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ARTICLE

Profiles of chemistry identity among Chinese high school students: antecedents and outcomes

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Chemistry identity is closely associated with students' engagement in chemistry learning, academic performance, and chemistry-related career development. However, chemistry identity is not a unitary construct; rather, it comprises multiple dimensions, including interest, competence, performance, and recognition, and students may exhibit different configurations of these identity dimensions. To examine heterogeneity in high school students' chemistry identity patterns, this study investigated 1,431 high school students and employed factor mixture modeling, grounded in the four-dimensional framework of science identity, to identify latent profiles of chemistry identity. In addition, the one-step approach and the BCH method were used to examine the relationships of antecedent and outcome variables with profile membership. The FMM results suggested three probabilistic profile patterns of chemistry identity: the academic competence-career alienation profile (37.6%), the robust identity profile (51.0%), and the interest-career driven profile (11.4%). These profiles should be interpreted as latent response patterns reflecting both overall level differences in chemistry identity and dimension-specific tendencies, rather than as sharply discrete student categories. Gender, perceived teacher support, and chemistry self-efficacy significantly predicted profile membership. Specifically, higher levels of teacher support were associated with a greater likelihood of membership in more adaptive chemistry identity profile patterns, whereas higher chemistry self-efficacy was more likely to predict membership in positive profiles such as the interest-career driven profile. In contrast, grade level, parental occupation, and class leadership role did not significantly predict profile membership. Further analyses revealed significant differences among the three profiles in chemistry academic achievement and chemistry university aspirations, with the interest-career driven profile showing the highest levels, followed by the robust identity profile, and the academic competence-career alienation profile showing the lowest levels. These findings indicate substantial heterogeneity in high school students' chemistry identity and highlight perceived teacher support and chemistry self-efficacy as important variables associated with more adaptive chemistry identity profiles.

Introduction

In the *PISA 2025 Science Framework*, the affective factors influencing competencies were broadened from the concept of scientific attitudes in earlier frameworks to the more comprehensive construct of science identity (OECD, 2023). In China, the Ministry of Education issued the *Opinions on Strengthening Science Education in Primary and Secondary Schools in the New Era*, which states that efforts should be made to "comprehensively improve students' scientific literacy, cultivate adolescents with the potential to become scientists and the willingness to devote themselves to scientific research, plant the seeds of science in children's minds, and guide them to dream of becoming scientists" (Ministry of Education of the People's Republic of China, 2023). Although this policy statement does not explicitly use the academic term *science identity*, its emphasis on emotional identification with science, career aspirations, and value commitment is highly consistent

with the core connotations of science identity. The introduction of science identity provides a new perspective for fostering scientific literacy and highlights the practical and long-term significance of cultivating students' science identity.

Identity has a strong influence on how students interact, participate, perform, and learn (Lave and Wenger, 1991; Bishop, 2012). Previous research has also shown that science identity significantly associated with students' science-related career aspirations (Carlone, 2017). However, primary and secondary science education has traditionally emphasized students' understanding of scientific knowledge and the nature of science, while students' science identity and related aspirations have received comparatively less attention. Given that science identity is considered a key factor in enabling students to think, make decisions, and act like scientists, it deserves greater consideration in science education (Li, 2025). Among Chinese high school students, science learning is organized around relatively independent school subjects, such as physics, chemistry, biology, and geography. Therefore, students' science identity may be better understood by examining how they identify with specific science subjects. In this context, chemistry identity can be regarded as an important subject-specific form of science identity. Empirical studies have shown that levels of

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science identity vary across subjects (Vincent-Ruz and Schunn, 2018; Chen and Wei, 2022). In the Chinese educational context, however, limited attention has been paid to the heterogeneity of high school students' chemistry identity. In particular, existing research has yet to fully reveal the differential combinations and latent patterns of students' multidimensional chemistry identity. Therefore, it is necessary to examine the current status of high school students' science identity from the perspective of chemistry as a school subject. Such an effort is important for helping educators better understand students' motivation for learning chemistry and their future career intentions (Pfeifer et al., 2024).

Science Identity Theory

Current research on science identity is mainly grounded in two influential models. First, Carlone and Johnson proposed a three-dimensional model of science identity consisting of competence, performance, and recognition (Carlone and Johnson, 2007). Within this framework, individuals are considered to possess a strong science identity when they demonstrate scientific competence, perform effectively in scientific activities, and receive recognition from both others and themselves as being capable in science. Subsequently, Hazari et al. extended and revised this framework through large-scale quantitative research on physics identity using data from the PRISE project. They argued that, for high school students and early undergraduate students, science identity is still in the process of development and has not yet fully stabilized. In this context, interest—defined as an individual's willingness to learn about and engage in science—serves as an important driving force in identity development (Hazari et al., 2010). Accordingly, the framework was expanded into a four-dimensional model of science identity, including interest, competence, performance, and recognition. Building on this four-dimensional identity framework, recent chemistry education research has further clarified how science identity perspectives can be operationalized in chemistry-specific contexts. Hosbein and Barbera argued that identity measures in chemistry education should be theoretically grounded and used the physics identity framework, including performance/competence, recognition, and interest, as the starting point for defining science and chemistry identity (Barbera, 2020). Their qualitative study showed that students' perceptions of science and chemistry identity could be aligned with broader affective and social-cognitive constructs, including mastery experiences, verbal persuasion, vicarious experiences, situational interest, and mindset. This work is particularly relevant to the present study because it provides a theoretical bridge between the components of chemistry identity and students' beliefs about their chemistry-related competence, the recognition they receive from others, and the interest they develop in chemistry learning.

In a subsequent study, Hosbein and Barbera (Hosbein and Barbera, 2020) developed and evaluated novel science and chemistry identity measures in university-level chemistry courses. Their work provided validity and reliability evidence for the Measure of Chemistry Identity (MoChI) and further

examined the relations among mastery experiences, verbal persuasion, situational interest, and science of chemistry identity. Although MoChI was developed in university-level chemistry contexts, this work is important for the present study because it clarifies how chemistry identity can be measured as a theoretically grounded, multidimensional construct. Importantly, their findings suggested that mastery experiences alone were not directly related to chemistry identity; rather, the more theoretically supported model indicated an indirect relation through verbal persuasion and situational interest. These findings suggest that chemistry identity is shaped not only by students' successful performance in chemistry, but also by interest-supporting experiences and recognition-related feedback. In the context of the present study, perceived teacher support can be understood as an important source of recognition-related feedback and verbal persuasion, whereas chemistry self-efficacy reflects students' competence-related beliefs about their ability to succeed in chemistry learning. Therefore, examining perceived teacher support and chemistry self-efficacy together with multidimensional chemistry identity profiles is theoretically warranted.

These chemistry-specific findings are consistent with the broader view that identity is not formed statically; rather, it is gradually constructed through continuous interactions with others and the surrounding environment, which gives it a distinctly social character. Accordingly, experiences in science education contexts, such as interactions with peers, teachers, and instructional materials, shape individuals' understandings of themselves. It is therefore necessary to pay attention to scientific participation and its relationship with science identity development in order to help students develop positive science identities (Kim and Sinatra, 2018). Compared with the three-dimensional model, the four-dimensional framework is particularly relevant for studying adolescent students because it incorporates interest as a key component of identity development, which is important for understanding young students' science-related self-perceptions and future choices (Hazari et al., 2010). Therefore, the present study adopts the four-dimensional science identity framework as its theoretical foundation to examine the characteristics of chemistry identity among Chinese high school students.

From a broader perspective, identity is a complex and multidimensional construct that refers to the way individuals develop multiple identities across different social contexts and integrate them into an overall understanding of the central question, "Who am I?" (Vincent-Ruz and Schunn, 2021). In general, identity can be divided into three levels: personal identity, social identity, and science identity (Hazari et al., 2010). Among these, Aschbacher et al. defined science identity as students' perceptions of who they are, what they believe they are capable of doing, and what kind of person they hope to become (Aschbacher et al., 2010).

Developmental Pathways of Science Identity

Previous studies have shown that the development of science identity is influenced by multiple factors. Weibing et al. summarized three major characteristics of science identity and



pointed out, first, that students' science identity is jointly shaped by external social structures and the development of the individual self (Wenger, 1998; Zhao et al., 2024). On this basis, related research has further identified three key pathways through which students' science identity develops (Vincent-Ruz and Schunn, 2018; Jiang and Wei, 2025): a sense of belonging and connectedness to the community, the alignment of internal and external attitudinal factors, and the degree of correspondence between school science and authentic science.

The first pathway, belonging and connectedness, emphasizes whether students experience acceptance and recognition during science learning. It focuses on how interactions with and support from significant others, such as teachers, peers, and parents, influence the formation of science identity. This pathway reflects a social constructionist perspective, according to which science identity originates not only from individuals' self-perceptions but is also shaped by others' recognition and broader social contexts (Moon et al., 2025). The second pathway posits that science identity is shaped by relatively stable attitudinal factors, encompassing both intrinsic and extrinsic aspects (Aschbacher et al., 2010). From this perspective, students' science interest, perceived value of science, and self-efficacy or competence beliefs are regarded as important factors closely associated with science identity development (Maltese and Tai, 2010; Oettingen and Gollwitzer, 2015). However, there remains some debate in the current literature as to whether these attitudinal variables are antecedents of science identity or constituent components thereof (Trujillo and Tanner, 2014). The third pathway, the correspondence between school science and authentic science, highlights the situated and dynamic nature of science identity. It concerns whether classroom instruction can provide learning experiences that approximate authentic scientific practice. For example, students may construct their chemistry identity when they are given opportunities to think and inquire like chemists in classroom settings that simulate authentic scientific contexts (Carlone and Johnson, 2007; Archer et al., 2010; Aschbacher et al., 2010).

Taken together, students' science identity should not be understood as the product of a single factor. Rather, it is gradually constructed and developed through lived experiences and social interactions within families, schools, and broader social contexts (Aschbacher et al., 2010). Based on this theoretical framework, it is necessary to situate the formation of science identity within specific disciplinary contexts and to further examine how it is manifested in chemistry learning, as well as how it relates to learning outcomes and career development.

Variables Related to Chemistry Identity

Existing research has shown that chemistry identity is closely related not only to students' perceptions of their roles within the discipline, but also to their academic performance and future developmental trajectories. Specifically, students with higher levels of chemistry identity tend to demonstrate better chemistry achievement (Ardura and Pérez-Bitrián, 2018) and are

more likely to pursue chemistry-related majors or career pathways in the future (Stets et al., 2017). These findings suggest that chemistry identity plays an important mediating and integrative role between individuals' motivational systems and their career decision-making.

Building further on the three developmental pathways of science identity discussed above, the variables examined in this study can be situated within specific theoretical dimensions. Perceived teacher support and parental occupation reflect influences at the levels of belonging and social structure, capturing how the support and resources students obtain in family and school contexts may shape their identity development. Research has shown that perceived teacher support is an important factor associated with students' chemistry learning and enhancing their chemistry academic performance (Shin and Chang, 2022; Ryan and Deci, 2023; Liu et al., 2025). From the perspective of self-determination theory, teacher support can satisfy students' basic psychological needs for competence, autonomy, and relatedness, thereby enhancing their learning motivation and learning efficiency (Ryan and Deci, 2017). Positive teacher–student interactions, especially those that are responsive to students' needs, are linked to more positive chemistry learning experiences (Gan and Peng, 2024). Studies have further shown that such support is associated with students' learning motivation, cognitive processes, learning behaviors, and emotional experiences, and is also linked to deeper and more active engagement in chemistry learning through stronger emotional investment and more positive learning attitudes (Li et al., 2021; J. Chen et al., 2023). Ultimately, these supportive experiences may contribute to higher chemistry achievement and help students develop a stronger chemistry identity.

