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ALIGNMENT BETWEEN CURRICULUM STANDARDS AND ASSESSMENT IN UNDERSTANDING CHEMICAL REACTION PRINCIPLES AT UPPER-SECONDARY SCHOOLS

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Abstract. *This study utilized the SEC (Survey of Enacted Curriculum) method to examine the alignment between Chinese high school chemistry curriculum standards (HSCCS) and the assessment of 'Chemical Reaction Principles' in the National College Entrance Examinations (NCEEs). The HSCCS and NCEEs were coded into two-dimensional matrices separately using SPSS, MATLAB, and EXCEL. The alignment coefficients were analyzed both macroscopically and specifically based on two dimensions: themes and cognitive levels. The findings indicated a generally low alignment between NCEEs and HSCCS in the 'Chemical Reaction Principles' domain, and no statistically significant alignment was observed. Comparing Porter alignment coefficients revealed a gradual increase in the overall alignment level between 2018–2022 NCEEs and HSCCS due to curricular reforms. Further specific analyses and comparisons highlighted significant discrepancies between NCEEs and HSCCS concerning themes and cognitive levels. Regarding themes, 'Ionic Reactions and Equilibrium in Aqueous Solutions' showed substantial alignment between NCEEs and HSCCS. However, for 'Application of Ionic Reactions and Equilibrium' and 'Systems and Energy,' NCEEs diverged significantly from or exceeded HSCCS requirements. Concerning cognitive levels, NCEEs demanded higher levels of student cognition compared to HSCCS.*

Keywords: *alignment, chemical reaction principles, content analysis, curriculum standards, upper-secondary schools*

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Introduction

National College Entrance Examinations (NCEEs) hold immense importance in China as a standardized examination determining an individual's eligibility for higher education institutions (Bai et al., 2014; Zivin et al., 2020). As a crucial link between primary and higher education, it plays a vital role in improving educational quality, driving national progress, enabling social mobility, and contributing to the country's modernization (Niu & Liu, 2022; Tian, et al., 2024). Consequently, assessing the NCEEs' quality becomes essential to facilitate the reform of its design and enhance its nurturing function effectively.

In the current context of curriculum reform, standards have become crucial benchmarks for curriculum management and evaluation. They provide a foundation for measuring teaching and learning, serve as a valuable reference for assessment development, and act as a critical model for developing teaching materials (Ministry of Education of China, 2020; Yu et al., 2022). In essence, standards establish precise requirements and expectations that guide classroom instruction and various forms of assessment (Misfeldt et al., 2019; Troia et al., 2018). Enhancing the alignment between essential components of the education system, such as assessment and standards, is paramount to ensuring the quality of education, attaining desired objectives, and facilitating the smooth progression of curriculum reform (Newton & Kasten, 2013; Paik et al., 2011; Qhibi et al., 2020).

The knowledge of 'Chemical Reaction Principles' holds utmost importance in upper-secondary school chemistry education (Ministry of Education of China, 2019, 2020). This essential component introduces students to the fundamental principles and methods of studying chemical reactions, encompassing topics such as energy transformations, the direction, limits, and rates of chemical reactions, and the behavior of substances in aqueous solutions (Harrison & De, 2005, Tyson et al., 1999). These foundational principles are crucial for students to develop a profound understanding of the nature and laws governing chemical reactions (Balcı, 2006; Tyson et al., 1999). Moreover, they not only form the core of basic chemistry knowledge but also serve as an indispensable guide for students' future scientific re-

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search and technological innovation (Ministry of Education of China, 2020). However, in the researcher's teaching practice through unstructured interviews, it was found that students had many difficulties in learning the 'Chemical Reaction Principles', and teachers also found it challenging to teach this part of the subject and to grasp the requirements of exams and standards.

