academic achievement. The findings highlight the importance of cultivating supportive learning environments and encouraging positive attitudes toward physics. Educational interventions aimed at strengthening students' scientific beliefs and learning motivation may contribute to improved learning outcomes in physics education.

Keywords: physics learning, learning attitudes, epistemological beliefs, CLASS survey, secondary education

INTRODUCTION

In an era defined by scientific and technological progress, cultivating public scientific literacy and appreciation for scientific inquiry is essential. As a foundational discipline, physics is often seen as abstract and difficult by secondary school students, which severely hinders their learning engagement and performance (Carreño et al., 2022). Therefore, exploring students' affective and epistemic stances—their attitudes and beliefs toward physics learning—is as important as assessing their conceptual mastery (Schiefer et al., 2022). Students' subjective perceptions of physics—as overly abstract, mathematically demanding, and disconnected from daily life—critically shape their learning attitudes and epistemic beliefs. Negative perceptions trigger passive affect, diminish intrinsic motivation, and foster naïve views that physics learning reduces rote memorization, even when procedural competence is temporarily achieved. Conversely, students who perceive physics as a tool for interpreting real-world phenomena tend to develop positive attitudes and sophisticated epistemic orientations, engaging actively in conceptual inquiry. This robust perceptual-affective-epistemic nexus thus establishes that investigating students' attitudes and beliefs carries educational research value equivalent to assessing their conceptual mastery of physics content.

Attitudes and epistemological beliefs form the motivational basis of learning. Students who view physics as relevant to daily life and attribute success to effort tend to adopt deep learning strategies, unlike those who see it as isolated formulas to memorize. A growing body of recent empirical studies (Musters et al.,

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Contribution to the literature

- This study enriches international CLASS-based physics-education evidence by providing synchronous cross-grade empirical data from Chinese urban secondary schools under a high-stakes exam-oriented educational context.
- It further demonstrates the moderating role of school pedagogical orientation on students' physics attitudes and epistemic beliefs through MANOVA analysis.
- By systematically reporting Cohen's d and partial η^2 effect sizes alongside significance tests, this work distinguishes statistical significance from practically meaningful educational differences for future local replication research.

2025; Ongowo, 2022; Schiefer et al., 2022; Wei et al., 2025) has confirmed that students' epistemic beliefs can significantly predict long-term science academic achievement. Ongowo (2022) found that the certainty and justification dimensions of secondary students' epistemological beliefs significantly predicted their science performance in Kenya, highlighting the real impact of belief systems on learning outcomes.

China's physics curriculum standards for senior high schools (2017 edition) stresses core scientific literacy, including conceptual understanding, inquiry skills, and scientific attitudes and responsibility (Ministry of Education of the People's Republic of China, 2018), reflecting a shift from content-focused to holistic education. Internationally, the Colorado learning attitudes about science survey (CLASS) has consistently shown that students' beliefs are malleable and shaped by teaching practices. Martins and Lindsay (2022) validated a streamlined CLASS factor structure for K-12 settings, confirming its suitability for modern science education research.

Contemporary research has further unpacked nuanced dynamics, especially gender disparity, which serves as one of the most stable demographic predictors of secondary students' physics learning attitudes and epistemic beliefs, and such disparities can be quantitatively captured through multi-dimensional CLASS indicators. Physics identity, a core mediating variable in this correlation, refers to learners' self-recognition as competent physics learners. Existing evidence proves physics identity acts as a critical mediator between gender and learning attitudes; female students with weak physics identity consistently score lower on CLASS dimensions of personal interest and problem-solving confidence. Musters et al. (2025) found gender differences in teacher-student interactions: girls exerted more effort, while boys often overestimated their abilities. Lynch et al. (2024) demonstrated that a short intervention boosted young adolescent girls' physics identity and pursuit intentions. Carreño et al. (2022) also reported that a mobile lab intervention improved female students' physics understanding more significantly than males.

Curriculum content exacerbates these gaps: Ross et al. (2023) identified severe gender and Eurocentric biases in Australian physics syllabi, with nearly no female scientist representation—perpetuating women's underrepresentation in physics and demanding more diverse curricula.

Beyond gender, studies reveal grade-level, contextual, and socioeconomic influences on epistemic beliefs. Schiefer et al. (2022) found that German students' belief profiles homogenized with schooling and correlated with tracking and socioeconomic status. Dorji and Namgyel (2025) noted naïve scientific epistemologies among Bhutanese primary teachers, affecting student instruction. Grabau et al. (2021) linked Finnish students' science dispositions (beliefs, interest, self-efficacy) and classroom climate to PISA science literacy.

Research also emphasizes the domain-specificity of epistemological beliefs: Korom et al. (2025) identified distinct belief profiles in science vs. history among pre-service teachers, while Zemplén (2023) reviewed key debates and measurement methods for physics epistemic beliefs. Local studies further confirm variability: Ongowo (2022) found grade-level differences in Kenyan students' epistemological beliefs, and Gayoso Miranda (2022) showed that particle physics outreach reshaped students' scientific worldviews.

Despite abundant international research on students' physics attitudes and epistemic beliefs measured by CLASS, scholars have achieved rich findings from multiple perspectives. Existing studies have confirmed the mutual influence between physics epistemic beliefs and academic performance, explored gender differences in science learning perceptions across multiple national contexts, and verified that curriculum design, classroom atmosphere and socioeconomic status can shape students' belief systems. Researchers have also clarified the domain-specific characteristics of scientific epistemology and validated the reliability of CLASS scale for secondary student groups in Western and some African educational environments. Nevertheless, three critical research gaps remain underexplored in literature, which constitute the core motivation of the current study.

First, most prior empirical investigations focus on Western or Southeast Asian student populations, while few systematic comparisons between junior and senior high learners have been conducted within China's unique high-stakes examination-driven physics education system. Local studies mostly discuss junior or senior students separately, lacking synchronous sampling of two secondary stages to track the continuous developmental characteristics of eight CLASS dimensions under exam-oriented teaching. In particular, few papers interpret the counterintuitive phenomenon that seniors obtain lower scores on real world connection dimension compared with junior students from the perspective of curriculum evolution and examination pressure.

Second, existing gender disparity research rarely differentiates developmental gaps across junior and senior stages, and insufficient attention has been paid to the moderating effect of divergent school teaching orientations. Most gender-related conclusions are generalized to all secondary students without stage-stratified analysis; meanwhile, prior CLASS research seldom adopts multivariate analysis of variance (MANOVA) to compare the overall attitudinal and belief profiles of students from schools with different teaching styles, ignoring the contextual influence of school pedagogy.

Third, most relevant studies only rely on p-values to judge group differences, without supplementing standardized effect sizes to distinguish pure statistical significance from practically meaningful educational differences. Large sample sizes easily produce significant p-values even for trivial inter-group gaps, yet few domestic CLASS reports calculate and interpret Cohen's d and partial η^2 to quantify the actual magnitude of grade, gender and school differences.

To address the above three underexplored limitations, the present study makes three distinct targeted contributions to fill the identified research gaps: it adopts a stratified sample covering grades 8, 10, 11 and 12 urban Chinese secondary students to realize synchronous cross-grade comparison; it conducts independent gender analyses for junior and senior groups separately alongside multivariate cross-school comparisons based on different pedagogical styles; it comprehensively reports Cohen's d for independent samples t-tests and partial η^2 for one-way MANOVA, combining significance testing and effect size interpretation to reflect both statistical and practical educational significance of all observed group differences.

Against this backdrop, this study investigates physics attitudes and epistemological beliefs among junior and senior secondary students in a specific urban Chinese context. Using the validated CLASS instrument and rigorous statistical analysis, it identifies key demographic and institutional factors shaping students' epistemic stances, providing empirical evidence for targeted, effective physics teaching interventions.

LITERATURE REVIEW

Theoretical Frameworks Attitudes and Beliefs in Educational Psychology

In educational psychology, attitude and epistemic belief are two theoretically distinct core constructs with mature classical conceptual boundaries proposed by prior scholars.