In addition, chemistry self-efficacy corresponds to the pathway concerning the alignment of internal and external attitudinal factors, reflecting how students' cognitive evaluations of their own chemistry-related capabilities may be linked to the internalization and stabilization of identity. Chemistry self-efficacy generally refers to students' confidence in their ability to successfully complete chemistry tasks, master chemistry skills, and meet the demands of chemistry coursework (Chang, 2015). Previous studies have shown that self-efficacy influences students' engagement, effort, and performance, as well as their course selection and future career choices (Bandura, 1986; Lau and Roeser, 2002; Taasobshirazi and Glynn, 2009; Ramnarain and Ramaila, 2018). Students with high self-efficacy are more likely to complete tasks seriously, persist for longer periods, and invest greater effort, whereas those with low self-efficacy are more likely to respond superficially and give up easily. Research has also indicated that stronger self-efficacy is linked to stronger science identity (Flowers III and Banda, 2016; Cwik and Singh, 2022).

The present study

Against the background of the new college entrance examination reform in Henan Province, the province has adopted the "3+1+2" subject-selection model for the National College Entrance Examination. Under this model, Chinese,

mathematics, and a foreign language are compulsory national examination subjects; students select one subject from physics and history, and two subjects from ideological and political education, geography, chemistry, and biology. (Henan Provincial Department of Education, 2022) Because most high schools in China do not offer an integrated science curriculum as an independent subject, students are instead required to select several relatively independent disciplines according to their personal interests and developmental plans. As a result, students' science learning experiences during high school vary considerably. Differences in the types and combinations of subjects that students study may lead to substantial differences in their science learning experiences and disciplinary participation pathways. In this context, Chinese students' levels of identity across different science subjects may not be consistent (Vincent-Ruz and Schunn, 2021), which may also create difficulties in their interpretation of and response to items intended to measure a "general science identity" (Chen and Wei, 2022). Therefore, it is necessary to distinguish among subject-specific identities and examine them from the perspective of specific disciplines. Previous studies have shown that disciplinary identity is highly domain-specific. For example, some students may develop a strong identity in chemistry while displaying a relatively weak identity in language-related subjects (Hazari *et al.*, 2020; Guo *et al.*, 2022). On this basis, the present study focuses on chemistry as a specific disciplinary context and examines the current status of chemistry identity among Chinese high school students.

At the same time, chemistry identity is inherently multidimensional, with different dimensions jointly shaping whether students see themselves as "chemistry people" (Hazari *et al.*, 2010). This multidimensional structure implies that students may vary across dimensions and, in turn, exhibit different configurations of identity characteristics. For example, some students may show relatively strong performance in understanding chemical knowledge and engaging in chemistry-related practices, while remaining weak in self-recognition or recognition by others, resulting in an overall lower level of chemistry identity (Guo *et al.*, 2022). This suggests that relying solely on variable-centered analyses of average effects may obscure the heterogeneity in how identity dimensions combine within the population (Ferguson *et al.*, 2020). Moreover, person-centered approaches are particularly suitable for exploring the development and cultivation of identity (e.g., science identity), as they can identify multiple meaningful latent groups within a sample, where individuals within these groups exhibit a high degree of similarity in their characteristic patterns. (Jung and Wickrama, 2008; Lockhart and Rambo-Hernandez, 2024). Previous person-centered studies have classified science identity among rural high school students and identified an optimal four-profile solution reflecting four traditional identity statuses: achievement, foreclosure, moratorium, and diffusion (Lockhart *et al.*, 2024). Because identity is also shaped by cultural background, researchers in the Chinese context have used cluster analysis to examine the group characteristics of secondary school students' science identity under a four-dimensional framework including scientific learning

competence, interest and performance in science courses, and science career interest, and identified four groups: compliant identity, potential identity, committed identity, and balanced identity (Wang and Yao, 2021).

However, research on the group characteristics of chemistry identity among Chinese high school students remains limited. To address this gap, the present study employs factor mixture modeling from a person-centered perspective to identify latent subgroups of chemistry identity and, on this basis, to identify latent subgroups of chemistry identity and, on this basis, to provide more targeted implications for differentiated instruction.

H1: High school students exhibit distinct latent profiles of chemistry identity across chemistry learning competence, chemistry classroom interest and performance, chemistry career interest, and chemistry recognition.

H2: Perceived teacher support and chemistry self-efficacy are significantly associated with students' chemistry identity profile membership.

H3: Gender, grade level, parental occupation, and class leadership role are significantly associated with students' chemistry identity profile membership.

H4: Chemistry identity profiles differ significantly in chemistry academic achievement and chemistry university aspirations.

Methods

Participants

At the school level, this study used a convenience sampling strategy. Four senior high schools in one city were invited to participate. To ensure that the sample covered students with different levels of prior academic achievement, the participating schools were selected across the local admission-score batches of general senior high schools. In this city, general senior high schools are grouped, from higher to lower admission selectivity, into first-, second-, and third-batch schools according to the cut-off scores used in senior high school admission. The number of questionnaires distributed across the different admission-score batches was kept approximately comparable so as to include students from different academic achievement ranges. Within each participating school, intact classes were randomly selected as the sampling units. The survey was administered only to Grade 10 and Grade 11 students, as Grade 12 students were preparing for the National College Entrance Examination and had a heavy academic workload. The on-site administration and collection of the questionnaires lasted one week, during which a total of 2,028 paper questionnaires were distributed. After collection, all paper questionnaires were manually entered into an Excel database by the research team. Prior to formal data analysis, the questionnaires were screened according to predefined exclusion criteria to identify invalid responses. Specifically, a questionnaire was considered invalid and excluded if it met any of the following criteria: first, more than one-third of the items were missing; second, the response pattern contained 12 or



more consecutive identical answers. Because the main scale used in this study contained 23 items, and because the long-string index criterion suggests that a string of identical responses exceeding half of the total scale length may indicate careless responding (Huang *et al.*, 2012; Curran, 2016), a cut-off value of 12 was adopted in the present study. Third, questionnaires were also excluded if they showed clearly invalid or uninterpretable response patterns, such as repeatedly selecting the same response option across conceptually unrelated items or providing obviously random or meaningless responses (Sjöström *et al.*, 1999). An Excel macro was written to implement these screening rules and identify invalid responses. After data cleaning, 1,431 valid questionnaires were retained for analysis, including 697 boys and 734 girls, yielding a valid response rate of 70.56%.

Survey administration

This study was conducted in January 2026 across four schools, and the distribution, collection, and data entry of the paper questionnaires were completed over a two-week period. Ethical approval for the study was obtained from the Academic Ethics Committee of Henan Normal University and other relevant institutions, and informed consent was obtained from the parents or legal guardians of all student participants. Prior to the formal administration of the questionnaire survey, the research team explained to all participants the purpose of the study and the intended use of the collected data. All personal information was kept confidential in strict accordance with relevant national and provincial laws and regulations. Participation was entirely voluntary, and no additional compensation was provided to the students.

Instruments

The self-report instruments used in this study were adapted from previously validated questionnaires or published measures. Because the survey was administered to Chinese high school students, the research team first translated the relevant English items into Chinese and, where necessary, adapted the wording to the high school chemistry context. For example, when a construct was measured in the chemistry domain, disciplinary terms such as “science” were replaced with “chemistry.” Cognitive interviews were then conducted to

examine whether students understood the translated and context-adapted items as intended. In this study, Tourangeau’s four-stage cognitive interviewing method was employed (Tourangeau, 1984; Deng *et al.*, 2021). The purpose of the cognitive interviews was not to redevelop the constructs, but to identify potential problems in students’ comprehension of item wording, disciplinary context, response options, and distinctions between similar items after translation and adaptation. High school students were asked to think aloud while responding to the questionnaire items, so that potential sources of bias in the four cognitive stages of comprehension, information retrieval, judgment, and response could be directly identified.

In the first round of cognitive interviews, two items from the chemistry self-efficacy questionnaire—“I am confident that I can do well on chemistry tests” and “I believe I can earn a grade of A in chemistry”—were perceived by most students as having essentially the same meaning. In addition, students expressed uncertainty about how to interpret the grade “A.” In the source item used for translation, the first statement explicitly referred to students’ confidence in doing well on chemistry tests. Therefore, in the present adaptation, we treated it as reflecting students’ self-perceived capability in a test-related chemistry context. By contrast, the fourth item was designed to reflect an objective standard of performance and thus represented an externally referenced evaluation. Based on the interview findings, the first item was revised to: “I am confident that I can perform well on chemistry tests and achieve results that satisfy me.” The fourth item was revised to: “I believe that I can achieve excellent results or rank among the top students in chemistry tests.” In addition, for the fifth item, originally phrased as “I am certain that I can understand chemistry,” students felt that the term “chemistry” alone was too vague and did not refer to specific content or school level. Accordingly, this item was revised to: “I am certain that I can master the knowledge and skills required in high school chemistry courses.” To enhance transparency and replicability, the full list of self-report questionnaire items used in this study, including the Chinese wording administered to students and the corresponding English translations, is provided in Table S3 in the Supporting Information.

Table 1 Examples of cognitive-interview-based revisions to chemistry self-efficacy items in Chinese and English

	Item1	Item2
Original Text	我有自信我能在化学考试中取得好成绩	我相信我能在化学课程中取得“A”
Translation(in English)	I am confident I will do well on chemistry tests	I believe I can earn a grade of 'A' in chemistry
Revised Text	我有信心在化学考试中发挥出色，取得令自己满意的成绩	我相信我能在化学考试中取得优异的成绩（或名列前茅）
Translation(in English)	I am confident that I can perform well on chemistry tests and achieve results that satisfy me.	I believe that I can achieve excellent results or rank among the top students in chemistry tests.

Chemistry Identity. Drawing on Hazari *et al.*'s four-dimensional framework of science identity, Chinese scholars Sitong Chen and Bing Wei (Chen and Wei, 2022) developed a science identity questionnaire in the Chinese educational context. The questionnaire was designed to measure science identity among junior and senior high school students and has demonstrated good structural validity.

It consists of 23 items and includes four subscales: scientific learning competence (8 items), interest and performance in science courses (7 items), science career interest (4 items), and science recognition (4 items). Although Chen and Wei's science identity questionnaire was developed in the Chinese educational context, the published article provided the item wording in English; therefore, the present



study used the published English wording as the source text for translation and chemistry-domain adaptation. In the adapted chemistry identity scale, the four dimensions were referred to as chemistry learning competence, chemistry classroom interest and performance, chemistry career interest, and chemistry recognition. All items are rated on a five-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). For the purposes of the present study, the questionnaire was adapted to measure chemistry identity by replacing the word “science” with “chemistry” in each item, while keeping all other wording unchanged. For example, the item “I think I perform well in science class” was adapted as “I think I perform well in chemistry class.” This adapted version was used to assess students’ chemistry identity.

Perceived Teacher Support. Perceived teacher support was measured using the Teacher as Social Context (TaSC) questionnaire originally developed by Belmont et al. and later adapted by Qian Huangfu (Huangfu et al., 2023). This questionnaire is a widely used instrument for assessing students’ perceived teacher support and contains five items rated on a five-point scale. The adapted version takes into account the characteristics of Chinese teachers’ support and care for students and includes two subdimensions: instrumental support and emotional support. Instrumental support consists of three items, such as “My chemistry teacher actively cares about my learning and provides guidance,” whereas emotional support consists of two items, such as “When I encounter difficulties or setbacks, my chemistry teacher encourages me.” Students rate each item on a scale from 1 (“strongly disagree”) to 5 (“strongly agree”), with higher scores indicating greater perceived teacher support in both learning and daily life.