Reviewing the current studies, theories on the alignment between standards and assessment have been abundant (Bonner et al., 2018; Fulmer et al., 2018; Fulmer & Polikoff, 2014), and practice-level case studies have been distributed across the Writing, Science, World Language Programs, Mathematics, and various other disciplines (Copur-Gencturk et al., 2021; Liu et al., 2009; Liu & Fulmer, 2008; Troia et al., 2018). However, the current case studies on alignment are mainly quantitative research on a discipline as a whole, and no studies specifically address the alignment between the standards and assessments in the 'Chemical Reaction Principles' section. Building upon the context above, this research investigates the alignment between the Chinese High School Chemistry Curriculum Standards (HSCCS) and the NCEEs, specifically in the 'Chemical Reaction Principles' domain. Alignment studies explore the overall alignment and differences in the distribution of themes and cognitive levels, analyzing the factors influencing their alignment. The findings of this study hold significance as they can provide teachers and students with scientifically supported and effective strategies for NCEE preparation. Moreover, the research outcomes can offer valuable insights for enhancing the quality of NCEE assessments and contribute to the ongoing progress of curriculum reform.

Literature Review

Curriculum Standards and Related Studies

Starting from the 1970s, there was a significant expansion of school curricula (U.S. Department of Education Office of Educational Technology, 2002), leading to increased diversity and decreased uniformity. This fragmentation of teaching and learning activities created a pressing need for standards to address the disparities in education across schools (Reys et al., 2007). Consequently, countries began developing standardized curriculum standards and initiated education reform movements based on these standards (Klein, 1999). While educational traditions and reform contexts vary among countries, curriculum standards are universally regarded as 'expected student learning outcomes.' They aim to establish clear educational expectations defined by the state and the public, serving as a basis for evaluating the performance of schools and other stakeholders (Klein, 1999; La Marca et al., 2000; Schmidt et al., 2001).

Against this backdrop and within the context of China's revised general high school curriculum standards in 2020 (Ministry of Education of China, 2020), this study defines curriculum standards as guiding documents that outline the nature, philosophy, objectives, structure, content, academic quality, and implementation recommendations of a subject's curriculum (La Marca et al., 2000; Schmidt et al., 2001). These standards form the foundation for establishing teaching objectives for each grade, assessing student performance, and developing teaching materials and test questions (Lu & Liu, 2012; Wei, 2019). Moreover, all references to curriculum standards in this research specifically pertain to the General High School Chemistry Curriculum Standards (2017 Edition Revised 2020) (HSCCS) (Ministry of Education of China, 2020).

In the realm of curriculum standards-based educational reform, researchers have actively delved into the subject of standards-based curriculum reform. Current research on curriculum standards primarily encompasses government documents and reports (Drake & Burns, 2004), the process of standards development (Webb, 2007), comparative analyses of curriculum standards across different countries (Wei & Ou, 2019), and the practical application and evaluation of standards within specific classroom teaching contexts (Park et al., 2019). These research endeavors collectively contribute to understanding and advancing curriculum standards and their implementation in education.

Alignment Analysis of Curriculum Standards and Assessment

In the education system, alignment primarily refers to the extent of coherence among various key components such as curriculum, teaching, and assessment (Lu & Liu, 2012; Webb, 2007; Yang, 2023). This study defines alignment as the degree of correspondence between HSCCS and NCEEs. Currently, analysis related to alignment within the domain of standards-based curriculum focuses on four key areas (Table 1): alignment between standards and assessment; alignment between standards and teaching; alignment between standards and teaching materials; alignment between school learning and assessment, and alignment among three or more educational elements.

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Table 1
Alignment Related research

Alignment Research Areas	Related Studies
Standards & Assessment	Contino, 2013; Flowers et al., 2006; Lu & Liu, 2012; Martone & Sireci, 2009; Newton & Kasten, 2013; Troia et al., 2018
Standards & Teaching	Kurz et al., 2010; Liu et al., 2009; Taub et al., 2020; Yang, 2023;
Standards & Teaching Materials	Polikoff, 2015; Yu et al., 2022
School Learning & Assessment	Kara & Cepni, 2011
Three or More Educational Elements	Mohamud & Fleck, 2010; Roach et al., 2008

Among these areas, the alignment between assessment and standards has been extensively studied. Research in this domain has primarily focused on examining the alignment between the two, employing quantitative congruence methods to estimate the match between assessments and state content standards in different regions (Flowers et al., 2006). Other studies have analyzed the alignment between physics curriculum standards and teacher instructional content in countries such as China and Singapore (Liu et al., 2009). Additionally, researchers have explored the relationship between the level of congruence between (assessment + standards) and student learning outcomes. Troia et al. (2018) employed text content coding to examine the congruence between US state English writing standards and assessments, exploring measures of content range, frequency, balance, cognitive complexity, and their correlation with student writing achievement. Discussions on common methods for conducting congruence analyses between assessment and standards have also been prevalent. Martone and Sireci (2009) describe the three most commonly used methods, highlight their strengths and limitations, and provide examples of their applications.