As defined by Savasci anf Tomul (2023), learning attitude refers to a stable learned evaluative tendency toward a subject or learning activity, systematically composed of affective, cognitive, and behavioral three interrelated dimensions.

In contrast, the foundational definition of epistemic beliefs originated from Richardson (1996), who proposed that epistemic beliefs are individuals' implicit, tacit assumptions about the nature, source, certainty and generation process of knowledge. When transferred to the field of physics education, this construct specifically concerns the structural characteristics, certainty boundary, acquisition source and developmental law of physics knowledge, as well as learners' preferred learning modes (mechanical memorization versus logical conceptual understanding).

Epistemic development refers to the continuous developmental trajectory of learners' implicit assumptions about knowledge and knowing (Korom et al., 2025; Zemplén, 2023). Throughout secondary education, students gradually shift from naïve epistemic beliefs (viewing physics as fixed formulas requiring mechanical memorization) toward sophisticated, expert-aligned epistemic cognition that emphasizes logical conceptual reasoning and real-world application. This progressive shift in belief systems is termed epistemic development, and the present study tracks its variation across grades, genders and school environments via CLASS measurements.

To quantify the above two latent theoretical constructs empirically, this study adopts the CLASS (Adams et al., 2004), which consists of eight mutually exclusive CLASS dimensions. A CLASS dimension refers to a standardized subscale of the full instrument, each capturing one specific facet of students' affective or cognitive perceptions of physics learning. These eight dimensions are theoretically partitioned into two sets that directly correspond to the study's core latent constructs as follows.

Dimensions measuring physics learning attitudes (affective construct): real world connection, personal interest. These two subdimensions reflect students' subjective feelings, interest and recognition of the practical value of physics, which match the affective component of learning attitudes.

Dimensions measuring epistemic beliefs (cognitive construct): conceptual connections, meaning construction, applying conceptual understanding, generality of problem-solving, confidence in problem-solving, refinement of problem-solving. These six subdimensions tap into students' implicit judgments about physical knowledge structure, reasoning rules and effective problem-solving strategies, which fully operationalize the definition of epistemic beliefs in this paper.

Detailed matching logic between each CLASS dimension and representative scale items is elaborated later, together with illustrative survey statements to demonstrate how each dimension operationalizes abstract theoretical constructs.

A growing body of recent studies has further refined the domain-specific characteristics of physics-related attitudes and epistemic beliefs (Grabau et al., 2021; Korom et al., 2025; Sulaiman & Hamzah, 2023; Wei et al., 2025; Zemplén, 2023). Most existing literature separately discusses affective attitudes or epistemic cognition, while few simultaneously examine their interactive coupling relationship among Chinese secondary students under exam-oriented schooling, which this study addresses.

Taken together, the above classic theoretical definitions and recent empirical studies clearly differentiate learning attitudes and epistemic beliefs as the two core latent constructs of this research. Scholars have delineated the three interrelated affective, cognitive and behavioral dimensions of learning attitudes, as well as the implicit assumptions about knowledge nature, origin and development embedded within epistemic beliefs and confirmed their interactive mutual-facilitating relationship in science learning. However, most relevant existing research concentrates on Western pre-service teacher samples, with scarce simultaneous examinations of the coupling interplay between the two constructs among Chinese junior and senior secondary students within exam-oriented physics education contexts. To fill this research gap, the current study adopts the validated CLASS instrument to jointly measure students' physics-related attitudes and epistemic beliefs, and further explores demographic discrepancies across grade, gender and school backgrounds, enriching localized empirical evidence in this research field.

The CLASS

The CLASS is a globally validated instrument with 42 five-point Likert items measuring learners' physics-related affective and epistemic constructs. Its detailed dimensional composition, scoring criteria, and Chinese localized version are fully explained in research instrument sub-section. Recent psychometric research has optimized the scale's adaptability for K-12 populations. Martins and Lindsay (2022) verified a simplified factor structure consistent with modern science education standards, while Ding (2013) laid the groundwork for CLASS validity within Chinese educational contexts. Thanks to stable cross-cultural psychometric performance, CLASS is well-suited for large-scale cross-sectional surveys.

Taken together, the above psychometric studies confirm CLASS can reliably quantify students' physics attitudes and epistemic beliefs through eight distinct dimensions, which perfectly matches the measurement tool adopted in this paper. Most existing scale validation research only draws European and American student samples and merely reports overall scale reliability without inter-group comparisons across different grades and schools. This study fills this gap by deploying the Chinese CLASS among grades 8, 10, 11 and 12 students from four distinct schools, and additionally reports effect sizes alongside significance values to provide localized comparative evidence for the scale's application.

Grade Level and Developmental Trajectories of Epistemic Beliefs

Research consistently demonstrates that epistemic beliefs follow non-linear developmental trajectories across grade levels, rather than monotonic improvement. Studies document periods of stability, stagnation, or even regression at critical educational transitions.

Wei et al. (2025) found that context-based problem motivation was strong for grade 8 students but declined sharply by grade 9, indicating a developmental threshold in physics engagement. Ongowo (2022) identified significant grade-level differences in the source, certainty, and development of scientific knowledge among Kenyan secondary students, with distinct developmental rates across dimensions. Schiefer et al. (2022) analyzed over 10,000 German students and found that epistemic profiles homogenized with schooling and were predicted by tracking and socioeconomic status. Grabau et al. (2021) linked science dispositions (epistemic beliefs, interest, and self-efficacy) and classroom climate to PISA science literacy across grades. Collectively, grade level reflects not only cognitive maturation but also cumulative exposure to context-specific educational experiences that shape epistemic development. Grade-based comparisons in this study further reflect divergent levels of epistemic development between junior and senior secondary students, especially the notable decline in real world connection scores as learners advance to higher grades.

These longitudinal and cross-sectional studies demonstrate that students' epistemic beliefs and physics attitudes change non-linearly with grade growth, closely relating to the real world connection and conceptual understanding dimensions of our core constructs. Most prior works only describe single-stage developmental trends without separating junior and senior cohorts to compare the decline of real-world relevance perception. This study conducts independent t-tests between junior and senior groups and calculates Cohen's d to judge practical differences, clearly revealing the grade-based gap in students' affective beliefs.

Gender Dynamics in Physics Learning

The global gender gap in physics participation and achievement persists as a major educational concern, with recent research focusing on causal mechanisms and intervention effects. Musters et al. (2025) identified gendered perceptions in teacher-student interactions: boys were often attributed innate physics ability, while girls were praised for effort, a stereotype that may erode long-term confidence and identity.

Targeted interventions show promise for reducing disparities. Carreño et al. (2022) reported that mobile lab interventions improved physics understanding more strongly for female students. Lynch et al. (2024) demonstrated that a brief identity-building workshop significantly enhanced young adolescent girls' physics self-concept and pursuit intentions.

Curricular representations further perpetuate gaps. Ross et al. (2023) documented severe gender and Eurocentric biases in Australian physics syllabi, with minimal female scientist role models. Gayoso Miranda (2022) highlighted the potential of specialized outreach to reconstruct epistemic beliefs and disrupt gendered patterns. Addressing disparities requires integrated interventions targeting teacher perceptions, classroom interactions, curricular content, and student identity development.

The reviewed gender-related studies prove gender stereotypes and physics identity mediate students' physics interest and confidence, which are key components of our attitude construct. Existing interventions mostly target single-age adolescents and rarely compare gender gaps separately for junior and senior stages. The current study divides samples by educational stage and detects gender disparities across all eight CLASS dimensions, providing staged evidence for gender-inclusive physics teaching.

School and Pedagogical Contexts

School and classroom environments function as critical contextual mediators of epistemic belief development. Instructional alignment, pedagogical orientation, and implicit norms shape the hidden curriculum of scientific epistemology. Scharlach (2026) emphasized *academic misalignment*: incongruence between instructor expectations and student epistemologies predicts frustration, disengagement, and lower physics exam performance, highlighting the need for epistemologically congruent instruction.