Chemistry Self-Efficacy. Chemistry self-efficacy was measured using the Self-efficacy subscale of the Chinese Chemistry Motivation Questionnaire II (CCMQII) (Zhang and Zhou, 2022). The CCMQII was developed and validated in the context of Chinese high school chemistry education and has demonstrated good psychometric properties, including acceptable construct validity, internal consistency, and factorial invariance. The self-efficacy subscale consists of five items assessing students’ confidence in their ability to understand chemistry, master chemistry knowledge and skills, and perform well on chemistry tests, laboratory work, and projects. All items were rated on a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Higher scores indicate stronger confidence in one’s ability to successfully engage in chemistry learning and achieve good performance, whereas lower scores indicate weaker confidence in one’s chemistry learning ability.

Chemistry Academic Achievement. Chemistry academic achievement was assessed using students’ chemistry midterm examination scores from the 2025 fall semester. The participating schools took part in different types of standardized midterm examinations, all of which were graded according to strict scoring criteria. The full score for each examination was 100 points. However, because the study involved different schools and grade levels, students did not take the same chemistry examination paper. Therefore, students’ midterm chemistry scores were standardized using SPSS 27.0 to improve comparability across groups and to approximate a normal distribution in the overall score pattern.

Chemistry University Aspirations. Chemistry university aspirations were assessed using a self-report item. Based on previous measures of STEM career aspirations (Tai et al., 2006; Cribbs et al., 2021) and the present study’s emphasis on disciplinary specificity, a chemistry-focused item was developed. Students were asked to report how likely they were to choose chemistry or a chemistry-related university major after graduating from high school. Responses were recorded on a five-point Likert scale, with higher scores indicating stronger chemistry university aspirations. It should be noted that chemistry university aspirations were conceptually related to, but measured separately from, the chemistry career interest dimension of chemistry identity. Chemistry career interest was treated as one component of the multidimensional chemistry identity scale and was used to identify latent profiles, whereas chemistry university aspirations were measured as a distal outcome variable referring specifically to students’ stated likelihood of choosing chemistry or a chemistry-related university major after high school.

Demographic and background variables. Students also reported demographic and background information, including gender, grade level, parental occupation, and class leadership position. Gender was coded as female = 0 and male = 1, and grade level was coded as Grade 10 = 1 and Grade 11 = 2. Parental occupation was measured by asking whether at least one parent was employed in a chemistry- or engineering-related occupation, and class leadership position was measured by asking whether the student currently held a formal class leadership role. Both parental occupation and class leadership position were treated as dichotomous variables and coded as yes = 0 and no = 1.

Statistical analysis

All statistical analyses were conducted using Mplus (Version 8.3) and R (Version 4.3.3). First, descriptive statistics, including means, skewness, kurtosis, and correlation coefficients, were calculated to provide a preliminary examination of data distribution characteristics and relationships among variables. According to Curran et al. (Curran et al., 1996), data can be regarded as approximately normally distributed when the absolute value of skewness is less than 2 and the absolute value of kurtosis is less than 7.

Because data were collected through self-report questionnaires from the same respondents, the results might be affected by common method bias (CMB). To assess potential CMB in the data, the unmeasured latent method factor approach was adopted (Podsakoff et al., 2003). Specifically, two confirmatory factor analysis (CFA) models were compared. First, a baseline model (M1) including all core constructs—perceived teacher support, chemistry self-efficacy, and chemistry identity—was specified. Second, on the basis of the baseline model, a global method factor orthogonal to all substantive latent variables was added to construct Model 2 (M2). The severity of common method bias was then evaluated by comparing changes in model fit indices (ΔCFI , ΔTLI , $\Delta RMSEA$, and $\Delta SRMR$) between the two models. Following Wen et al., if the inclusion of the method factor substantially improves model fit (i.e., $\Delta CFI \geq 0.10$, $\Delta TLI \geq 0.10$, and $\Delta RMSEA \leq -0.05$, $\Delta SRMR \leq -0.05$), serious common method bias is considered to be present (Wen et al., 2018).

To examine the structural validity of the measurement instruments, confirmatory factor analyses were conducted separately for the perceived teacher support, chemistry self-efficacy, and chemistry identity scales. Given that educational measurement data may exhibit non-normality and heteroscedasticity, robust maximum likelihood estimation (MLR) was used to improve the robustness of parameter estimates and standard errors (Kline, 2023). Model fit was considered acceptable when the comparative fit index (CFI) and Tucker–Lewis index (TLI) were at or above 0.90, and the root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR) were at or below 0.08 (Hu and Bentler, 1999). Because chemistry identity was conceptualized as a multidimensional construct, in addition to testing the overall multidimensional CFA model, separate unidimensionality tests were performed for each subdimension to confirm the basic unidimensionality of the corresponding subscales. Internal consistency reliability was assessed using McDonald's ω , with values above 0.70 indicating good reliability (McDonald, 2013).

Measurement invariance is a prerequisite for meaningful cross-group comparisons (Riordan and Vandenberg, 1994). Therefore, gender-based measurement invariance was tested for the perceived teacher support, chemistry self-efficacy, and chemistry identity scales using R. First, single-group CFA models were estimated for each scale using robust maximum likelihood (MLR) estimation (Muthen and Muthen, 2017), and the model fit indices RMSEA (< 0.080), SRMR (< 0.090), CFI (> 0.900), and TLI (> 0.900) were reported. Subsequently, measurement invariance was tested by fitting a series of increasingly restrictive models, including configural invariance, weak factorial invariance (metric invariance), strong factorial invariance (scalar invariance), and strict invariance (residual invariance or invariant uniqueness) (Widaman and Reise, 1997). RMSEA, SRMR, CFI, and TLI were reported for each model. Invariance was supported when the changes in fit indices satisfied $\Delta CFI \leq 0.010$ and $\Delta RMSEA \leq 0.015$ (Chen *et al.*, 2008).

Factor mixture modeling was then conducted in Mplus, with Excel used as an auxiliary tool for visualization, to identify latent subgroups of chemistry identity and to explore differences in students' academic adaptation across these subgroups. Models with an increasing number of latent profiles were estimated step by step, and model comparison and selection were based on fit indices. In determining the optimal number of latent classes, multiple indicators were considered jointly. Entropy and the average latent class probabilities were used to evaluate classification accuracy, with values closer to 1 indicating more reliable classification; both indices should ideally reach at least 0.80 (Jung and Wickrama, 2008). In addition, relative fit indices such as the Akaike information criterion (AIC), Bayesian information criterion (BIC), and adjusted Bayesian information criterion (aBIC) were used to assess model fit, with lower values indicating better fit. The Lo–Mendell–Rubin likelihood ratio test (LMRT) and bootstrap likelihood ratio test (BLRT) were used to compare adjacent class solutions, and significant LMRT and BLRT results indicate that a model with k classes fits better than a model with $k - 1$ classes. Furthermore, when selecting the

number of classes, it is also necessary to ensure that the number of participants in each class is not too small; each class should include at least 1% of the total sample (Jung and Wickrama, 2008). Although relative fit indices served as the primary basis for determining the number of classes, the interpretability and substantive meaning of the classes were also taken into account.

Finally, the one-step approach and the BCH method (Ferguson *et al.*, 2020) were applied, based on the optimal model and the selected number of latent classes, to examine the relationships between latent profile membership and other relevant variables.

Suitability for measurement scales

Perceived Teacher Support. To assess the structural validity of the perceived teacher support scale, a one-factor model was specified and confirmatory factor analysis (CFA) was conducted. Results showed that all five items had standardized factor loadings above 0.40 (see Appendix Table A1), indicating acceptable convergent validity. The model demonstrated strong values for CFI, TLI, and SRMR, although the RMSEA was above the conventional cutoff, $\chi^2(5) = 172.024$, $p < .001$, CFI = 0.974, TLI = 0.948, RMSEA = 0.153, 90% CI [0.134, 0.173], and SRMR = 0.022 (see Table 1). It should be noted that RMSEA may be inflated in models with small degrees of freedom and may overstate model misfit in short unidimensional CFA models (Kenny *et al.*, 2015). Therefore, RMSEA was not interpreted in isolation; instead, model fit was evaluated in conjunction with CFI, TLI, SRMR, and standardized factor loadings. Given the very small degrees of freedom and the favourable performance of the other fit indices, the overall model fit was considered acceptable. McDonald's omega coefficient was 0.941, indicating excellent internal consistency.

Chemistry Self-Efficacy. To evaluate the structural validity of the chemistry self-efficacy scale, a one-factor CFA was conducted. All five retained items showed standardized factor loadings above 0.40 (see Appendix Table A2), supporting adequate convergent validity. The model showed good values for CFI, TLI, and SRMR, although the RMSEA exceeded the conventional cutoff, $\chi^2(5) = 104.226$, $p < .001$, CFI = 0.984, TLI = 0.968, RMSEA = 0.118, 90% CI [0.099, 0.138], and SRMR = 0.017 (see Table 1). As noted above, RMSEA may be inflated in short unidimensional CFA models with small degrees of freedom and the strong performance of the other fit indices, the overall structural validity of the scale was deemed acceptable. McDonald's omega coefficient was 0.936, indicating excellent internal consistency. Taken together, the results support the reliability and structural validity of the chemistry self-efficacy scale for subsequent analyses.

Chemistry Identity. To assess the structural validity of the chemistry identity scale, a four-factor model was specified and confirmatory factor analysis was conducted. The results supported the four-factor structure, with acceptable model fit, $\chi^2(224) = 1820.328$, $p < .001$, CFI = 0.918, TLI = 0.907, RMSEA = 0.071, 90% CI [0.068, 0.074], and SRMR = 0.051 (see Table 1). All 23 items had standardized factor loadings above 0.40 (see

Appendix Table A3), ranging from 0.473 to 0.911, which supports the convergent validity of the four-factor model. To further examine the unidimensionality of each factor, separate single-factor CFA tests were conducted for the four dimensions: chemistry learning competence, chemistry classroom interest and performance, chemistry career interest, and chemistry recognition. The results indicated that all four subdimensions showed acceptable overall model fit (see Table 1), and all item loadings exceeded 0.40. Specifically, standardized factor loadings ranged from 0.457 to 0.845 for chemistry learning competence, from 0.487 to 0.730 for chemistry classroom interest and performance, from 0.687 to 0.812 for chemistry career interest, and from 0.823 to 0.915 for chemistry

recognition. Because the chemistry identity scale is multidimensional, reliability was reported at the subdimension level rather than as a single total-score coefficient. McDonald's omega coefficients ranged from 0.826 to 0.933 across the four subdimensions, indicating good to excellent internal consistency. Overall, the factor structure and reliability results support the measurement quality of the chemistry identity scale and justify the use of scores for its four dimensions in subsequent analyses. The item-level factor loadings are reported in the Supporting Information. (S2. Standardized Factor Loadings for the Questionnaire).

Table 2 Data-model fit statistics and omega values for the measurement scales (n = 1431)

	χ^2 (df)	p-Value	CFI	TLI	RMSEA [90% CI]	SRMR	Omega
Complete model							
Perceived teacher support	172.024(5)	<0.001	0.974	0.948	0.153 [0.134–0.173]	0.022	0.941
Chemistry self-efficacy	104.226(5)	<0.001	0.984	0.968	0.118 [0.099–0.138]	0.017	0.936
Chemistry identity four-factor	1820.328(224)	<0.001	0.918	0.907	0.071 [0.068–0.074]	0.051	—
Individual factor of the chemistry identity							
Learning competence	319.885(20)	<0.001	0.942	0.919	0.102 [0.093–0.112]	0.039	0.873
Classroom performance and interest	142.820(14)	<0.001	0.956	0.934	0.080 [0.069–0.092]	0.034	0.826
Career interest	26.835(2)	<0.001	0.989	0.967	0.093 [0.064–0.126]	0.019	0.842
Recognition	15.270(2)	<0.001	0.997	0.992	0.068 [0.039–0.102]	0.008	0.933

Note: italicized values indicate that they meet the model fit criteria (CFI & TLI \geq 0.90, RMSEA \leq 0.08, SRMR \leq 0.10 and omega \geq 0.70).