Theoretical Framework of Alignment Analysis: SEC Alignment Method

Current research related to alignment analysis in the curriculum domain has primarily employed three models: Webb (Webb, 1999), SEC (Blank et al., 2001; Porter et al., 2007; Porter & Smithson, 2001, 2002), and Achieve (Resnick et al., 2004). These models differ significantly in their evaluation frameworks and dimensions, each possessing distinct characteristics and applications (Martone & Sireci, 2009). Among the three models, the Porter Alignment Index of the Survey of Enacted Curriculum (SEC) alignment model is a reliable indicator of improved student performance, displaying a high correlation with other alignment indicators (Porter & Smithson, 2021, 2002). Moreover, the coding process used for Porter alignment analysis has been demonstrated to be highly reliable (Porter & Smithson, 2021, 2002). Given the quantitative nature of this study and the need for a common measurable standard, the SEC alignment analysis was chosen.

The SEC model of alignment analysis was developed by Porter and Smithson in 2001. This model focuses on constructing a 'content-cognitive level' matrix to assess the degree of alignment between student achievement and classroom instruction (Blank et al., 2001; Polikoff et al., 2011). Alignment, according to Porter (2002), emerged as a core concept in educational reform centered around curriculum standards that transformed the education system and influenced curriculum resources, teachers' professional development, and examinations and assessments (Blank et al., 2001; Polikoff et al., 2011; Porter & Smithson, 2001).

Alignment analysis supported by the SEC model involves constructing a two-dimensional matrix representing curriculum standards, classroom teaching, or academic assessment, with two dimensions: learning content and cognitive requirements. The alignment coefficients, denoted as *P*, are calculated by comparing the data with reference values obtained through statistical software to determine the degree of alignment (Porter & Smithson, 2001; Porter, 2002). The alignment coefficient formula is as follows (1):

$$P = 1 - \frac{\sum \left| X - Y \right|}{2} \quad (1)$$

In this formula, X represents specific target numbers in matrix 1, while Y represents specific target numbers in matrix 2. The Porter Alignment Index (*P*) ranges between 0 and 1, with values closer to 1 indicating greater

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alignment and values closer to 0 indicating more significant deviation (Lu & Liu, 2012; Porter & Smithson, 2001).

Research Questions

This study employs the SEC analysis method to examine the alignment between the HSCCS and the 2018–2022 NCEEs in the 'Chemical Reaction Principles' at the Chinese upper secondary level. The study aims to address the following three questions:

1. What is the overall alignment between the HSCCS and the NCEEs?
2. To what extent is there alignment between the HSCCS and the NCEEs in terms of themes of 'Reaction Systems and Energy', 'Direction, Limits, and Rates of Chemical Reactions', and 'Ionic Reactions and Equilibria in Aqueous Solutions'?
3. What is the level of alignment between the HSCCS and the NCEEs regarding cognitive level?

Research Methodology

The Development of the Alignment Analytical Framework

In this study, the HSCCS (2017 Edition 2020 Revision) issued by the Ministry of Education of China (Ministry of Education of China, 2020) and the 2018–2022 NCEEs (National 1/B Version) were selected as the study materials. Specifically, the study focused on the 'Chemical Reaction Principles' section of upper-secondary school chemistry to help teachers clarify the direction and focus in teaching this section and, in turn, help students solve their long-standing difficulties in learning the 'Chemical Reaction Principles'. To facilitate the analysis, an alignment analysis framework was designed based on the HSCCS and SEC analysis methods (Liu & Fulmer,2008; Porter, 2002). Based on the coding principles (Wei & Ou, 2019, Yu et al., 2022), the HSCCS and 2018–2022 NCEEs were then coded and transformed into two-dimensional matrixes: Theme and Cognitive Level.