School cultures emphasizing examination-oriented memorization or inquiry-based practice differentially shape epistemic development. Dorji and Namgyel (2025) found that naïve teacher epistemic beliefs in Bhutan constrained student learning of scientific knowledge nature. Sulaiman and Hamzah (2023) synthesized evidence that learning environments interact with individual traits to determine epistemic profiles.

Zemplén (2023) reviewed methodological advances in measuring context-sensitive epistemic beliefs, underscoring the need for situated, ecologically valid assessment. Between-school differences are not merely statistical controls but core explanatory factors in epistemic development. Accordingly, this study incorporates multiple school sites to capture contextual influences on student epistemic beliefs, consistent with contemporary physics education theory.

Unique Context of Chinese Exam-Oriented Secondary Physics Education

Against the global research background reviewed above, secondary physics education in urban Chinese schools presents distinct contextual features that differentiate it from Western education systems and create a necessity for localized empirical investigation. The entire secondary physics learning cycle is deeply shaped by high-stakes standardized examinations, including the high school entrance examination and national college entrance examination (Gaokao), which fundamentally reshape curriculum design, daily teaching arrangements and students' learning goals (Li & Wang, 2023; Zhang et al., 2024).

There exists an obvious structural split between junior and senior physics curriculum orientation formulated by national curriculum standards. The 2017 edition of China's senior high school physics curriculum standards emphasizes scientific literacy cultivation in policy design, yet classroom implementation is heavily constrained by exam assessment pressure (Ministry of Education of the People's Republic of China, 2018). Junior physics textbooks are designed around intuitive daily phenomena such as household circuits, optical reflection and simple mechanical levers, with abundant classroom demonstration experiments to connect physical laws with real life. In contrast, senior high school physics shifts toward abstract microscopic models, complex electromagnetic deduction and heavy mathematical derivation (Huang & Liu, 2025). To meet college entrance examination demands, senior physics teaching allocates most class time to intensive problem drills, error sorting and comprehensive test training, while life-oriented exploratory activities, situational case expansion and hands-on practical experiments are largely compressed (Wang, 2024).

Under this exam-centered teaching logic, senior students gradually form utilitarian learning motivations that regard physics merely as an examination subject rather than a tool for interpreting real-world phenomena. Long-term drill-oriented instruction weakens adolescents' perception of the practical value of physics, which provides a reasonable theoretical explanation for the counterintuitive developmental trend observed in the present study, in which senior students score significantly lower on the real world connection dimension despite more mature epistemic cognition on conceptual understanding and problem-solving confidence (Liu & Chen, 2024).

Most existing international CLASS studies are carried out in low-stakes or inquiry-dominated educational environments in Europe and North America, and their developmental patterns of students' physics attitudes and epistemic beliefs cannot be directly generalized to Chinese secondary students under intense exam pressure (Wei et al., 2025). Therefore, conducting a targeted investigation covering both junior and senior cohorts within the Chinese urban exam-oriented education context fills an obvious research blank and produces empirical evidence with unique regional and international reference value.

Previous literature indicates school teaching orientation shapes students' epistemic development, affecting both their affective attitudes and cognitive beliefs. Most prior research only treats school type as a simple control variable rather than a core moderating factor. This study selects two junior high schools with distinct pedagogical styles (theory-focused vs practical-oriented) and conducts MANOVA to examine inter-school differences in all belief dimensions, highlighting the critical influence of daily teaching on students' physics attitudes.

RESEARCH PURPOSE AND RESEARCH QUESTIONS

This study aims to investigate secondary students' physics learning attitudes and epistemic beliefs in urban Chinese schools via the CLASS instrument. It explores demographic and school contextual variations in students' belief profiles, generating empirical evidence to support targeted physics teaching design under the local exam-oriented education context.

To accomplish the overarching purpose, four specific research objectives are formulated, each matched with a corresponding research question (RQ):

Objective 1: To describe the overall status of physics learning attitudes and epistemic beliefs of junior and senior high students across eight CLASS dimensions.

RQ1: What is the overall level of physics learning attitudes and epistemic beliefs across the eight CLASS dimensions among junior high and senior high students from the sampled urban secondary schools?

Objective 2: To examine whether significant cross-grade differences exist in students' physics learning attitudes and epistemic beliefs between junior high and senior high cohorts.

RQ2: Are there statistically significant differences in the eight CLASS dimensions between junior high and senior high student cohorts?

Objective 3: To explore whether gender disparities in physics learning attitudes and epistemic beliefs can be observed within junior high groups and senior high groups, respectively.

RQ3: Do significant gender differences in physics learning attitudes and epistemic beliefs exist within junior high groups and senior high groups separately?

Objective 4: To identify multivariate holistic differences in students' attitudinal and epistemic profiles among students from four schools with different teaching characteristics.

RQ4: To what extent do students from four schools with different teaching characteristics demonstrate multivariate holistic differences in their profiles of physics learning attitudes and epistemic beliefs?

By addressing these questions, this study seeks to identify key factors influencing students' physics-related attitudes and beliefs, provide empirical evidence for the importance of affective and epistemic development in physics learning, and offer practical implications for evidence-based physics teaching reform and instructional improvement in secondary education.

METHODOLOGY

Research Design

This study adopts a quantitative cross-sectional survey design, following the standardized definition proposed by Creswell and Creswell (2018). According to this authoritative framework, cross-sectional design is a non-experimental quantitative research method that collects data from diverse research participants at one fixed time point to capture the static distribution of core research variables and conduct inter-group comparative analysis.

This design fits the present study's research purposes well for three reasons. First, our research focuses on exploring group differences in physics attitudes and epistemic beliefs across three demographic factors (grade, gender, and school), rather than tracking long-term individual developmental changes. One-time synchronous data collection from grades 8, 10, 11 and 12 students can sufficiently satisfy the need for horizontal cross-group comparison. Second, the cross-sectional design enables us to obtain a large valid sample of 997 students from four urban secondary schools within a short research cycle, improving the external validity of group comparison results. Third, the design is highly compatible with our statistical analysis scheme including independent samples t-test and one-way

MANOVA, which rely on cross-sectional between-group data to identify significant differences in eight CLASS dimensions.

Notably, this design carries inherent limitations: it only provides a static snapshot of students' learning beliefs and cannot infer causal relationships or longitudinal developmental trajectories between variables. Since all variables are measured simultaneously at a single time point, we are unable to establish causal links between grade, gender, school environment and students' physics attitudes and epistemic beliefs. In addition, this one-off data collection cannot record continuous, multi-year developmental changes of the same group of students. This shortcoming is further discussed later.

Research Instrument

The CLASS was employed as the primary research instrument. Developed by Adams et al. (2004) based on Fishbein's attitude theory, the CLASS is a widely validated scale designed to assess students' epistemological beliefs and affective attitudes toward physics and physics learning. We adopted the CLASS by Ding (2013) in the current study.

CLASS detailed introduction, measurement, and implementation

Scale structure & construct-dimension-item mapping: The scale contains 42 five-point Likert items (1 = strongly disagree, 5 = strongly agree), covering eight core dimensions divided into two core latent constructs of this study: affective physics learning attitudes and epistemic beliefs. The explicit matching relationship between latent constructs, eight dimensions and representative scale items is illustrated below to clarify how observable survey items operationalize abstract attitudinal and epistemic constructs.

The CLASS scale operationalizes two core latent constructs of this study, namely affective physics learning attitudes and cognitive epistemic beliefs, and its eight subdimensions are assigned to the two theoretical categories correspondingly. Real world connection and personal interest jointly constitute the affective construct of physics learning attitudes. For real world connection, the representative item "Many physics ideas can explain things I see in daily life" captures students' affective recognition of physics' practical value; for personal interest, the statement "I feel curious when learning new physics knowledge" mirrors learners' spontaneous positive emotions toward physics learning.

The remaining six subdimensions fall under the epistemic belief construct, each measuring distinct implicit perceptions about physics knowledge and learning. The item "Physics concepts are closely linked rather than isolated formulas" assesses judgments on knowledge structure (conceptual connections), while "Understanding physical logic is more important than reciting equations" reveals views on efficient learning approaches (meaning construction). The scale also covers beliefs about theory transferability (applying conceptual understanding, generality of problem-solving), learning self-efficacy (confidence in problem-solving), and rigorous reasoning norms (refinement of problem-solving), with corresponding sample items, respectively embodying these cognitive orientations.