Results

To assess the potential impact of common method bias, the unmeasured latent method factor approach was employed (Podsakoff et al., 2003). The baseline model (M1) demonstrated a good fit to the data (CFI = 0.929, TLI = 0.922, RMSEA = 0.060, SRMR = 0.045). After introducing the latent method factor into the baseline model, the resulting changes in model fit were as follows: Δ CFI = -0.001, Δ TLI = -0.004, Δ RMSEA = 0.001, and Δ SRMR = 0.004. All of these changes were far below the cut off values recommended by Wen et al. for indicating serious common method bias (Wen et al., 2018). In other words, model fit did not improve substantially after the inclusion of the method factor, and the error indices even

showed slight increases. These results suggest that common method bias was not a major concern in the present study.

Descriptive statistics and correlational analysis

The means, standard deviations, and correlation coefficients of all variables are presented in Table 1. The skewness values ranged from -0.373 to 0.050, and the kurtosis values ranged from -0.173 to 0.264, all of which fell within the acceptable thresholds for normal distribution (Curran et al., 1996). In addition, all variables were significantly and positively correlated with one another. Specifically, teacher support, self-efficacy, and the four dimensions of chemistry identity—chemistry learning competence, chemistry classroom interest and performance, chemistry career interest, and chemistry recognition—were all significantly positively correlated with chemistry academic achievement.

Table 3 Descriptive statistics and correlational analysis (N=1431)

Variables	M	SD	Skew	Kurt	1	2	3	4	5	6	7
1. PTS	3.797	0.892	-0.373	-0.115	1						
2. CSE	3.369	0.942	-0.171	-0.105	.361**	1					
3. CLC	3.212	0.719	-0.051	-0.173	.329**	.803**	1				
4. CCIP	3.615	0.655	-0.203	0.264	.453**	.609**	.689**	1			
5. CCI	3.092	0.801	-0.191	0.252	.352**	.544**	.648**	.679**	1		
6. CR	2.666	0.899	0.05	-0.022	.286**	.593**	.718**	.547**	.683**	1	
7. CAA					.064*	.337**	.380**	.269**	.306**	.359**	1

Note: * p <0.050, ** p <0.010, *** p <0.001, PTS = Perceived teacher support; CSE = Chemistry self-efficacy; CLC = Chemistry learning competence; CCIP = Chemistry classroom interest and performance; CCI = Chemistry career interest; CR = Chemistry recognition; CAA = Chemistry academic achievement.

Measurement invariance testing

The results showed that, for the perceived teacher support scale, the configural invariance model (M1), metric invariance

model (M2), and scalar invariance model (M3) across gender all demonstrated good model fit. Further comparisons of changes in fit indices between models indicated that the changes in Δ CFI

and Δ RMSEA were all within acceptable ranges, suggesting that the scale exhibited a stable measurement structure across gender groups (Putnick and Bornstein, 2016).

For the chemistry self-efficacy scale, the cross-group analyses likewise showed a high degree of stability. From the configural invariance model to the metric invariance model, Δ CFI was -0.001 and Δ RMSEA was -0.016 ; from the metric invariance model to the scalar invariance model, Δ CFI was -0.002 and Δ RMSEA was -0.009 . The overall magnitude of change was small and met the criteria for measurement invariance.

Similarly, the chemistry identity scale also demonstrated good measurement consistency across gender groups. From the configural invariance model to the metric invariance model, Δ CFI was -0.001 and Δ RMSEA was -0.001 ; from the metric invariance model to the scalar invariance model, Δ CFI was -0.005 and Δ RMSEA was -0.001 . None of these changes exceeded the recommended cut off values.

Taken together, all three core scales passed the test of measurement invariance across gender. These findings indicate that there was no systematic bias in how male and female students understood and responded to the scale items, and that the scale scores could validly reflect differences in the underlying latent constructs. This provides a reliable measurement basis for subsequent comparative analyses across groups. Detailed results for each questionnaire are presented in the Supplementary Information (S1. Measurement Invariance Test Results).

Testing H1: Latent profiles of chemistry identity

Preliminary latent profile analysis indicated that the profile means across the four dimensions displayed a largely parallel pattern, suggesting that the differences among the candidate profiles were primarily reflected in overall level differences rather than sharply distinct dimensional configurations (Morin et al., 2016). Previous research has pointed out that, in person-centered analyses, when multiple indicators share a strong overall level effect, shape differences among profiles may be masked by level differences, and profiles that are primarily distinguished by level differences may also reflect a higher-order construct underlying the observed dimensions (Morin and Marsh, 2015). Because chemistry identity comprises multiple interrelated dimensions, individual differences among students may simultaneously manifest as shared overall level differences across dimensions and latent subgroup differences (Morin et al., 2016). In such cases, purely categorical models may need to extract additional classes to absorb the unexplained common variation within classes, whereas factor mixture modeling can further capture such within-class variation through continuous latent factors (Clark et al., 2013; Asparouhov and Muthén, 2014). Therefore, the present study further employed factor mixture modeling (FMM). FMM integrates factor analysis and latent class analysis within a single framework, enabling the simultaneous representation of continuous latent variation and categorical latent subgroups (Şen and Cohen, 2024). Moreover, comparing factor analysis, latent class analysis, and FMM is a commonly recommended analytical strategy in latent structure research (Chen et al.,

2015). Thus, FMM was used not to demonstrate that students fall into sharply separated empirical categories, but to better represent the possibility that chemistry identity profiles may contain both an overall level component and dimension-specific patterning across the four identity dimensions.

Because the log-likelihood function of mixture models may contain multiple local maxima, robust maximum likelihood estimation (MLR) in Mplus was used (Muthén and Muthén, 2017). In addition, a multiple random-start strategy was adopted by increasing the number of random sets of starting values during parameter estimation. Specifically, 500 random starts were specified in the initial stage and 100 final-stage optimizations were used (STARTS = 500 100), in order to ensure replication of the best log-likelihood value and the stability of the results (Asparouhov and Muthén, 2019; Morin et al., 2020). The results showed that the best log-likelihood value was successfully replicated across multiple runs, indicating that the model had converged to a global optimum.

Based on a comprehensive evaluation of multiple model fit indices, the three-profile solution was ultimately selected as the optimal model. Although AIC, BIC, and aBIC continued to decrease as the number of classes increased, the four-profile model did not show a significant improvement over the three-profile model in the LMRT test ($p > 0.05$), and its smallest class proportion dropped to 10.9%, suggesting possible overextraction. By contrast, the three-profile model not only showed substantially better information criteria than the two-profile model, but also yielded the highest entropy value (0.752). This value indicates acceptable classification quality, although profile membership should still be interpreted with some caution. In addition, the class proportions were relatively balanced, with the smallest class accounting for 11.4% of the sample, which meets recommended standards for class stability in latent profile analysis. Therefore, considering the statistical fit indices, classification quality, and the substantive interpretability of the model, the three-profile solution was identified as the best latent structure of chemistry identity among high school students.

Profile 1 (37.6% of the sample) was characterized by relatively high scores on chemistry learning competence, but markedly low scores on chemistry career interest and chemistry recognition. This pattern suggests that these students possess academic competence in chemistry but lack a clear career vision related to the subject. Accordingly, this profile was labeled the academic competence–career alienation profile.

Profile 2 (51.0% of the sample) represented the largest group in the sample. Its pattern was the most balanced across all dimensions, and it showed the highest score among the three groups on chemistry recognition. This profile reflects a relatively stable sense of belonging to and adaptation within the chemistry domain. It was therefore labeled the robust identity profile.

Profile 3 (11.4% of the sample), although showing relatively lower scores in self-evaluated competence and current chemistry identity, demonstrated very high levels of chemistry classroom interest and performance as well as chemistry career interest. This pattern indicates strong intrinsic motivation and a

clear future-oriented career focus. Accordingly, this profile was labeled the interest–career driven profile. To improve readability, the three profiles can be summarized in plain language as follows: Profile 1 reflects relatively strong chemistry learning competence but limited chemistry career interest and chemistry recognition; Profile 2 reflects a relatively balanced and stable chemistry identity pattern; and Profile 3 reflects interest- and career-driven engagement with chemistry, accompanied by comparatively limited recognition.

Overall, these labels are interpretive shorthand used to summarize characteristic response patterns of the latent

profiles, rather than directly observed empirical categories. Given the largely parallel pattern observed in the preliminary LPA and the moderate entropy of the selected FMM solution, the three profiles should be interpreted cautiously as probabilistic chemistry identity patterns. These patterns reflect both overall level differences in chemistry identity and relative dimension-specific tendencies, particularly in chemistry career interest and chemistry recognition. In this qualified sense, the results support H1.

Table 4. Fit Indices for Factor mixture modeling

Profile	AIC	BIC	aBIC	Entropy	LMRT	BLRT	Proportions
Profile-2	75340.672	75830.292	75534.863	0.743	0.000	0.000	0.346/0.654
Profile-3	74815.165	75431.139	75059.470	0.752	0.635	0.000	0.376/0.510/0.114
Profile-4	74356.560	75098.887	74650.979	0.743	0.259	0.000	0.234/0.109/0.472/0.185

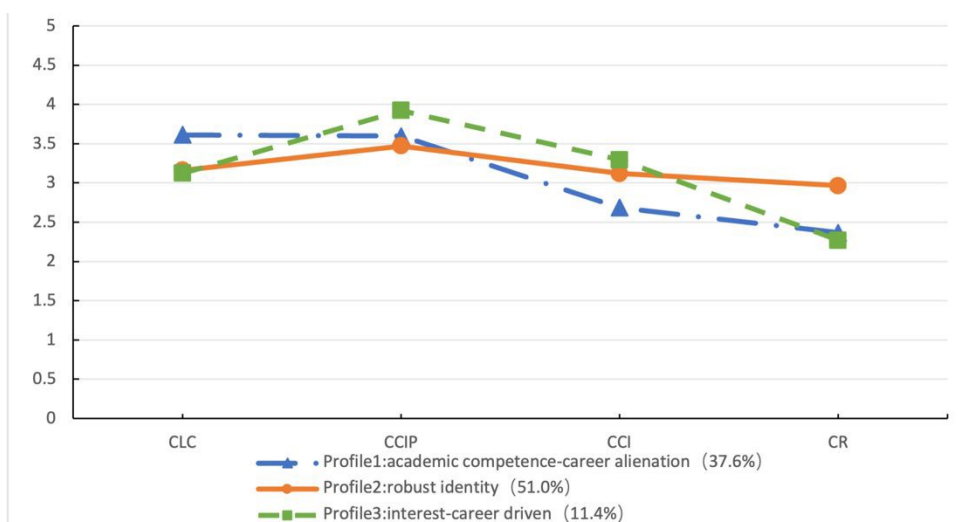


Fig1. Results of the Factor mixture modeling fit for chemistry identity.

Testing H2 and H3: Variables associated with chemistry identity profile membership

Among the demographic variables, gender was the only significant predictor of profile membership. Relative to Profile 3, male students had much lower odds of belonging to Profile 1 (OR < 0.001) and Profile 2 (OR = 0.040), and were also less likely to belong to Profile 1 than to Profile 2 (OR = 0.004). Substantively, this indicates that male students were most concentrated in Profile 3, whereas female students were more likely to be classified into Profiles 1 and 2, especially Profile 1.

Perceived teacher support showed a clear gradient pattern across profiles. For each one-unit increase in teacher support, the odds of belonging to Profile 1 rather than Profile 3 were reduced to 0.151 (an 84.9% reduction), and the odds of belonging to Profile 2 rather than Profile 3 were reduced to 0.342 (a 65.8% reduction). Teacher support also significantly differentiated Profile 1 from Profile 2 (OR = 0.441, a 55.9% reduction). These results indicate a clear ordering, with teacher support highest in Profile 3, intermediate in Profile 2, and lowest in Profile 1.