1. The Categories of Themes in the 'Chemical Reaction Principles'

Because of the large number of knowledge points in this part of 'Chemical Reaction Principles', the themes need to be divided appropriately and rationally. The concept of 'Chemical Reaction Principles' was divided into three dimensions and 11 themes according to the conceptual system of the HSCCS (Table 2) (Ministry of Education of China, 2020). HSCCS include 3 main themes, 11 sub-themes, and 40 knowledge points. 40 knowledge points were chosen as the basis for coding because they are more clearly and precisely expressed.

Table 2
Themes in the 'Chemical Reaction Principles' (Ministry of Education of China, 2020)

Main Theme	Sub-Theme
Reaction Systems and Energy	Systems and Energy
	Chemical Reactions and Thermal Energy
	Chemical Reactions and Electrical Energy
Direction, Limits, and Rates of Chemical Reactions	Direction and Limits of Chemical Reactions
	Chemical Reaction Rate
	Modulation of Chemical Reactions
Ionic Reactions and Equilibria in Aqueous Solutions	Behavior of Electrolytes in Aqueous Solutions
	Ionization Equilibrium
	Hydrolytic Equilibrium
	Precipitation Dissolution Equilibrium
	Application of Ionic Reactions and Equilibria

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2. The Identification of Cognitive Levels

In this research, the 5 levels of cognitive level in the existing SEC analysis method (Porter, 2002; Porter & Smithson, 2002) were adapted and reclassified into three levels according to the curriculum standards and the relevant research findings of subject experts (Ministry of Education of China, 2020; Motlhabane, 2017; Yu et al., 2022). The reason for the adaptation and classification based on the new curriculum was that:

(1) Curriculum standards were developed by experts in the field based on national conditions and long-term research and were relatively authoritative and referable (Klein, 1999; Ministry of Education of China, 2020).
(2) The requirements of the curriculum standards for each part of the subject matter were expressed as a combination of behavioral verbs and specific knowledge points, and specific behavioral verbs such as know, understand, or master were used to describe the level that students need to achieve (Ministry of Education of China, 2020), which could help researchers to make judgments about the cognitive level of each knowledge point in the curriculum standards.
(3) Teachers mainly taught according to the cognitive levels required by the curriculum standards. They knew little about the 5 cognitive levels they were accustomed to using in the original SEC alignment analysis model; therefore, the localized modification of the cognitive levels according to the curriculum standards could more accurately reflect the teachers' chemical reactions.

According to the requirements of the new curriculum and the analysis and interpretation of experts, the cognitive learning objectives of NCEEs were divided into 3 different levels, each level corresponding to a specific descriptive verb, namely: 'Level A', 'Level B', and 'Level C'. The behavioral verbs corresponding to each cognitive level are shown in Table 3 below.

Table 3
Cognitive Levels for Each Behavioral Verb of the Curriculum Standards

Cognitive level	Behavioral verb
A	Know, say, identify, describe, example, list
B	Understand, can express, identify, distinguish, and compare
C	Master, apply, explain, explain, predict, classify, summarize, and analyze

3. SEC Alignment Analytical Framework for 'Chemical Reaction Principles'

The alignment analytical framework based on the above coding methods was generated, as Table 4 shows.

Table 4
Alignment Analysis Framework

Dimensions	Themes	Cognitive level			Summation
		A	B	C	
Reaction Systems and Energy	Systems and Energy				
	Chemical Reactions and Thermal Energy				
	Chemical Reactions and Electrical Energy				
Direction, Limits, and Rates of Chemical Reactions	Direction and Limits of Chemical Reactions				
	Chemical Reaction Rate				
	Modulation of Chemical Reactions				

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Dimensions	Themes	Cognitive level			Summation
		A	B	C	
Ionic Reactions and Equilibria in Aqueous Solutions	Behavior of Electrolytes in Aqueous Solutions				
	Ionization Equilibrium				
	Hydrolytic Equilibrium				
	Precipitation Dissolution Equilibrium				
	Application of Ionic Reactions and Equilibria				
	Summation				

Coding and Data Analysis

Once the alignment analysis framework has been established, it is necessary to code the HSCCS and the 2018–2022 NCEEs separately according to the framework and then analyze their alignment. The resulting content matrices were converted into ratio matrices to compare the degree of alignment between the HSCCS and the NCEEs. The study employed an overall analysis by calculating the Poter alignment coefficient, followed by a specific analysis of the two dimensions (themes and cognitive level). This approach aimed to evaluate the quality of the NCEEs and gain insights into the level of alignment with the curriculum standards.