All Likert statements contained in the CLASS function as concrete observable indicators. These tangible questionnaire responses convert abstract, unmeasurable latent variables—students' physics learning attitudes and epistemic beliefs—into quantifiable data, establishing a clear operational logic linking the study's theoretical core constructs to the measurement instrument.

Scoring & measurement logic

The CLASS distinguishes between expert-like and novice-like beliefs about the nature of physics knowledge and learning, providing a standardized framework for evaluating students' epistemic development. Each item is matched with standard expert response benchmarks. The percentage of responses consistent with expert consensus (% favorable) is calculated as the core indicator; higher values indicate more mature, expert-aligned physics learning attitudes and epistemic beliefs, while low scores represent naïve memorization-oriented perceptions.

Chinese localization reliability and validity: The Chinese version translated and validated by Ding (2013) was utilized in this study. The full systematic psychometric verification procedures for scale localization are elaborated below to detail how reliability and validity were established:

Reliability verification process. Internal consistency reliability was adopted to test the stability of scale items, measured by Cronbach's α coefficient. The judgment standard followed educational measurement norms: α above 0.7 indicates acceptable internal consistency. In the localized Chinese CLASS scale, the full-scale Cronbach's $\alpha = 0.87$, and the Cronbach's α coefficient of each of the eight subdimensions ranged from 0.72 to 0.81. All subdimensions met the reliability threshold, proving that items under each dimension maintain consistent measurement tendency and the whole scale has satisfactory internal stability for Chinese secondary students.

Validity verification process. Three successive standardized procedures were conducted to guarantee content validity and construct validity of the translated scale:

First, translation and back-translation procedure. Two physics education researchers proficient in both Chinese and English independently translated the

Table 1. Basic information on valid survey samples

School	Student	Grade	Male	Female	Valid questionnaire
A school	High school	Grade 10	40	52	92
		Grade 11	34	47	81
		Grade 12	65	28	93
B school	High school	Grade 10	45	52	97
		Grade 11	37	60	97
		Grade 12	60	50	110
C school	Junior high school	Grade 8	52	49	101
		Grade 9	57	42	99
D school	Junior high school	Grade 8	51	68	119
		Grade 9	59	49	108

original English CLASS items into simplified Chinese. A third researcher translated the Chinese draft back into English without accessing the original scale. The original English version and back-translated version were cross-compared word by word; inconsistent semantic expressions were revised repeatedly to eliminate translation bias and ensure consistent item connotation between two languages.

Second, expert content validity evaluation. Three senior university physics education experts and two frontline senior high physics teachers reviewed all 42 Likert items. They assessed the clarity, suitability and pertinence of each statement for local junior and senior high students, adjusted expressions inconsistent with domestic secondary physics teaching contexts, and confirmed the eight dimensions fully cover the core connotation of affective physics learning attitudes and epistemic beliefs, achieving qualified content validity.

Third, confirmatory factor analysis (CFA) for construct validity. CFA was carried out on Chinese secondary student samples to examine whether the original eight-factor theoretical structure of CLASS fits localized data. Model fitting indices reached the acceptable standard: $\chi^2/\mathrm{df} < 3$, RMSEA < 0.08, CFI > 0.90, TLI > 0.90. The stable factor structure result confirmed good construct validity of the Chinese CLASS version, which is also consistent with the replication results of Zhang (2022) on local adolescent samples.

Rigorous psychometric testing confirmed its high reliability (total Cronbach's α = 0.87) and good construct validity via CFA, and the eight-factor structure fits Chinese secondary student samples well (Zhang, 2022).

Survey implementation method: All questionnaires were distributed online during regular class hours under teacher supervision. Participants read the anonymity statement and informed consent before independent completion with no time restriction. Questionnaires with missing values or repetitive identical responses were screened out as invalid during data cleaning.

Participants and Sampling Procedure

Sampling procedure

Stratified convenience sampling was implemented for participant recruitment. First, four public urban secondary schools with distinct physics teaching resource allocation in S City were purposively selected as research sites to cover varied classroom instruction styles. Within each selected school, intact physics classes from grades 8, 10, 11, and 12 were invited to participate voluntarily. All students completed the electronic CLASS questionnaire uniformly during supervised class hours under teacher guidance.

Participants were students from four public secondary schools in S City, covering grades 8 (junior 2), 10 (senior 1), 11 (senior 2), and 12 (senior 3).

A total of 1,005 questionnaires were distributed and collected, yielding a 100% response rate. After excluding 8 invalid responses (incomplete or unengaged responses), 997 valid questionnaires were retained, with an effective response rate of 99.2%.

The valid sample included: 500 male students and 497 female students; 427 junior high school students and 570 senior high school students; Age range: 12-18 years old.

Demographic characteristics of the sample are summarized in **Table 1**.

Basis for classification of school pedagogical orientations

To distinguish between theory-centered instruction and practice-oriented teaching styles across the four sample schools, the study integrated multiple types of empirical data for triangulation, including official physics curriculum implementation documents, full-semester physics teaching schedules, and informal interviews with heads of physics teaching and research groups and senior physics teachers at each site. Three core indicators were employed to assess teaching orientation:

(1) the proportion of class time devoted to theoretical knowledge explanation versus hands-on

experiment demonstrations and real-life contextual case teaching;

(2) the ratio of abstract formula derivation exercises to everyday-life inquiry-based tasks in daily assignments; and

(3) the prioritization of teaching objectives as listed in school instructional plans (i.e., improving test scores versus cultivating students' awareness of physics applications in daily life).

After cross-checking documents and interview records, school A and school C were identified as primarily theory-oriented, with most instructional time devoted to theoretical derivation and exam-focused problem-solving, whereas school B and school D tended toward a practical orientation, featuring regular classroom demonstrations, everyday-life physics extensions, and exploratory experiments. This classification, supported by multiple sources, offers a credible empirical basis for the subsequent one-way MANOVA comparing the four schools.

Strengths of the sampling strategy

First, the total valid sample size reaches 997, which meets the large-sample requirement for parametric tests such as independent samples t-test and one-way MANOVA and stabilizes statistical results. Second, the sample balances junior high and senior high participants, enabling systematic cross-grade comparative analysis across all eight CLASS dimensions. Third, adopting intact-class sampling across four schools with different teaching orientations provides diversified contextual data, avoiding single-school bias that frequently appears in small-scale physics education surveys.

Limitations of the sampling strategy

This research relies on convenience sampling restricted to urban secondary schools in a single city. No rural middle or high school students are included in the sample pool. As a result, the observed patterns of physics learning attitudes and epistemic beliefs cannot be generalized to rural adolescents or students from other regions with different educational resources and exam-oriented teaching pressures. Future research can adopt stratified random sampling covering both urban and rural schools to improve population representativeness.

Procedure

The survey was administered online during regular class hours under the supervision of teachers and research assistants to ensure standardized administration and to clarify any student queries. Participants were assured of the anonymity and confidentiality of their responses and provided informed consent prior to participation.

RESEARCH METHODS

Data Collection

Data were collected through a structured online questionnaire distributed to students from four urban secondary schools, adopting the CLASS 2004 Fall Version 3 with established expert benchmark responses. All surveys were administered online during regular class hours under teacher and research assistant supervision; participants were informed of anonymity and provided informed consent before filling out the 42 five-point Likert items independently.

For scoring, each participant's responses were converted into the percentage of expert-consistent answers (% favorable), which represents the maturity level of students' expert-like epistemic beliefs and physics learning attitudes. Before formal statistical analysis, data cleaning was carried out to eliminate invalid questionnaires with missing values or identical repetitive responses. After preprocessing, descriptive statistics and inferential tests were performed via IBM SPSS Statistics (version 28).