Chemistry self-efficacy primarily distinguished Profile 3 from the other two profiles. For each one-unit increase in self-efficacy, the odds of belonging to Profile 1 rather than Profile 3 were reduced to 0.008 (a 99.2% reduction), and the odds of belonging to Profile 2 rather than Profile 3 were reduced to 0.084 (a 91.6% reduction). However, self-efficacy did not significantly distinguish Profile 1 from Profile 2. This suggests that high self-efficacy was a defining characteristic of Profile 3, whereas Profiles 1 and 2 were relatively similar on this variable. By contrast, grade level, parental occupation, and class leadership role were not significant predictors of profile membership, as their confidence intervals all included 1. Thus, chemistry identity profile membership in the present sample appeared to be more strongly related to gender and contextual supports than to grade, parental occupational background, or class leadership status.

Overall, the results supported H2, as perceived teacher support and chemistry self-efficacy were significantly associated with chemistry identity profile membership. H3 was partially supported: gender was significantly associated with



profile membership, whereas grade level, parental occupation, and class leadership role were not.

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Table 5 Multinomial Logistic Regression Analysis for Different Profiles

Variable	Class1 vs Class3	Class2 vs Class3	Class1 vs Class2
	B(OR)[Lower, Upper]	B(OR)[Lower, Upper]	B(OR)[Lower, Upper]
Gender	-8.70(<0.001) [0.000, 0.000]	-3.21(0.040) ***[0.017, 0.064]	-5.49(0.004) *[0.001, 0.008]
Grade	-0.10(0.902) [0.639, 1.274]	-0.02(0.984) [0.729, 1.264]	-0.09(0.917) [0.570, 1.474]
Parents' Career	0.08(1.079) [0.598, 1.560]	-0.05(0.948) [0.562, 1.334]	0.13(1.138) [0.336, 1.941]
Teacher Support	-1.89(0.151) ***[0.091, 0.250]	-1.07(0.342) ***[0.240, 0.488]	-0.82(0.441) ***[0.327, 0.595]
Self-Efficacy	-4.83(0.008) ***[0.000, 0.274]	-2.48(0.084) ***[0.051, 0.138]	-2.36(0.094) [0.003, 3.106]
Leader	-0.05(0.952) [0.662, 1.241]	-0.03(0.967) [0.649, 1.284]	-0.02(0.984) [0.811, 1.158]

Note : Gender was coded as female = 0 and male = 1. Grade was coded as 10th grade = 1 and 11th grade = 2. Parents' career was a dichotomous variable indicating whether at least one parent was employed in a chemistry- or engineering-related occupation (yes = 0, no = 1). Teacher support and self-efficacy were measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Leader was a dichotomous variable indicating whether the student held a class leadership position (yes = 0, no = 1). 95% CI for OR. * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$.

Testing H4: Differences in chemistry academic achievement and chemistry University aspirations across chemistry identity profiles

The BCH analyses revealed highly significant differences among the three latent profiles in both chemistry academic achievement ($\chi^2 = 191.542$, $p < 0.001$) and chemistry university aspirations ($\chi^2 = 224.850$, $p < 0.001$). Moreover, both outcome variables showed a consistent stepwise distribution across the three profiles. With regard to chemistry academic achievement, Profile 3 (interest-career driven profile) had the highest score ($M = 0.528$), followed by Profile 2 (robust identity profile) ($M = 0.083$), whereas Profile 1 (academic competence-career alienation profile) had the lowest score ($M = -0.505$). Pairwise comparisons indicated that all differences between profiles were statistically significant. A similar descending pattern was

observed for chemistry university aspirations, with scores decreasing from Profile 3 ($M = 3.388$) to Profile 2 ($M = 3.104$) and then to Profile 1 ($M = 2.281$), and all pairwise differences were statistically significant. Notably, the university aspiration score of Profile 1 was clearly below the scale midpoint, indicating a tendency toward alienation from chemistry-related careers. By contrast, Profile 3 showed the most favorable pattern on both academic achievement and university aspirations, indicating that the interest-career driven profile was associated with higher chemistry academic achievement and stronger intentions to pursue chemistry university aspirations.

These results supported H4, indicating that chemistry identity profiles differed significantly in both chemistry academic achievement and chemistry-university aspirations.

Table 6 Group Differences in Chemistry Academic Achievement and Chemistry university Aspirations among the Chemistry identity Profiles

Profile	Chemistry Academic Achievement M (SE)	Chemistry University Aspirations M (SE)
Academic competence-career alienation profile	-0.505 (0.052)	2.281 (0.053)
Robust identity profile	0.083 (0.035)	3.104 (0.034)
Interest-career driven profile	0.528 (0.054)	3.388 (0.063)
χ^2 (df)	191.542***(2)	224.850***(2)
Pairwise comparisons	1 < 2, 1 < 3, 2 < 3	1 < 2, 1 < 3, 2 < 3

Note: * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$

Discussion

The present study suggests that chemistry identity among Chinese high school students is characterized by heterogeneity that is partly level-based and partly configurational. Students exhibited different response patterns across the dimensions of chemistry learning competence, chemistry classroom performance and interest, chemistry career interest, and chemistry recognition. However, these profiles should not be interpreted as sharply discrete student types. Rather, consistent with the methodological distinction between level and shape effects in person-centered analyses, the profile solution appears to reflect a substantial overall chemistry identity component together with several dimension-specific

tendencies. Moreover, the three chemistry identity profiles differed significantly in both chemistry academic achievement and chemistry university aspirations, indicating that chemistry identity is closely associated not only with students' current academic performance but also with their future developmental orientations. These findings further suggest that examining chemistry identity solely at the level of overall mean scores may be insufficient to capture the complex differences among students in the process of identity development. This point is particularly relevant given that students' science career interest and science attitudes may decline as they grow older (Potvin and Hasni, 2014; Tröbst et al., 2016), which underscores the practical significance of investigating the mechanisms underlying such heterogeneity. Accordingly, the present study adopted a person-

centered perspective to identify distinct chemistry identity profiles among Chinese high school students and further examined their associations with learning-related variables. This approach not only enriches the existing research on chemistry identity in the Chinese educational context but also provides new evidence for understanding patterns of chemistry identity development across different cultural settings.

Profiles of chemistry identity among chinese high school students

The factor mixture analysis in the present study suggested three probabilistic profile patterns of chemistry identity among Chinese high school students. These patterns should be understood as summaries of latent response tendencies rather than as fixed or naturally occurring categories. Importantly, the profiles were not entirely independent of overall chemistry identity level; instead, they appeared to combine level-based differences with relative differences across specific dimensions. This finding is consistent with the general conclusion of existing person-centered identity research, namely that students' disciplinary identity is not a single continuum but rather comprises different latent subgroup structures (Lockhart et al., 2024). Notably, chemistry recognition scores were consistently the lowest among the four dimensions across all three profiles. Previous research has suggested that identity possesses a distinctly social-constructive nature: its formation involves not only individuals' self-understanding and meaning-making but also depends on sociocultural participation and recognition from others through interaction (Le et al., 2019). Accordingly, compared with dimensions such as competence and interest, which can be developed through individual autonomous learning, the formation of chemistry recognition places greater demands on the external feedback environment. This may be an important reason for the consistently lower scores on this dimension across all three profiles. This cross-profile commonality suggests that, regardless of students' levels of competence and interest, creating more opportunities for students to receive chemistry recognition may be a shared priority for current chemistry education.

Profile 1, the academic competence–career alienation profile, accounted for 37.66% of the total sample. As shown in the profile plot, students in this group maintained relatively high levels of chemistry learning competence and chemistry classroom interest and performance, with both scores around 3.6, but showed markedly lower levels of chemistry career interest and chemistry recognition. Compared with traditional perspectives that explain students' science-related career choices primarily in terms of academic achievement or ability, science identity theory emphasizes that strong learning competence and good classroom performance do not necessarily translate into stronger disciplinary identity or career orientation. A well-developed science identity also requires the joint development of dimensions such as recognition and sense of belonging (Lee and Mun, 2023). Therefore, the “high competence–low recognition” separation pattern observed in Profile 1 provides support for this theoretical perspective based on a sample of Chinese high school students. It also indicates that, in the present sample,

chemistry learning competence and chemistry recognition did not necessarily showed in parallel.

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Existing research also supports this finding. Studies have shown that even students who perform well in chemistry learning may not necessarily view themselves as “chemistry people” (Castano *et al.*, 2025). Similarly, research in physics education has found that achievement or ability alone is insufficient to fully explain whether students develop a strong disciplinary identity and career orientation (Hazari *et al.*, 2010). In addition, Profile 1 was also characterized by relatively high classroom interest but low career interest, suggesting that positive classroom-level experiences do not necessarily correspond to a higher level of future career orientation. Previous research has likewise indicated that although students' science competence and perceived classroom value are related to university aspirations, the relationship is not a simple one-to-one correspondence. Compared with students who merely believe that they “can do well in science,” those who also perceive personal meaning and future utility in science learning are more likely to report stronger STEM career interest (Aschbacher *et al.*, 2010). This is consistent with the pattern observed in Profile 1: these students scored relatively high on chemistry learning competence and chemistry classroom interest and performance, but did not show a corresponding level of chemistry career interest.

Overall, Profile 1 suggests that these students' strengths were mainly reflected in their current academic performance and classroom participation, but these strengths did not develop in parallel with corresponding levels of career interest and chemistry recognition. Previous studies suggest that future-oriented career interest and its connection with identity may also be related to perceived value, science-related experiences, contextual resources, and social support (Archer *et al.*, 2012; Jones *et al.*, 2021). However, because the present study did not directly examine these factors, they are discussed here only as contextual references for interpreting the findings, rather than as direct explanations for the formation of profile differences. The fact that this profile represented the largest proportion of the sample, 37.66%, suggests that improving academic achievement alone may be insufficient to promote the development of chemistry identity among these students. Educators may also need to attend to how students can establish meaningful connections between chemistry learning and their personal development.

Students in Profile 2 displayed moderate levels across all four dimensions—chemistry learning competence, chemistry classroom performance and interest, chemistry career interest, and chemistry recognition—exhibiting a relatively balanced overall structure but lacking prominent strengths or distinctive features. Drawing on identity development research, this pattern can be understood as a relatively stable but not yet fully developed identity state (Meeus *et al.*, 1999), in which students maintained a basic level of engagement with and recognition of chemistry learning but had not yet developed a stronger career orientation or a more clearly defined sense of disciplinary belonging. This profile accounted for the largest proportion of the sample (51.0%), suggesting that for a substantial portion of Chinese high school students, chemistry represents a

"stable but not prominent" learning domain. Similarly, previous person-centered studies have also reported large intermediate identity subgroups. For example, in a science identity study based on the exploration–commitment framework, Lockhart et al. identified a large Foreclosed class (94/156, approximately 60.3%) in which the Z-scores on both dimensions were close to zero (Exploration = -0.035, Commitment = -0.027), reflecting a relatively intermediate positioning (Lockhart et al., 2024). However, because that study was based on a two-dimensional identity framework, its results cannot be directly mapped onto the four-dimensional profiles identified in the present study. Nevertheless, the fact that both studies identified large intermediate subgroups suggests, to some extent, that a stable but not prominent identity state may be a relatively common pattern in disciplinary identity development.