1. Coding and analysis of HSCCS

The dimension 'Reaction Systems and Energy' was coded as "1", 'Direction, Limits, and Rates of Chemical Reactions' was coded as "2", etc. Under each dimension, some themes were coded as "1.1", "1.2", and "1.3" .... E.g., the theme 'Systems and energy' under the first dimension was coded as "1.1", and 'Chemical Reactions and Thermal Energy' was coded as "1.2". These themes were juxtaposed. There are specific knowledge points under the themes that were coded as "1.1.1" and "1.1.2" .... Based on the above coding method, three levels of numerical coding were formed in the thematic dimension.

In addition, in the HSCCS, the objective descriptions of specific knowledge points are in the form of 'action verb + knowledge point', so the cognitive level of each knowledge point can be judged according to the cognitive level of the action verb. E.g., in the curriculum standard, there is such an objective as 'The working principle of primary batteries and common chemical power sources', which corresponds to the behavior verb 'understand'. This behavior verb belongs to 'level B', so it is counted as "1" in the cell of 'level B' of 'chemical reactions and electrical energy'.

During the actual coding process, some problems were encountered. To conduct the study better, the following coding principles were established:

(1) If there are multiple knowledge points in the description of the same knowledge objective, coders should choose to code the knowledge points separately (Yu et al., 2022). For example, in 'Understand the principles of salt hydrolysis and the main factors affecting salt hydrolysis', 'The principles of salt hydrolysis', and 'The main factors affecting salt hydrolysis' were two knowledge points. In this case, the two knowledge points should be coded separately. Since both knowledge points belong to the theme 'Chemical reactions and electrical energy' and since they both correspond to a cognitive level of 'Level B', they are counted as 2 on the 'Level B' cell of the two-dimensional content matrix 'Chemical reactions and electrical energy'.

(2) In the coding process, if a knowledge point contains more than one behavioral verb, the behavioral verb with the highest cognitive level is selected to code the knowledge point (Wei & Ou, 2019). For example, in the expression of the knowledge point 'Understand Hess law and its simple application', the behavioral verbs for 'Hess law' include 'understand (cognitive level B)' and 'apply (cognitive level C)', in this case, according to the principle of 'on high, not low', 'Hess law' is coded as level C at the cognitive level, so the cell of level C in the content matrix 'Chemical reactions and heat energy' counts 1.

(3) If a knowledge point contains only experiential target behavior verbs, the knowledge point should not be coded.

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(4) If an objective statement contains multiple types of behavioral verbs, such as outcome and experiential, only the behavioral verbs of the outcome objective are considered. E.g., 'To understand the effects of concentration, pressure, and temperature on chemical equilibrium through experimental investigation' contains two verbs: 'investigate' and 'understand'. In this case, only 'to understand' is coded, and the process verb 'to investigate' is not coded.

According to the above coding principles, two graduate students in the program coded the curriculum standards separately. The Pearson correlation coefficient between the two coding results was calculated using SPSS at 0.985 ($p = .01$), indicating that the coding data of this study are stable and reliable. After thorough discussion and negotiation regarding the inconsistencies in the coding results between the two individuals, the final coding of the standards was determined (Table 5). To facilitate the subsequent alignment analysis, the two-dimensional content matrix criteria were transformed into a two-dimensional ratio matrix with the ratio integrated equal to 1.