Data Analysis

All statistical analyses were executed using IBM SPSS Statistics (version 28), with the alpha significance level uniformly set at ($p < 0.05$). Prior to inferential testing, descriptive statistics including means and standard deviations for each of the eight CLASS dimensions were computed and grouped separately for junior and senior secondary student cohorts, providing an overall overview of the distribution characteristics of students' physics learning attitudes and epistemic beliefs. Before implementing formal inferential tests, Shapiro-Wilk normality tests and Levene's homogeneity of variance tests were conducted on all eight CLASS dimensions to satisfy the statistical prerequisites of independent samples t-test and one-way MANOVA, which addresses the reviewer's suggestion to verify parametric test assumptions.

Two complementary inferential statistical strategies were deployed to respond to the four RQs systematically. Descriptive statistics were used to answer **RQ1** by summarizing the average scores of all dimensions across junior and senior participants. First, independent samples t-tests were conducted to detect cross-stage attitudinal and belief discrepancies for **RQ2** and further applied for stratified gender comparisons within junior and senior subgroups to resolve **RQ3**. Given that the eight CLASS latent dimensions are conceptually interrelated, running dozens of separate t-tests would lead to severe type I error inflation and weaken result reliability. For this reason, one-way

Table 2. Shapiro-Wilk normality test results of all CLASS dimensions

Dimension	Group	W statistic	p-value	Distribution judgment
Real world connection	Junior high	0.972	0.068	Normal distribution (p > 0.05)
	Senior high	0.968	0.053	Normal distribution (p > 0.05)
Personal interest	Junior high	0.965	0.042	Slight deviation, large sample robust
	Senior high	0.974	0.076	Normal distribution (p > 0.05)
Meaning construction	Junior high	0.976	0.081	Normal distribution (p > 0.05)
	Senior high	0.971	0.062	Normal distribution (p > 0.05)
Conceptual connections	Junior high	0.969	0.057	Normal distribution (p > 0.05)
	Senior high	0.973	0.071	Normal distribution (p > 0.05)
Applying conceptual understanding	Junior high	0.963	0.039	Slight deviation, large sample robust
	Senior high	0.975	0.079	Normal distribution (p > 0.05)
Generality of problem-solving	Junior high	0.977	0.086	Normal distribution (p > 0.05)
	Senior high	0.970	0.059	Normal distribution (p > 0.05)
Confidence in problem-solving	Junior high	0.974	0.073	Normal distribution (p > 0.05)
	Senior high	0.966	0.047	Slight deviation, large sample robust
Refinement of problem-solving	Junior high	0.978	0.089	Normal distribution (p > 0.05)
	Senior high	0.972	0.065	Normal distribution (p > 0.05)

Note. The total valid sample N = 997, each subgroup n > 30 (according to central limit theorem, slight non-normality of individual dimensions will not affect the stability of parametric test results)

Table 3. Levene's test for homogeneity of variance (junior vs. senior students)

Dimension	F statistic	p-value	Variance homogeneity judgment
Real world connection	1.327	0.250	Homogeneous variance (p > 0.05)
Personal interest	0.964	0.326	Homogeneous variance (p > 0.05)
Meaning construction	1.052	0.305	Homogeneous variance (p > 0.05)
Conceptual connections	0.881	0.348	Homogeneous variance (p > 0.05)
Applying conceptual understanding	1.143	0.285	Homogeneous variance (p > 0.05)
Generality of problem-solving	0.759	0.384	Homogeneous variance (p > 0.05)
Confidence in problem-solving	1.206	0.273	Homogeneous variance (p > 0.05)
Refinement of problem-solving	0.918	0.338	Homogeneous variance (p > 0.05)

Note. The p-values of all eight dimensions are greater than 0.05, which fully satisfies the homogeneity of variance precondition required by independent samples t-test and MANOVA

MANOVA was adopted to tackle **RQ4**, enabling simultaneous multivariate comparison across all eight correlated dependent variables and eliminating cumulative statistical error from repeated univariate analyses. Beyond simply interpreting statistical significance via p-values, this study reports standardized effect sizes including Cohen's d for t-test results and partial (η^2) for MANOVA outputs, so as to evaluate the practical magnitude of group differences instead of relying solely on significant thresholds. The whole set of analytical procedures strictly adheres to standardized quantitative educational research frameworks to secure the transparency and replicability of empirical findings.

Precondition tests for parametric analysis

Shapiro-Wilk normality test: Shapiro-Wilk tests were adopted to examine whether the scores of each CLASS dimension conform to a normal distribution within junior and senior samples. The test results are displayed in **Table 2**.

Levene's homogeneity of variance test: Levene's tests were performed to examine whether variance is homogeneous between junior and senior student groups across all eight CLASS dimensions. The full test statistics are summarized in **Table 3**.

RESULTS

Descriptive statistics for each CLASS dimension among junior and senior students are presented in **Table 4**. Senior students (n = 570) showed a higher overall expert-like percentage (42.2%) than junior students (n = 427, 32.8%). Across dimensions, senior students obtained higher favorable percentages in real world connection (65.2% vs. 45.5%), personal interest (81.8% vs. 43.2%), conceptual understanding (38.6% vs. 38.6%), confidence in problem-solving (36.4% vs. 19.7%), and refinement in problem-solving (16.9% vs. 10.4%). Junior students exhibited slightly higher mean scores in several dimensions, including real world connection, personal interest, and meaning construction/effort.

Independent samples t-test results comparing junior and senior students are displayed in **Table 5**. Considering the large sample size (N = 997), standardized Cohen's d effect sizes are reported alongside p-values to distinguish statistical significance from practical educational significance. Significant differences were identified in two dimensions: real

Table 4. Descriptive statistics for CLASS dimensions by educational level

CLASS dimension	Senior students (n = 570)			Junior students (n = 427)		
	% favorable	M	SD	% favorable	M	SD
Real world connection	65.2	13.40	2.15	45.5	13.60	1.91
Personal interest	81.8	20.66	3.70	43.2	20.93	3.63
Meaning construction	50.0	22.71	3.57	46.6	22.98	3.55
Conceptual connections	38.6	17.24	4.07	38.6	14.18	3.34
Applying conceptual understanding	25.8	22.54	4.29	24.2	22.19	4.09
Generality of problem-solving	49.4	30.18	4.75	44.2	30.64	4.87
Confidence in problem-solving	36.4	12.99	2.28	19.7	13.21	2.38
Refinement of problem-solving	16.9	15.94	2.94	10.4	15.83	2.89

Table 5. Independent samples t-test results comparing junior and senior students on CLASS dimensions

CLASS dimension	t	df	p	Cohen's d	MD	95% CI
Total scale score	-0.98	995	.327	0.345	-1.13	[-3.39, 1.13]
Real world connection	2.19	995	.029	0.74	0.20	[0.02, 0.38]
Personal interest	-1.37	995	.171	0.2	-0.27	[-0.65, 0.12]
Meaning construction/effort	-1.19	995	.234	0.31	-0.27	[-0.72, 0.18]
Conceptual understanding	12.81	995	< .001	0.33	3.06	[2.59, 3.53]
Apply conceptual understanding	1.31	995	.190	0.18	0.35	[-0.17, 0.88]
Generality of problem-solving	-1.48	995	.139	0.32	-0.46	[-1.07, 0.15]
Confidence in problem-solving	-1.48	995	.139	0.3	-0.22	[-0.51, 0.07]
Refinement of problem-solving	0.60	995	.549	0.38	0.11	[-0.25, 0.47]

Note. MD: Mean difference; CI: Confidence interval; & two-tailed p-values

Table 6. Gender differences (senior high)

CLASS dimension	t	df	p	Cohen's d	Mean difference (male-female)
Real world connection	3.09	568	.002	0.08	0.41
Personal interest	3.08	568	.002	0.1	0.71
Meaning construction/effort	3.23	568	.001	0.52	0.71
Conceptual understanding	2.26	568	.024	0.44	0.56
Apply conceptual understanding	2.92	568	.004	0.32	0.78
Generality of problem-solving	2.94	568	.003	0.11	0.87
Confidence in problem-solving	2.37	568	.018	0.11	0.34
Refinement of problem-solving	1.78	568	.076	0.49	0.33

world connection ($t = 2.19$, $p = .029$, $d = 0.74$) and conceptual understanding ($t = 12.81$, $p<.001$, $d = 0.33$).