Profile 3, the interest–career driven profile, accounted for 11.4% of the total sample, representing the smallest proportion among the three profiles. In terms of the profile pattern, students in this group scored the highest on chemistry classroom performance and interest, while also maintaining a relatively high level of chemistry career interest. Their chemistry learning competence was at a moderately high level but was not the highest among the three profiles, and their chemistry recognition did not reach the highest level either. Previous research has demonstrated that interest and future-related utility value play important roles in promoting students' sustained engagement in disciplinary learning, enhancing academic performance, and strengthening career orientation (Hidi and Renninger, 2006; Hulleman and Harackiewicz, 2009; Hulleman *et al.*, 2010). From this perspective, the elevated levels of classroom interest and career interest in Profile 3 constitute the key psychological characteristics that distinguish this group from the other profiles. At the same time, the relatively small proportion of this profile is noteworthy. This proportion indicates that, in the present sample, students who simultaneously exhibited high levels of both classroom interest and career interest were relatively few. This finding can be situated within existing research suggesting that classroom-based science interest and science career interest do not share a straightforward correspondence; the link between the two may be influenced by factors such as career awareness and supportive learning experiences (Archer et al., 2012; DeWitt and Archer, 2015; Kang et al., 2023). However, the present study did not directly examine these mechanisms, and this interpretation therefore requires further investigation in future research. Accordingly, Profile 3 can be understood as a student group characterized by relatively well-developed interest and a clearer future orientation; yet its small proportion also suggests that this favorable combination was not prevalent in the present sample. This finding also resonates with the emphasis in identity research on the recognition dimension—namely, that interest, competence, or performance do not necessarily translate into a correspondingly high level of identity (Potvin and Hazari, 2014), which helps explain why Profile 3, despite having high classroom interest and career interest, did not show the highest level of chemistry recognition.

The influence of antecedent variables on students' membership in chemistry identity profiles

The findings revealed that gender, perceived teacher support, and chemistry self-efficacy significantly predicted students' membership in the chemistry identity latent profiles. The following discussion addresses the significant effects of these three variables, drawing on theoretical analysis and existing empirical research.

Gender. Gender significantly predicted students' chemistry identity profile membership. Specifically, male students were more likely to belong to Profile 3 (the interest–career driven profile), whereas female students were more likely to belong to Profiles 1 and 2. In light of the profile characteristics, male students were more likely to be classified into the profile characterized by higher classroom interest and career orientation, whereas female students were more likely to be distributed across Profiles 1 and 2. This finding is consistent with existing science education research on gender differences in STEM career interest and science motivation profiles. Sadler et al. found significant gender differences in STEM career interest among high school students, with male students showing overall higher levels of STEM career interest (Sadler et al., 2012). Wang et al. similarly reported that, in a sample of Chinese high school students, male students had significantly higher STEM career interest than female students, and noted that factors such as self-efficacy, career awareness, and social support were associated with this difference (Wang et al., 2023). More directly, Steegh et al. conducted a latent profile analysis among Chemistry Olympiad participants and found that students' motivation profiles were differentiated by career motivation, interest, and domain identification, and that gender predicted profile membership (Steegh *et al.*, 2021). Taken together, the influence of gender on profile membership in the present study is better understood as reflecting differences between male and female students in their configurations across chemistry identity dimensions—particularly in the probability of belonging to the interest–career driven profile—rather than simply indicating that female students had lower overall chemistry identity than male students. Because chemistry identity is a multidimensional construct, the present study did not use a single composite score to compare overall identity levels between genders, but instead focused on the profile characteristics formed by different dimensional configurations.

Perceived teacher support. Perceived teacher support significantly predicted students' chemistry identity profile membership and exhibited a gradient pattern: higher levels of perceived teacher support were associated with a greater likelihood of belonging to Profile 3 and Profile 2, and a lower likelihood of belonging to Profile 1. In light of the profile characteristics, higher perceived teacher support was more likely to correspond to profiles in which classroom interest and career interest were more prominent, rather than to a uniform increase across all identity dimensions. In other words, differences in perceived teacher support effectively differentiated students' profile membership. Previous research has shown that student–teacher positioning in classroom interactions (Hazari et al., 2015), as well as teacher feedback and teacher recognition, are closely associated with students' science

identity development (Kim M., 2018; Chiu, 2024a). Extending these findings, the present study, through latent profile analysis, further revealed that perceived teacher support was not only associated with students' chemistry identity but also differentiated students' likelihood of belonging to different identity profiles. Specifically, teacher support was related not only to the overall level of chemistry identity but also to the way students' scores were configured across the dimensions of chemistry learning competence, chemistry classroom performance and interest, chemistry career interest, and chemistry recognition. This finding provides more nuanced person-centered evidence for understanding the relationship between teacher support and chemistry identity, suggesting that the role of teacher support is reflected not only in elevating overall identity levels but also in differentiating membership across distinct identity profiles.

Chemistry self-efficacy. Chemistry self-efficacy significantly predicted students' chemistry identity profile membership. Specifically, higher levels of chemistry self-efficacy were associated with a greater likelihood of belonging to Profile 3 (the interest–career driven profile). This finding is consistent with previous research indicating that self-efficacy, as an important cognitive factor influencing career decision-making, is closely related to the range and persistence of individuals' career choices (Betz and Hackett, 1981; Lent *et al.*, 1987). Profile 3 was characterized by prominent classroom interest and career interest, and existing empirical research has also demonstrated a significant positive association between self-efficacy and learning interest (Zimmerman and Kitsantas, 1997; Donnay and Borgen, 1999). Accordingly, the finding that students with higher self-efficacy were more likely to belong to Profile 3 can be understood as reflecting the association between self-efficacy and an identity configuration in which classroom interest and career interest are particularly prominent. On the other hand, the present study found that chemistry self-efficacy did not effectively differentiate between Profile 1 and Profile 2. This result resonates with a fundamental perspective of person-centered research. Previous studies have shown that person-centered analytical approaches are capable of identifying characteristic configurations formed by multiple dimensions simultaneously, and that differences among profiles often need to be understood from the perspective of the overall configuration (Chen and Usher, 2013; Steegh *et al.*, 2021). The chemistry identity profiles identified in the present study were jointly defined by the dimensions of chemistry learning competence, chemistry classroom performance and interest, chemistry career interest, and chemistry recognition. Therefore, the finding that chemistry self-efficacy did not differentiate between Profile 1 and Profile 2 is better understood as indicating that its predictive role has certain boundaries, rather than suggesting that its role is unimportant.

Students' grade level, class leadership position, and parental occupation type did not significantly predict chemistry identity profile membership. First, regarding grade level, this finding is consistent with the conclusion of Vincent-Ruz and Schunn, who, after conducting measurement invariance testing and group-based analyses, reported that the mean scores on science identity did not

differ significantly between seventh- and ninth-grade students, and emphasized the comparability of science learning arrangements across the two grade levels (Vincent-Ruz and Schunn, 2018). From a person-centered perspective, the present study further corroborates this conclusion, indicating that grade level was not only unrelated to the overall level of chemistry identity but also unable to effectively differentiate students' membership across different chemistry identity profiles. According to Carlone and Johnson's science identity framework (Carlone and Johnson, 2007), the formation of chemistry identity depends on individuals' practical engagement in specific learning contexts and recognition from the learning community, rather than being directly determined by the natural progression of grade level. However, the present study did not directly examine the specific relationship between grade level and classroom experiences, and this interpretation therefore awaits further verification in future research. Second, regarding class leadership position, identity theory suggests that identities from different sources need to be verified and reinforced within their corresponding contexts (Stets and Burke, 2000). The experience of serving as a class leader primarily strengthens general role identities such as "leader" or "responsibility bearer," and its influence tends to operate through general pathways such as learning autonomy, learning engagement, and time allocation. Previous research has also indicated that its effect on specific academic outcomes is relatively limited (Deng *et al.*, 2020). The present finding is consistent with this view, further suggesting that the general role identity conferred by class leadership may not effectively differentiate students' profile membership across the dimensions of chemistry identity. Finally, regarding parental occupation, this finding diverges from some previous research. Prior studies have shown that students with science university aspirations tend to come from families with science-supportive environments, and that parents, as important sources of science knowledge, have a significant influence on students' science interest and career choices (Dabney *et al.*, 2013; Rüschenpöhler and Markic, 2020; Stahl *et al.*, 2021). However, the present results suggest that having at least one parent employed in a chemistry- or engineering-related occupation does not necessarily equate to the presence of a chemistry-supportive environment at home. One possible explanation is that, in the context of the increasingly fast pace of contemporary Chinese society, opportunities for family members to interact and communicate around science-related topics may be relatively limited, making it difficult for parents' chemistry- or engineering-related occupational backgrounds to be effectively translated into a direct influence on students' chemistry identity (S. Chen *et al.*, 2023). From a person-centered perspective, the present study further indicates that parental occupation was not only unrelated to the overall level of students' chemistry identity but also unable to effectively differentiate profile membership.

Relationships between latent profiles and outcome variables

The BCH analyses showed significant differences among the three chemistry identity profiles in chemistry academic achievement, following the pattern Profile 3 > Profile 2 > Profile 1. Notably, Profile 1 had the highest self-rated score on the chemistry learning

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competence dimension among the three profiles, yet showed the lowest chemistry academic achievement. By contrast, Profile 3 had a relatively lower self-rated score on the chemistry learning competence dimension, but showed the highest chemistry academic achievement. This pattern indicates that students' self-rated chemistry learning competence does not directly correspond to their chemistry academic achievement.

This finding is consistent with previous discussions of the relative contributions of cognitive ability and non-cognitive factors to academic achievement. Prior research has suggested that only approximately 25% of the variance in students' academic achievement can be attributed to cognitive ability, whereas as much as 75% may stem from non-cognitive factors (Kuncel *et al.*, 2004). As a core component of non-cognitive factors, motivation may predict academic achievement even more strongly than cognitive ability itself (Meyer *et al.*, 2019). Moreover, even after controlling for prior achievement, motivation remains a key predictor of subsequent academic achievement (Steinmayr and Spinath, 2009).

In relation to the profile characteristics identified in the present study, Profile 3 had the highest scores among the three profiles on both chemistry classroom interest and performance and chemistry career interest. As interest is an important component of learning motivation (Hidi, 2006), it may have played an important role in the higher chemistry academic achievement observed in this profile. By contrast, although Profile 1 reported relatively high self-rated chemistry learning competence, it scored lower on interest-related dimensions, which corresponded with its lower chemistry academic achievement. From a person-centered perspective, the present study further shows that high self-rated competence and high academic achievement do not necessarily co-occur within the same profile, a pattern that may be difficult to reveal through previous variable-centered research. However, given the cross-sectional design of the present study, the causal relationship between interest and academic achievement requires further examination in future longitudinal research.

In addition to chemistry academic achievement, the BCH analyses also showed significant differences among the three profiles in chemistry university aspirations, with Profile 3, the interest–career driven profile, showing the highest level and Profile 1, the academic competence–career alienation profile, showing the lowest level. It should be noted that chemistry university aspirations are conceptually related to, but not identical with, the chemistry career interest dimension of chemistry identity. Chemistry career interest is one component of the multidimensional chemistry identity scale and was used to identify students' latent profiles; it mainly reflects students' interest and value orientation toward future chemistry-related development within their identity structure. By contrast, chemistry university aspirations were measured as an outcome variable and refer specifically to students' self-reported likelihood of choosing chemistry or a chemistry-related university major after high school. Therefore, the higher level of chemistry university aspirations observed in Profile 3 should be interpreted in light of its higher chemistry career interest, rather than as an outcome entirely independent of the profile-defining indicators.

Lockhart *et al.* similarly found that science identity classifications were significantly associated with students' science career interest (Lockhart *et al.*, 2024). Notably, Profile 3 showed the highest chemistry university aspirations but the lowest score on chemistry recognition among the three profiles. This suggests that chemistry university aspirations are not simply determined by the overall level of chemistry identity, but are more closely related to the specific configuration of students' scores across different identity

dimensions, especially the prominent levels of chemistry classroom interest and performance and chemistry career interest. From a person-centered perspective, the present study reveals this differentiated pattern, which may be difficult to capture through previous variable-centered research.