Table 5

Two-Dimensional Content (Ratio) Matrix of The Curriculum Standards

Dimensions	Themes	Cognitive level			Summation
		A	B	C	
Reaction Systems and Energy	Systems and Energy	2 (0.050)	2 (0.050)	0 (0.000)	4 (0.100)
	Chemical Reactions and Thermal Energy	0 (0.000)	2 (0.050)	1 (0.025)	3 (0.075)
	Chemical Reactions and Electrical Energy	1 (0.025)	5 (0.125)	1 (0.025)	7 (0.175)
Direction, Limits, and Rates of Chemical Reactions	Direction and Limits of Chemical Reactions	3 (0.075)	3 (0.075)	0 (0.000)	6 (0.150)
	Chemical Reaction Rate	2 (0.050)	3 (0.075)	0 (0.000)	5 (0.125)
	Modulation of Chemical Reactions	1 (0.025)	1 (0.025)	0 (0.000)	2 (0.050)
Ionic reactions and equilibria in aqueous solutions	Behavior of Electrolytes in Aqueous Solutions	0 (0.000)	1 (0.025)	0 (0.000)	1 (0.025)
	Ionization Equilibrium	0 (0.000)	5 (0.125)	1 (0.025)	6 (0.150)
	Hydrolytic Equilibrium	0 (0.000)	2 (0.050)	0 (0.000)	2 (0.050)
	Precipitation Dissolution Equilibrium	0 (0.000)	2 (0.050)	0 (0.000)	2 (0.050)
	Application of Ionic Reactions and Equilibria	0 (0.000)	0 (0.050)	2 (0.050)	2(0.050)
	Summation	9 (0.225)	26 (0.650)	5 (0.125)	40 (1.000)

Note: Values in parentheses are ratio matrices, values outside parentheses are content matrices

2. Coding and Analysis of NCEEs

When coding the NCEEs, all the items involving the knowledge points of the 'Selective Compulsory 1: Chemical Reaction Principles' were screened, and the solution process was also listed first. Then, according to the theme and cognitive level of the knowledge points involved in each step, the corresponding scores were filled into the cells of the corresponding two-dimensional content matrix, forming a two-dimensional matrix with scores as units, and then standardized into a two-dimensional ratio matrix. The analysis of the NCEE questions revealed that there are two types of questions involving chemistry: single-choice and subjective fill-in-the-blank questions. For single-choice questions, there are four options, sometimes involving different knowledge points, so when processing them, it is necessary to code each option separately and convert 6 points per question into one option, i.e., 1.5 points, to fill in the corresponding knowledge point and cognitive level two-dimensional framework. In addition, the subjective questions also need to be coded precisely to each blank of each sub-question. Similarly, if there is more than one knowledge point per blank, the marks of this blank will be equally distributed and filled into the two-dimensional matrix. The coding results (two-dimensional matrix) for the 2018–2022 NCEEs are shown in Appendix 1.

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3. Alignment Comparison

The data collected and coded were filled into the cells of the corresponding matrix to obtain the two-dimensional content matrices of the corresponding HSCCS and the NCEEs for a particular year. The alignment coefficient *P* was used to determine whether the HSCCS are effectively implemented in the NCEEs using the unadorned function in MATLAB (Porter & Smithson, 2001; Porter, 2002).

In addition, Porter's alignment coefficient *P* only reflects the degree of alignment between the NCEEs and the HSCCS in general. However, it does not allow for an in-depth discussion and analysis of the specific alignment or deviation of the themes and cognitive levels of the two subjects (Porter & Smithson, 2001; Lu & Liu, 2012). The concept of 'ratio differential' was introduced to analyze the degree of deviation or alignment between any two variables at each theme or cognitive level (Yang, 2023; Yu et al., 2022). The formula for calculating the ratio difference is as follows:

$$\Delta R=|R_x-R_y| \quad (2)$$

R_x represents the ratio of a theme to a cognitive level in the NCEE questions, and R_y is the ratio of a theme to a cognitive level in the curriculum standards. R>0 means that the ratio of a content topic or cognitive level in the NCEEs is higher than that required by the curriculum standards, and vice versa. ΔR represents the degree of deviation between these two variables, with larger values indicating a greater unalignment.

Research Results

Overall Alignment Results

Bringing the ratio matrix of the 2018–2022 NCEEs and the ratio matrix of the HSCCS into the Porter alignment coefficient formula gives an overall picture of the alignment of the 2018–2022 NCEEs with the HSCCS. The Porter alignment coefficient formula is as follows:

$$P = 1 - \frac{\sum_{i=1}^{n} |X_i - Y_i|}{2} \quad (3)$$

(n denotes the number of cells in each ratio matrix. The previously defined alignment analysis framework results in an '11*3' content matrix, so n equals 33 in this study; represents the value of cell i in the two-dimensional ratio matrix of the HSCCS; denotes the value of cell i of the NCEE rate matrix)

The alignment coefficients for the 2018–2022 NCEEs and the HSCCS were obtained from the Porter coefficients coefficient formula above, as shown in Table 6. The *P* values range from 0 to 1, with higher values representing a higher degree of alignment between the NCEEs and the HSCCS.