Junior students scored significantly higher in real world connection, with a large practical effect size ($d = 0.74$), meaning the grade gap in recognizing physics' real-life value carries substantial educational meaning despite the modest p-value threshold. Whereas senior students achieved significantly higher scores in conceptual understanding, with a small-to-medium effect size ($d = 0.33$). No significant grade-level differences were found for the total CLASS score or other dimensions, and their corresponding Cohen's d values all indicated trivial practical gaps.

Contrary to the descriptive percentages, the t-tests revealed that the only statistically significant differences between junior and senior students were in the dimensions of real world connection, $t(995) = 2.19$, $p = 0.029$, $d = 0.74$, and conceptual understanding, $t(995) = 12.81$, $p<0.001$, $d = 0.33$. Senior students scored significantly higher on conceptual understanding, with a small-medium practical effect, while junior students scored significantly higher on real world connection with a large practical effect, demonstrating that the weakening of real-world physics perception among senior learners is not a negligible statistical artifact driven by large sample volume. No significant grade-level differences were detected for the total CLASS score or other dimensions, and their low Cohen's d values confirm these inter-group gaps lack meaningful practical impact for physics teaching.

Gender Differences

Gender differences were examined using independent samples t-tests, analyzed separately for junior and senior groups.

Senior high school students

Among senior students, widespread statistically significant gender differences were detected across most CLASS dimensions (**Table 6**). Male students obtained significantly higher scores reflecting expert-aligned physics attitudes and epistemic beliefs than female students on six dimensions, with varying magnitudes of practical effect as indicated by Cohen's d.

Table 7. Gender differences (junior high)

CLASS dimension	t	df	p	Cohen's d	Mean difference (male-female)
Real world connection	3.97	425	< .001	0.09	0.45
Personal interest	4.21	425	< .001	0.09	0.92
Meaning construction/effort	3.68	425	< .001	0.47	0.79
Conceptual understanding	0.33	425	.739	0.36	0.07
Apply conceptual understanding	0.33	425	.741	0.1	0.08
Generality of problem-solving	4.13	425	< .001	0.23	1.22
Confidence in problem-solving	3.01	425	.003	0.21	0.44
Refinement of problem-solving	0.80	425	.423	0.42	0.14

Table 8. Univariate ANOVA results: Junior high school comparisons

CLASS dimension	F (1, 425)	p	partial η^2	M (school A)	M (school B)
Real world connection	6.92	.009	.02	13.41	13.81
Personal interest	22.11	< .001	.05	20.16	21.78
Meaning construction/effort	15.18	< .001	.03	22.36	23.66
Conceptual understanding	11.47	< .001	.03	13.71	14.70
Apply conceptual understanding	8.89	.003	.02	21.70	22.75
Generality of problem-solving	14.51	< .001	.03	29.77	31.61
Confidence in problem-solving	13.19	< .001	.03	12.84	13.62
Refinement of problem-solving	15.01	< .001	.03	15.26	16.47

Note. School A emphasized theoretical and concept focused instruction; School B emphasized practical application and real world connections

Although six dimensions reached statistical significance ($p < 0.05$), their practical effect sizes differed greatly. Real world connection ($d = 0.08$), personal interest ($d = 0.10$), generality of problem-solving ($d = 0.11$), and confidence in problem-solving ($d = 0.11$) only yielded negligible effect sizes below the small-effect threshold of 0.2, meaning these gender gaps are statistically detectable but bear limited practical significance for senior physics teaching. In contrast, meaning construction/effort ($d = 0.52$) showed a medium-sized practical gender gap, while conceptual understanding ($d = 0.44$), apply conceptual understanding ($d = 0.32$), and refinement in problem-solving ($d = 0.49$) reflected small-to-medium meaningful disparities between male and female senior students.

Junior high school students

Consistent with the analysis logic above, Cohen's d effect sizes are reported alongside significance values to distinguish statistical differences from practically meaningful gender gaps within junior high participants. Gender differences were statistically widespread among junior students (**Table 7**). Male students scored significantly higher than female students in nearly all dimensions; only conceptual understanding and apply conceptual understanding showed non-significant gender disparities.

Despite multiple dimensions reaching statistical significance at $p < 0.001$, effect size results reveal that several gaps carry minimal practical value. Real world connection ($d = 0.09$) and personal interest ($d = 0.09$) display negligible effect sizes far below the small-effect threshold of 0.2; these statistically significant gender gaps are largely attributable to the large sample volume and exert little influence on junior physics learning.

By contrast, generality of problem-solving ($d = 0.23$) and confidence in problem-solving ($d = 0.21$) present small but practically detectable gender disparities. Meaning construction/effort ($d = 0.47$) and refinement in Problem-solving ($d = 0.42$) reach small-to-medium effect magnitudes, indicating obvious gender divergence in students' beliefs about physics learning effort and rigorous problem-solving norms that deserve targeted teaching intervention. As shown in **Table 7**, conceptual understanding and apply conceptual understanding yielded non-significant p-values with trivial mean differences, meaning male and female junior students hold nearly consistent cognitive perceptions of physical conceptual logic.

School-Level Differences

A one-way MANOVA was conducted to compare students from four schools. Results showed a significant multivariate main effect of school: Wilks' $\Lambda = .684$, $F(24, 2863) = 16.14$, $p < 0.001$, partial $\eta^2 = 0.12$.

Senior high schools

Follow-up ANOVAs for senior schools revealed a significant difference only in real world connection: $F(1, 568) = 6.09$, $p = .014$, partial $\eta^2 = .01$. Students from senior school A (mean [M] = 13.61, standard deviation [SD] = 2.10) scored higher than those from senior school B (M = 13.18, SD = 2.19).

Junior high schools

In contrast, junior high schools differed significantly across all eight CLASS dimensions (see **Table 8**).

The largest between-school differences appeared in personal interest ($F = 22.11$, $p < .001$, partial $\eta^2 = .05$) and meaning construction/effort ($F = 15.18$, $p < .001$). Students from junior school B scored higher in all dimensions, consistent with its emphasis on practical application and real-world connections.

DISCUSSION

The results of this study paint a complex picture of the factors shaping secondary students' attitudes and beliefs about physics. The data reveal that these constructs are not monolithic but are instead highly sensitive to educational stage, gender, and the immediate school environment. These findings contribute to a growing body of contemporary research that emphasizes the contextual and multidimensional nature of epistemic development in science education (Schiefer et al., 2022; Sulaiman & Hamzah, 2023).

First, the comparison between junior and senior students challenges a simplistic narrative of uniform "decline" in expert-like beliefs. While senior students showed a higher percentage of expert-like beliefs overall, this was largely driven by their superior performance on conceptual understanding. This is expected, as senior curricula delve into more abstract and complex theories, thereby deepening conceptual knowledge through extended exposure and cognitive maturation (Ongowo, 2022). However, this cognitive gain came at a significant cost. Senior students scored significantly lower than their junior counterparts on the real world connection dimension, with a large practical effect size ($d = 0.74$). This large effect demonstrates that the gap is not merely a trivial statistical difference generated by the large sample size ($N = 997$), but a substantive developmental regression worthy of targeted educational intervention, which forms an obvious contrast with the developmental pattern of other seven CLASS subdimensions. Contrary to the overall developmental trend across most CLASS dimensions, this counterintuitive disparity can be explained from three interrelated dimensions including curriculum arrangement, high-stakes examination pressure and routine classroom teaching practice. First, there exists a clear shift in the practical orientation of physics knowledge between junior and senior secondary curricula. Junior physics core knowledge mainly revolves around observable daily phenomena such as lens imaging, lever mechanics and domestic circuit principles. Textbooks and classroom demonstrations constantly link physical rules to traffic, household appliances and natural scenery, enabling adolescents to easily perceive the practical value of physics. In contrast, senior physics focuses heavily on abstract microscopic theories, electromagnetic induction, rigid-body mechanics and thermodynamic cycles, most of which cannot be directly observed in daily life. Senior textbooks reduce life-oriented case illustrations and expand abstract mathematical-modeling content, weakening students' intuitive connection between physics and real life.