Implication for practice

The practical implications of the present study should be understood as exploratory and interpretive rather than prescriptive. Because the identified profiles are probabilistic latent patterns rather than directly observed student types, they should not be used as a fixed basis for assigning students to instructional groups. First, the present study found that scores on the chemistry recognition dimension were relatively low across all three profiles, a trend that was particularly pronounced in Profiles 1 and 3. It should be noted that, as discussed in the preceding section, differences in item phrasing and response anchors across dimensions may affect the direct comparability of mean scores, and therefore this result should not be simply interpreted as indicating that chemistry recognition is necessarily the weakest aspect of students' identity development; rather, it should be regarded as a trend worthy of further attention. With this caveat in mind, chemistry recognition, as a core component of chemistry identity, nonetheless suggests that teachers should attend to students' experiences of both "self-recognition" and "recognition from others" in chemistry learning (Wang and Yao, 2021).

Second, the present study found that Profile 3 (the interest–career driven profile) showed the highest levels of both chemistry academic achievement and university aspirations, whereas Profile 1 (the academic competence–career alienation profile), despite having relatively high self-rated learning competence, showed the lowest levels of university aspirations and academic achievement. This contrast suggests that relying solely on strengthening knowledge mastery may be insufficient to help students develop a stable identity. Guiding students to actively reflect on the connections between chemistry learning and their own future development—that is, helping students perceive the utility value of learning chemistry (Fryer and Ainley, 2019; Walton and Crum, 2020)—may be more critical. In the context of China's New Gaokao reform, previous research has indicated that students' interest in chemistry learning is the primary factor influencing their decision to select and continue studying chemistry (Qiang and Yan, 2021). Teachers can create authentic scientific contexts that connect chemistry knowledge with real-world applications and strengthen chemistry career education (Qiang and Yan, 2021), helping students construct meaningful connections among "learning content, real-world applications, and future planning," which may help students perceive the value of learning chemistry more clearly (McWhirter *et al.*, 2000).

Third, the present study found that gender significantly predicted profile membership, with female students being more likely to be classified into Profiles 1 and 2 rather than Profile 3. As key agents in students' gender socialization processes (Rayaprol *et al.*, 2023), teachers should be mindful of the influence of gender stereotypes on instructional expectations (Perander *et al.*, 2020) and provide all students with equal opportunities to "think and act like scientists" through inquiry-based learning approaches (Zhai *et al.*, 2014), thereby reducing the impact of gender differences on chemistry identity development.

Limitations and future directions

Although the present study adopted a person-centered approach to reveal the latent heterogeneity in high school students' chemistry identity and further examined the roles of relevant antecedent and outcome variables, several limitations remain that warrant attention in future research.

First, the present study employed a cross-sectional research design in which all variables were measured at a single time point. Consequently, the results primarily reflect associations among variables rather than supporting stronger causal inferences. Chemistry identity is inherently developmental and contextual; its formation and change typically constitute a dynamic process in which students gradually construct their identity through sustained classroom participation, social interactions, and disciplinary learning experiences. Although the present study identified distinct latent profiles and found that perceived teacher support and chemistry self-efficacy were significantly associated with profile membership, bidirectional effects or stage-specific changes may exist among these variables and chemistry identity that cannot be fully captured through cross-sectional data. Future research could employ longitudinal designs to further examine the developmental trajectories of students' chemistry identity across different grade levels, as well as the sustained mechanisms through which teacher support, self-efficacy, and other variables are related to the identity development process.

Second, the interpretation of the latent profiles should also be treated with caution. Although the three-profile FMM solution was selected based on statistical fit, classification quality, and substantive interpretability, the preliminary LPA showed a largely parallel pattern across the four chemistry identity dimensions. This indicates that the profiles were influenced by an overall level component of chemistry identity. Therefore, the profiles identified in this study should not be interpreted as sharply separated latent classes or fixed empirical student types. Rather, they should be understood as probabilistic chemistry identity patterns that combine overall level differences with dimension-specific tendencies. Future research could further examine the stability and validity of these patterns using longitudinal data, independent samples, and alternative modeling approaches such as bifactor or bifactor-ESEM models to more directly evaluate the global and specific components of chemistry identity. In addition, because the latent profiles identified in the present study are based on cross-sectional data, their operationalizability in instructional practice requires further verification. Although the present study reveals differentiated characteristics across chemistry identity profiles, these findings should be regarded as providing directions for future research rather than as direct evidence for immediate instructional intervention. Future studies could further investigate whether utility-value interventions can support chemistry identity development among students who show low chemistry career interest but relatively high academic competence, and which classroom feedback strategies may be effective in enhancing students' chemistry recognition experiences. Answers to these questions will require further examination through longitudinal tracking studies and instructional intervention experiments.

Third, the present study has certain limitations, regarding sample selection. Participants were primarily drawn from 10th- and 11th-grade students at four schools of varying academic levels within a single city, using convenience sampling with class-level administration. More specifically, the sample was not intended to be statistically representative of all Chinese high school students, but rather to provide coverage of students from different school levels within the local context. 12th-grade students were not included due to the practical constraints of academic pressure they face. As a result, the present findings should be interpreted as applying primarily to 10th- and 11th-grade students in the sampled city and should not be generalized uncritically to students in other regions, school systems, or grade levels across China. Although this approach was operationally feasible and facilitated coverage of students from schools of different levels, the geographic scope of the sample was relatively limited and did not encompass 12th-grade students. In particular, students' chemistry learning experiences and identity construction processes may differ across regions, school types, and contexts characterized by varying levels of examination pressure in China. In addition, because Grade 12 students are at a distinctive stage of examination preparation, subject-selection decision-making, and future planning, their chemistry identity patterns and related motivational characteristics may differ from those observed in Grades 10 and 11. Future research could conduct comparative studies across multiple regions and school types on a larger scale and include 12th-grade students in the analysis to enhance the representativeness and generalizability of the findings.

Fourth, the present study has potential for further expansion in its examination of antecedent variables. Grounded in relevant theoretical frameworks of science identity and informed by key antecedent variables that have been repeatedly validated in prior research, the present study selected variables with strong theoretical foundations, representativeness, and explanatory power—including perceived teacher support, parental occupation, and chemistry self-efficacy—from both the external sociocultural context and internal psychological mechanism levels. These variables reflect, to a certain extent, the critical sources of influence on students' chemistry identity formation, including school support, family background, and individual competence beliefs, and thus possess a solid theoretical basis and practical significance. However, the development of chemistry identity is not determined by a single factor or a limited number of factors; rather, it is a dynamic construction process shaped by the joint operation of multiple factors across family, school, and broader sociocultural contexts. Accordingly, the current model has not fully incorporated other potentially important factors, such as peer support, family science interactions, classroom instructional approaches, perceived disciplinary value, sense of belonging, opportunities for scientific practice, and the degree of alignment between school science and authentic science. Future research could, within a more comprehensive theoretical framework, incorporate additional contextual and psychological variables relevant to chemistry identity formation



and investigate potential mediation, moderation, and sequential mechanisms among different factors, thereby providing a more holistic explanation of the developmental patterns of Chinese high school students' chemistry identity.

Fifth, the present study also has a limitation in its measurement of chemistry university aspirations. In this study, chemistry university aspirations were assessed using a single self-report item. Although this approach was practical and relevant in the context of a large school-based survey, it is less robust than a multi-item scale, provides less comprehensive coverage of the construct, and does not allow internal consistency to be evaluated in the same way. Therefore, findings related to chemistry university aspirations should be interpreted with caution. Future research could employ multi-item measures to assess this construct more comprehensively and further validate the present findings.

Conclusions

Grounded in a four-dimensional framework of science identity, the present study employed factor mixture modeling to examine patterns of high school students' chemistry identity: the academic competence-career alienation profile, the robust identity profile, and th

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e interest-career driven profile, suggesting meaningful heterogeneity in high school students' chemistry identity patterns. Further analysis revealed that gender, perceived teacher support, and chemistry self-efficacy significantly predicted students' profile membership, and significant differences were observed across profiles in both chemistry academic achievement and chemistry career inclination, with the "interest-career-driven" profile exhibiting the most favorable outcomes. These findings indicate that teacher support and chemistry self-efficacy are important variables associated with students' chemistry identity patterns, and that interest and career orientation play critical roles in students' chemistry learning development. The present study provides empirical evidence for understanding the differentiated characteristics of Chinese high school students' chemistry identity and offers exploratory implications for supporting students' chemistry identity development and career awareness education in high school chemistry teaching.

Conflicts of interest

There are no conflicts to declare.

Data availability

The raw data underlying this study are not publicly available due to ethical and privacy considerations, as they contain potentially identifiable participant information. Anonymized data supporting the main findings of the study may be available from the corresponding author, Yurong Liu, upon reasonable request. Access will be subject to a data use agreement to ensure appropriate use of the data and the protection of participant privacy. Further details regarding data access and conditions of use may be obtained by contacting Yurong Liu (liuyur66@163.com).

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ARTICLE

S1. Measurement Invariance Test Results**Perceived teacher support questionnaire**

To examine the structural stability of the perceived teacher support scale across gender groups, single-group confirmatory factor analyses were conducted separately for the male and female samples. In the male sample, the model fit indices were CFI = 0.972, TLI = 0.944, RMSEA = 0.158 (90% CI [0.130, 0.187]), and SRMR = 0.023. In the female sample, the corresponding indices were CFI = 0.975, TLI = 0.950, RMSEA = 0.152 (90% CI [0.125, 0.180]), and SRMR = 0.021. Overall, the fit pattern was highly similar across the two gender groups, suggesting that the scale showed satisfactory structural stability for both male and female students.

Multigroup confirmatory factor analysis was then conducted to test the measurement invariance of the perceived teacher support scale across gender groups. The results indicated that, from the configural invariance model to the metric invariance model, CFI remained unchanged ($\Delta\text{CFI} = 0.000$), whereas RMSEA decreased slightly ($\Delta\text{RMSEA} = -0.025$). From the metric invariance model to the scalar invariance model, CFI again showed no change ($\Delta\text{CFI} = 0.000$), and RMSEA further decreased ($\Delta\text{RMSEA} = -0.016$). Because these changes did not exceed the recommended cutoff criterion ($\Delta\text{CFI} \leq 0.01$), the findings support good measurement invariance of the scale across male and female students.

Table S1. Single-Group Confirmatory Factor Analysis for the perceived teacher support Questionnaire

Group	CFI	TLI	RMSEA [90% CI]	SRMR
Man	0.972	0.944	0.158 [0.130, 0.187]	0.023
Woman	0.975	0.95	0.152 [0.125, 0.180]	0.021

Table S2. Gender Measurement Invariance Test for the perceived teacher support Questionnaire

Model	χ^2	df	CFI	TLI	RMSEA [90% CI]	SRMR	ΔCFI	ΔRMSEA
M1: Configural	181.13	10	0.974	0.947	0.155 [0.135, 0.175]	0.019	—	—
M2: Metric	182.52	14	0.974	0.963	0.130 [0.113, 0.147]	0.021	0	-0.025
M3: Scalar	185.14	18	0.974	0.971	0.114 [0.099, 0.129]	0.021	0	-0.016

Chemistry self-efficacy questionnaire

First, single-group confirmatory factor analyses were conducted separately for the male and female samples to examine the factor structure of the chemistry self-efficacy scale. The results showed that, in the male sample, the model fit indices were CFI = 0.991, TLI = 0.981, RMSEA = 0.089 (90% CI [0.061, 0.119]), and SRMR = 0.014. In the female sample, the corresponding fit indices were CFI = 0.974, TLI = 0.947, RMSEA = 0.150 (90% CI [0.123, 0.178]), and SRMR = 0.022. Overall, the CFI and TLI values in both groups exceeded 0.90, and the SRMR values were below 0.08, indicating that the scale showed acceptable model fit across gender groups and could therefore be subjected to further multigroup measurement invariance testing.