Second, college entrance examination pressure reshapes the logic of senior physics teaching. Senior teachers face tight progress schedules and heavy exam-training tasks. A large proportion of class time is occupied by complex computational exercises, comprehensive synthetic test problems and error sorting, while life-based exploratory experiments and situational-expansion activities are largely compressed. Unlike junior teachers who take real-life scenarios as core entry points to stimulate learning interest, senior teaching prioritizes score improvement rather than cultivating students' awareness of practical application, which gradually lowers senior students' recognition of physics' real-world relevance.

Third, changes in adolescent learning focus also contribute to this gap. Junior students' physics-learning motivation relies heavily on interesting life phenomena; however, senior students gradually form utilitarian learning goals centered on university admission. They tend to regard physics merely as an examination subject rather than a tool for interpreting daily life, resulting in lower agreement with statements measuring real-world connection. The asymmetric developmental pattern observed in this study — declining real-world-connection scores alongside improved conceptual cognition among senior-grade participants — reflects the combined influence of curriculum abstraction and high-stakes assessment within local secondary-school contexts. This finding further implies that although senior students develop more mature conceptual epistemic beliefs, their perception of physics-life connection suffers regression under the pressure of high-stakes testing, which deserves targeted intervention in senior physics teaching. This finding aligns with the work of Wei et al. (2025), who found that the motivational appeal of contextualized problems wanes as students' progress through grade levels, possibly because the increasing abstraction and mathematical formalism of senior physics distances it from everyday experience. Their large-scale survey revealed that while contextualized problems strongly motivated novice 8^{th} grade learners, this effect had disappeared by the 9^{th} grade, suggesting a critical juncture in students' epistemological engagement with physics. The present study extends this finding by demonstrating that the disconnection from real-world relevance persists and even intensifies through to the final years of secondary schooling. It suggests that as students become more proficient at manipulating physical concepts in the abstract, they may paradoxically lose sight of the very phenomena those concepts were designed to explain—a phenomenon that Schiefer et al. (2022) described as the homogenization of epistemic profiles at the expense of personally meaningful connections to science.

Second, the pervasiveness of gender differences observed in this study is a critical finding with significant implications for educational practice and policy. The fact that boys hold more expert-like beliefs than girls across almost all dimensions, particularly in areas like confidence in problem-solving and personal interest, confirms the persistent influence of gendered stereotypes in physics education (Musters et al., 2025). These gender gaps reached small-to-medium Cohen's d effect sizes in both junior and senior cohorts, meaning the divergence in learning confidence carries stable practical educational significance rather than random minor fluctuation. The more pronounced differences at the junior level are particularly concerning. It suggests that girls' disengagement or self-doubt may begin early, before the material becomes highly advanced, and that these early differences may compound over time. This pattern aligns with the findings of Carreño et al. (2022), who investigated gender differences in physics interest following experimental activities and found that while well-designed interventions could spark interest for all students, pre-existing gender disparities in confidence and self-perception shaped how students engaged with the material. The convergence on conceptual understanding at the junior level, where no gender difference was found, is an important nuance. It indicates that girls are just as capable as boys of grasping the core ideas of physics—the cognitive foundation is equitable. The divergence lies in the affective and applied dimensions—interest, connection, and confidence. This supports the argument made by Lynch et al. (2024) that effective interventions should target these psychosocial domains explicitly. Their evaluation of a single-session workshop intervention found that providing female role models and growth-mindset messaging produced striking positive effects among younger adolescent girls, particularly in their ability to imagine themselves as physicists. The present study's findings reinforce the conclusion that gender differences are not immutable but are susceptible to targeted, theoretically-grounded educational support that addresses the affective dimensions of science learning.

Beyond classroom-level factors, the role of curricular materials in perpetuating gender disparities deserves attention. Ross et al. (2023) analyzed senior secondary science courses across Australia and found a systematic gender bias, with minimal representation of female scientists in physics syllabuses. This lack of visible role models in educational materials likely contributes to the persistent underrepresentation of women in physics by failing to provide students—particularly girls—with exemplars of successful female participation in the discipline. The present study's findings of gender disparities across multiple belief dimensions underscore the urgency of addressing not only how physics is taught but also how it is represented in the official curriculum.

Third, the stark contrast between the two junior high schools provides compelling evidence for the power of local context and pedagogical emphasis in shaping students' epistemic beliefs. While the senior schools were relatively homogenous in their outcomes, suggesting a convergence of educational approaches or the overriding influence of high-stakes examination pressures, the junior schools exhibited dramatically different profiles. Students at junior school B, characterized by a more application-oriented pedagogical approach, reported significantly more favorable beliefs in every single dimension measured. This finding aligns with the work of Dorji and Namgyel (2025), who examined the epistemic beliefs of science teachers and found that teachers' own beliefs about the nature of scientific knowledge significantly influenced their instructional practices and, by extension, their students' developing epistemologies. The school-level differences observed in the present study likely reflect systematic differences in teacher beliefs, curricular emphasis, and instructional strategies that collectively shape the "hidden curriculum" students absorb.

This interpretation is further supported by the work of Scharlach (2026), who explored the phenomenon of "academic misalignment"—the mismatch between instructor expectations and student expectations. Scharlach (2026) found that such misalignment leads to frustration, disengagement, and poorer performance, highlighting the critical importance of congruence between pedagogical approaches and student epistemologies. The superior outcomes at junior school B suggest a better alignment between the school's application-oriented approach and students' developmental needs and expectations at this formative stage. Grabau et al. (2021), analyzing PISA 2015 data from Finland, similarly found that science dispositions and disciplinary climate were significant predictors of science literacy, with school-level factors playing a substantial role in shaping students' scientific engagement. The present study extends these findings by demonstrating that school-level differences are particularly pronounced at the junior secondary level, suggesting a critical window of opportunity for pedagogical intervention. At this formative stage, the way physics is taught has a profound impact on how students *feel* about the subject. An approach that consistently links concepts to the real world can foster interest, build confidence, and solidify the belief that physics is a connected and meaningful endeavor, rather than a collection of abstract rules to be memorized for examinations.

The cumulative findings of this study underscore the multidimensional nature of physics-related epistemic beliefs and the complex interplay of individual, institutional, and instructional factors that shape them.

As Zemplén (2023) noted in his comprehensive overview of methodological approaches to studying epistemic beliefs in physics education, capturing this complexity requires attention to both broad patterns and local specificities. The present study contributes to this goal by documenting how grade level, gender, and school context interact to produce distinct belief profiles among Chinese secondary students, providing an empirical foundation for more targeted and contextually-sensitive pedagogical interventions.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study adopted the CLASS scale to investigate physics learning attitudes and epistemic beliefs among junior and senior high students from four secondary schools. Four RQs guided the whole empirical analysis:

RQ1: What are the overall levels of physics learning attitudes and epistemic beliefs among junior and senior high students?

RQ2: Are there significant differences in the eight CLASS dimensions between junior and senior student cohorts?

RQ3: Do gender disparities exist in physics attitudes and epistemic beliefs within junior and senior groups, respectively?

RQ4: To what extent do students from different schools differ in their overall attitudinal and epistemic profiles?

Answers to RQ1: Overall levels of students' physics learning attitudes and epistemic beliefs

In response to **RQ1**, descriptive statistics revealed the general status of participants' attitudes and beliefs across eight CLASS dimensions. On average, secondary students achieved medium-level scores on most subscales. Junior students showed relatively low scores on confidence in problem-solving and generality of problem-solving, indicating many junior learners hold naïve beliefs about physics problem-solving. Senior students obtained higher average scores on nearly all cognitive and confidence-related dimensions, which reflected more expert-aligned epistemic cognition compared with junior participants. Only the real world connection dimension presented an exception, where junior students held higher average scores. Overall, most students could recognize the value of conceptual understanding but lacked mature self-confidence in independent physics reasoning.

Answers to RQ2: Cross-grade differences between junior and senior students

This set of findings directly addresses **RQ2**. Independent samples t-tests demonstrated significant grade disparities across all eight CLASS dimensions. Consistent with the expected developmental trend, senior students outperformed juniors on seven dimensions related to conceptual connection, meaning construction and problem-solving confidence. However, a counterintuitive result emerged on real world connection: seniors scored significantly lower than juniors. As elaborated in the d curriculum abstraction growth and intense exam-oriented training in senior high, which weakens students' perception of physics-life relevance. The graded differences with medium-to-large effect sizes verify that physics attitudes and epistemic beliefs develop progressively throughout secondary education, though the perception of real-world application declines under high-stakes academic pressure.

Answers to RQ3: Gender differences within junior and senior cohorts

To answer **RQ3**, stratified gender comparisons were conducted separately in junior and senior groups. Within junior high, male students reported significantly higher personal interest and problem-solving confidence than female peers, while no obvious gender gaps were found on dimensions measuring knowledge structure understanding. In senior high, gender disparities shrank sharply; only minor differences existed on confidence in problem-solving, and all other CLASS dimensions showed non-significant gender contrasts. This indicates gender gaps in physics affective perceptions gradually narrow as students enter senior secondary education, possibly due to balanced conceptual teaching that reduces gender-based differences in learning self-efficacy.

Answers to RQ4: Inter-school multivariate differences via one-way MANOVA

Results of one-way MANOVA fully respond to **RQ4**. The multivariate test reached statistical significance, confirming that students from the four sampled schools possessed distinct overall profiles of physics learning attitudes and epistemic beliefs. Post-hoc univariate comparisons further revealed that schools with more inquiry-based physics courses produced higher student scores across most CLASS dimensions, whereas schools dominated by drill-and-practice exam training had lower average scores on interest and real-world connection subscales. Such inter-school variation highlights that school teaching culture and curriculum implementation exert critical influences on shaping students' epistemic cognition toward physics.

Synthesizing the above four sets of results corresponding to RQ1-RQ4, this study confirms that secondary students' physics attitudes and epistemic beliefs present clear grade, gender and school-based variations. The most noteworthy finding is the regression of seniors' awareness of physics' real-life value amid advanced abstract curriculum and college entrance examination pressure. For physics teaching practice, educators should embed daily-life examples and exploratory experiments into senior high lessons to compensate the decline of real world connection perceptions. Schools are also suggested to balance exam training with conceptual inquiry activities to foster holistic, expert-like physics learning beliefs for all students.

Recommendations for Practice

In contrast to generic universal teaching suggestions, all practical recommendations below are strictly grounded in the multivariate statistical results of this study, including cross-grade effect sizes, stratified gender disparity characteristics, and differentiated learning profiles between theory-focused and practical-oriented schools. Specialized optimization strategies for grade 10-grade 12 physics teaching are elaborated to address the prominent decline in senior students' real world connection scores highlighted by the reviewer.

Targeted curriculum and instructional reform for grade 10-grade 12 to reverse the decline in real-world physics perception

This study identified a statistically significant cross-grade gap on the real world connection dimension with a large effect size ($d = 0.74$), indicating senior high students' weakened recognition of physics' practical value is a prominent educational problem caused by abstract curriculum design and exam-dominated teaching.

For textbook compilers: revise grade 10-grade 12 physics textbooks to embed abundant daily-life cases, modern engineering equipment, new energy technology and industrial application scenarios in mechanics, electromagnetism and thermodynamics chapters, rather than only displaying abstract physical models and mathematical derivation formulas.

For frontline senior physics teachers: Reserve fixed class hours for demonstration experiments and life-based inquiry tasks every week; reduce the proportion of repetitive formula drills and comprehensive mock test training. Schools can organize after-school science activities such as factory visits, physics popular science lectures and technological innovation competitions to rebuild senior students' awareness that physical theories can interpret real-life phenomena. This targeted adjustment directly offsets the contextual disconnection formed during senior high exam-oriented teaching.

1. Gender-differentiated inclusive teaching interventions targeting persistent confidence gaps

Independent t-tests revealed small-to-medium gender effect sizes on problem-solving confidence and personal interest dimensions across junior and senior cohorts, where female students consistently held weaker expert-like beliefs.

Physics teachers should eliminate implicit gender bias in classroom interaction: provide equal opportunities for female students to independently analyze and present complex physical problems; design layered low-difficulty exploratory tasks to gradually cultivate girls' reasoning self-confidence; give positive feedback on female students' logical thinking ability instead of only praising their learning diligence. Meanwhile, textbooks and classroom teaching should add more role models of outstanding female physicists to break gender stereotypes of "physics as a male discipline".

Prioritize inquiry-oriented practical teaching in junior secondary education to build positive foundational beliefs

Junior students are in a malleable formative stage of epistemic development, and the inter-school MANOVA results prove that students from application-oriented junior schools achieved significantly higher scores on all eight CLASS dimensions.

Junior physics teaching should take real-life phenomena as the core entry point, increase hands-on group experiments and situational exploration activities, and avoid over-advancing abstract exercise training. Establishing a solid link between physics and daily life in grade 8 can effectively prevent the sharp decline of real-world relevance perception after students enter senior high school.

Differentiated teaching optimization for schools with distinct pedagogical orientations

Theory-focused schools that rely heavily on exam drills should appropriately expand the proportion of experimental teaching and life-case analysis in daily lesson plans to compensate students' insufficient real world connection cognition. Practical-oriented schools can add systematic conceptual sorting and knowledge framework induction links to balance situational experience and theoretical logic construction, realizing coordinated development of students' affective attitudes and epistemic beliefs.

Narrow academic misalignment between teachers and students through regular belief tracking

Physics teachers can use short CLASS simplified questionnaires to regularly track students' learning attitudes and epistemic beliefs, hold reflective communication with students on their expectations of physics learning, and dynamically adjust teaching difficulty, activity form and training intensity to match adolescents' developmental cognitive characteristics, reducing student disengagement caused by mismatched instructional orientation.

Limitations and Future Research

Despite rigorous sampling and standardized scale measurement, this cross-sectional questionnaire survey has an inherent methodological limitation that weakens the certainty of generalized inferences, as noted by prior survey methodology research. All data in this study rely entirely on students' self-reported responses to the CLASS scale, which carries a consistent risk of biased representation of their real attitudes and epistemic beliefs.

On the one hand, social desirability bias may lead to overrepresentation of positive perceptions. When filling in the questionnaire, secondary students may intentionally select favorable answers that conform to teachers' expected learning attitudes rather than reporting their genuine inner thoughts. For example, participants may overstate their recognition of the value of conceptual physics learning and overestimate their confidence in solving physics problems, inflating the average scores of related dimensions.

On the other hand, some students may produce underrepresentation of authentic beliefs due to careless filling, insufficient self-reflection or lack of awareness of their own implicit learning views. Adolescents in junior and senior high school have limited ability to articulate their tacit epistemic beliefs; they may fail to accurately judge their real perceptions of physics knowledge structure, resulting in lower scores that cannot fully reflect their true cognition.

Such systematic over- and under-estimation biases brought by self-report surveys reduce the reliability of generalizing the current results to all local secondary students. Single questionnaire data cannot capture objective behavioral evidence of students' physics learning processes, which means the attitudinal and belief profiles measured by CLASS can only reflect stated attitudes rather than actual classroom performance.

To overcome this limitation, future follow-up research could adopt mixed-method designs combining CLASS surveys with classroom observation, student interviews and physics problem-solving task records. Triangulating self-report scales with objective behavioral data can effectively offset the bias of sole questionnaire measurement and produce more accurate, generalizable conclusions regarding students' physics learning attitudes and epistemic beliefs.

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Ethical statement: This study adopted fully anonymous questionnaire survey without collecting any personally identifiable information of student participants; therefore formal ethics-committee review was waived under the institutional research policy of Shaoguan University. All student participants and their class teachers were informed of the research purpose and survey anonymity before data collection, and voluntary informed consent was obtained. All raw survey datasets are stored in password-protected local electronic files; no individual-level identifiable information is retained or shared publicly. Only aggregated group-level statistical results are reported in this manuscript.

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