Subsequently, to examine the measurement invariance of the chemistry self-efficacy scale across gender groups, configural invariance, metric invariance, and scalar invariance models were tested sequentially. The results indicated that all three models demonstrated acceptable fit. Further comparisons of changes in fit indices showed that, from the configural invariance model to the metric invariance model, $\Delta\text{CFI} = -0.001$ and $\Delta\text{RMSEA} = -0.016$; from the metric invariance model to the scalar invariance model, $\Delta\text{CFI} = -0.002$ and $\Delta\text{RMSEA} = -0.009$. According to the criteria proposed by Chen (2007), namely that ΔCFI should not be lower than -0.01 and ΔRMSEA should not exceed 0.015, these findings support good measurement invariance of the scale across gender groups.



Table S3. Single-Group Confirmatory Factor Analysis for the chemistry self- efficacy Questionnaire

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Group	CFI	TLI	RMSEA [90% CI]	SRMR
Male	0.991	0.981	0.089 [0.061, 0.119]	0.014
Female	0.974	0.947	0.150 [0.123, 0.178]	0.022

Table S4. Gender Measurement Invariance Test for the chemistry self- efficacy Questionnaire

Model	χ^2	df	CFI	TLI	RMSEA [90% CI]	SRMR	Δ CFI	Δ RMSEA
M1: Configural	119.523	10	0.982	0.964	0.124 [0.104, 0.144]	0.016	—	—
M2: Metric	130.154	14	0.981	0.973	0.108 [0.091, 0.125]	0.028	-0.001	-0.016
M3: Scalar	143.746	18	0.979	0.977	0.099 [0.084, 0.114]	0.031	-0.002	-0.009

Chemistry identify questionnaire

Before testing measurement invariance, single-group confirmatory factor analyses were conducted separately for the male and female samples. In the male sample, the model fit indices were CFI = 0.871, TLI = 0.855, RMSEA = 0.086 (90% CI [0.081, 0.090]), and SRMR = 0.063. In the female sample, the corresponding indices were CFI = 0.881, TLI = 0.866, RMSEA = 0.088 (90% CI [0.084, 0.092]), and SRMR = 0.073. Overall, the RMSEA and SRMR values were within acceptable ranges in both groups, supporting further multigroup measurement invariance testing.

Subsequently, configural, metric, and scalar invariance models were tested to examine the measurement invariance of the chemistry identity scale across gender groups. The configural invariance model showed $\chi^2 = 2867.737$, $df = 448$, CFI = 0.877, TLI = 0.861, RMSEA = 0.087, and SRMR = 0.065. The metric invariance model showed $\chi^2 = 2907.113$, $df = 467$, CFI = 0.876, TLI = 0.865, RMSEA = 0.086, and SRMR = 0.067. The scalar invariance model showed $\chi^2 = 3008.184$, $df = 486$, CFI = 0.871, TLI = 0.866, RMSEA = 0.085, and SRMR = 0.069. Further comparisons indicated that, from the configural model to the metric model, Δ CFI = -0.001 and Δ RMSEA = -0.001, and from the metric model to the scalar model, Δ CFI = -0.005 and Δ RMSEA = -0.001.

Table S5 Single-Group Confirmatory Factor Analysis for the chemistry identify Questionnaire

Group	CFI	TLI	RMSEA	RMSEA 90% CI	SRMR
Male	0.871	0.855	0.086	[0.081, 0.090]	0.063
Female	0.881	0.866	0.088	[0.084, 0.092]	0.073

Table S6. Gender Measurement Invariance Test for the chemistry identify Questionnaire

Model	χ^2	df	CFI	TLI	RMSEA [90% CI]	SRMR	Δ CFI	Δ RMSEA
M1: Configural	2867.737	448	0.877	0.861	0.087 [0.084, 0.090]	0.065	—	—
M2: Metric	2907.113	467	0.876	0.865	0.086 [0.083, 0.089]	0.067	-0.001	-0.001
M3: Scalar	3008.184	486	0.871	0.866	0.085 [0.082, 0.088]	0.069	-0.005	-0.001



S2. Standardized Factor Loadings for the QuestionnaireView Article Online
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Table S1 Standardized factor loadings for perceived teacher support questionnaire (N = 1431)

Item	Standardized factor loading
TS1	0.818
TS2	0.912
TS3	0.912
TS4	0.881
TS5	0.826

Note. All factor loadings exceeded 0.40.

Table S2 Standardized factor loadings for chemistry self- efficacy questionnaire (N = 1431)

Item	Standardized factor loading
SE1	0.865
SE2	0.792
SE3	0.88
SE4	0.922
SE5	0.866

Note. All factor loadings exceeded 0.40.

Table S3 Standardized factor loadings for the 23 items of each individual factor of the identify questionnaire (N = 1431)

Dimension	Item	Standardized factor loading
Chemistry learning competence	CI1	0.627
	CI2	0.801
	CI3	0.816
	CI4	0.759
	CI5	0.673
	CI6	0.757
	CI7	0.482
	CI8	0.631
Chemistry classroom interest and performance	CI9	0.72
	CI10	0.473
	CI11	0.549
	CI12	0.649
	CI13	0.714
	CI14	0.644
	CI15	0.677
Chemistry career interest	CI16	0.671
	CI17	0.781
	CI18	0.799
Chemistry recognition	CI19	0.764
	CI20	0.836
	CI21	0.911
	CI22	0.867
	CI23	0.911

Note. All factor loadings exceeded 0.40.



S3. Chinese questionnaire items and corresponding English translations

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Part 1. Demographic and background information

No.	中文题项	English translation	Response options
1	性别	Gender	Female / Male
2	年级	Grade level	Grade10/Grade11
3	你最近一次期中化学考试成绩为:	What was your score in the most recent midterm chemistry examination?	Open-ended
4	你目前是否担任班级学生干部 (如班长、学习委员、课代表等)?	Do you currently hold a formal class leadership position, such as class monitor, learning committee member, or subject representative?	Yes/No
5	高中毕业后,你选择化学或与化学密切相关的大学专业 (如化学、应用化学、材料化学、化学工程、环境化学、生物化学等)的可能性有多大?	How likely are you to choose chemistry or a chemistry-related university major after high school, such as chemistry, applied chemistry, materials chemistry, chemical engineering, environmental chemistry, or biochemistry?	Completely unlikely / Unlikely / Uncertain / Likely / Highly likely
6	你是否参加过学校组织的化学或科技相关活动 (如科技节、实验竞赛、科技社团、化学探究活动等)?	Have you participated in chemistry- or science-and-technology-related activities organized by your school, such as science and technology festivals, experimental competitions, science and technology clubs, or chemistry inquiry activities?	Yes / No
7	父母中是否有人从事与化学或工程技术相关的工作 (教师、科研人员、工程师、技术人员、医生、药师等)?	Is either of your parents engaged in a chemistry- or engineering-related occupation, such as teacher, researcher, engineer, technician, doctor, or pharmacist?	Yes / No

Part 2. Questionnaire 1: Perceived teacher support

Response scale for all items:

1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree.

Item	中文题项	English translation
PTS1	化学老师会倾听我的想法与感受。	My chemistry teacher listens to my thoughts and feelings.
PTS2	化学老师会主动关心我的学习情况并给予指导。	My chemistry teacher actively cares about my learning and provides guidance.
PTS3	化学老师会主动关心我的情绪及学习状态。	My chemistry teacher actively cares about my emotions and learning state.
PTS4	当我遇到困难或挫折时,化学老师会鼓励我。	When I encounter difficulties or setbacks, my chemistry teacher encourages me.
PTS5	我的化学老师会肯定我的进步。	My chemistry teacher acknowledges my progress.

Part 3. Questionnaire 2: Chemistry self-efficacy

Response scale for all items: 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree.

Item	中文题项	English translation
CSE1	我有信心在化学考试中发挥出色,取得令自己满意的成绩。	I am confident that I can perform well on chemistry tests and achieve results that satisfy me.
CSE2	我有信心化学实验和探究活动中表现出色。	I am confident that I can perform well in chemistry experiments and inquiry activities.
CSE3	我相信我可以掌握化学课程的知识与技能。	I believe that I can master the knowledge and skills taught in chemistry courses.
CSE4	我相信我能在化学考试中取得优异的成绩 (或名列前茅)。	I believe that I can achieve excellent results or rank among the top students in chemistry tests.



Item	中文题项	English translation
CSE5	我确信自己能够掌握高中化学课程所要求的知识和技能。	I am certain that I can master the knowledge and skills required in high school chemistry courses.

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Part 4. Questionnaire 3: Chemistry identity

Response scale for all items: 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree.

Dimension	Item	中文题项	English translation
Chemistry learning competence	CI1	我认为自己在化学课堂上的表现很好	I think I perform well in chemistry class.
	CI2	我相信我能够学好化学	I believe that I can learn chemistry well.
	CI3	我能够在化学科目上取得好成绩	I can achieve good grades in chemistry.
	CI4	我能够很好地理解与化学有关的定律和原理	I can understand chemistry-related laws and principles well.
	CI5	我能运用化学解释日常生活中的自然现象	I can use chemistry to explain natural phenomena in everyday life.
	CI6	我认为化学是我的强项	I consider chemistry to be one of my strengths.
	CI7	我能够在化学竞赛项目中获得不错的成绩	I can achieve good results in chemistry competitions.
	CI8	如果我努力尝试, 我相信即便是化学知识中最难的部分我也能够学会	If I try hard, I believe that I can learn even the most difficult parts of chemistry.
Chemistry classroom interest and performance	CI9	我喜欢参与各种与化学有关的活动	I enjoy participating in various chemistry-related activities.
	CI10	我能够完成化学作业	I can complete my chemistry assignments.
	CI11	我认为化学课上学到的知识在现实世界中很重要	I think the knowledge learned in chemistry class is important in the real world.
	CI12	我能在实验中熟练地使用工具和操作仪器	I can skillfully use tools and operate instruments in experiments.
	CI13	我相信我能在化学课上学到很多知识	I believe that I can learn a lot in chemistry class.
	CI14	我喜欢化学课上出现的各种化学器材	I like the various pieces of chemistry equipment used in chemistry class.
	CI15	我能顺利地开展一项化学探究活动	I can successfully carry out a chemistry inquiry activity.
Chemistry career interest	CI16	我有打算在未来从事化学方面的工作	I plan to work in a chemistry-related field in the future.
	CI17	我喜欢上与化学有关的课	I enjoy taking chemistry-related courses.
	CI18	和从事化学行业的人交谈会让我感到很愉悦	Talking with people who work in chemistry-related fields makes me feel happy.
	CI19	我对那些与化学有关的职业感兴趣	I am interested in chemistry-related careers.
Chemistry recognition	CI20	我认为自己是一个精于化学的人	I consider myself to be a chemistry person.
	CI21	同学们认为我是一个精于化学的人	My classmates consider me to be a chemistry person.
	CI22	化学老师认为我是一个精于化学的人	My chemistry teacher considers me to be a chemistry person.
	CI23	家人和朋友认为我是一个精于化学的人	My family and friends consider me to be a chemistry person.



Data Availability Statement

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Due to ethical considerations and privacy protection requirements, the raw data supporting the conclusions of this manuscript will not be made publicly available. These data contain sensitive information, and public sharing may compromise the privacy of the research participants.

However, the anonymized data supporting the main findings of this study are available from the corresponding author, Yurong Liu, upon reasonable request. Researchers who wish to access the data will be required to sign a data access agreement specifying how the data may be used and ensuring that participant confidentiality is maintained.

For further information regarding the data and conditions of access, please contact liuyur66@163.com

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