Table 6
Porter Alignment Coefficient for 2018–2022 NCEEs and HSCCS

Test Year	2018	2019	2020	2021	2022
P	.40	.45	.44	.47	.52

To more accurately study the degree of alignment between the 2018–2022 NCEEs and the HSCCS, the Unidrnd function in Matlab software was used to randomly assign the 40 knowledge points in the HSCCS and the marks of the 'Chemical Reaction Principles' in each year's NCEE to two "11×3" two-dimensional content. The matrix was used to calculate the critical value of the alignment coefficient at the 0.05 significance level, i.e., the minimum acceptable level of alignment in this case. The threshold values for significant alignment between the HSCCS and the NCEEs in this study are shown in Table 7. Only when the alignment coefficient of the test is greater than the threshold value will the assessment be statistically significant and aligned with the standards.

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Table 7
Means, Standard Deviations, and Critical Values of P Under Normal Distribution

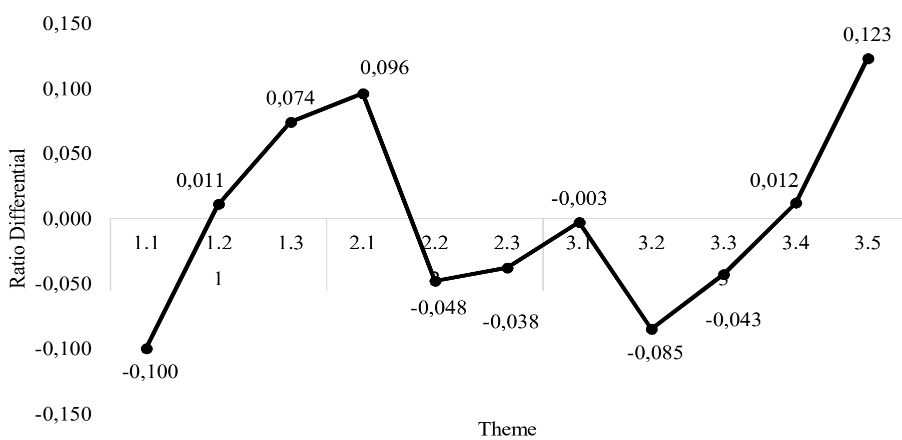
Test Year	M_P	SD_P	TH_P	Difference between P and the alignment threshold
2018	.46	.07	0.54	.14
2019	.46	.07	0.59	.14
2020	.49	.07	0.60	.16
2021	.48	.07	0.57	.10
2022	.42	.07	0.57	.05

From the parameters related to the P-values in Table 7, it can be seen that there is no statistically significant alignment between the 2018–2022 NCEEs and the HSCCS in the 'Chemical Reaction Principles'. Among the five sets of assessments, the level of alignment between the NCEEs and the HSCCS is the highest in 2022, followed by 2021, and the worst in 2020. In general, the alignment between the NCEEs and the HSCCS increased year by year with the advancement of the new curriculum reform, except for 2020.

Alignment Result of Themes

A comparison of the average distribution of the 2018–2022 NCEEs on each theme with the distribution of each theme required by the HSCCS is in Figure 1.

Figure 1
Difference Between the Average Rate of NCEEs in Each Content and The Rate of the HSCCS



Note: 1: Reaction Systems and Energy; 2: Direction, Limits, and Rates of Chemical Reactions; 3: Ionic Reactions and Equilibria in Aqueous Solutions; 1.1: Systems and Energy; 1.2: Chemical Reactions and Thermal Energy; 1.3: Chemical Reactions and Electrical Energy; 2.1: Direction and Limits of Chemical Reactions; 2.2: Chemical Reaction Rate; 2.3: Modulation of Chemical Reactions; 3.1: Behavior of Electrolytes in Aqueous Solutions; 3.2: Ionization Equilibrium; 3.3: Hydrolytic Equilibrium; 3.4: Precipitation Dissolution Equilibrium; 3.5: Application of Ionic Reactions and Equilibria

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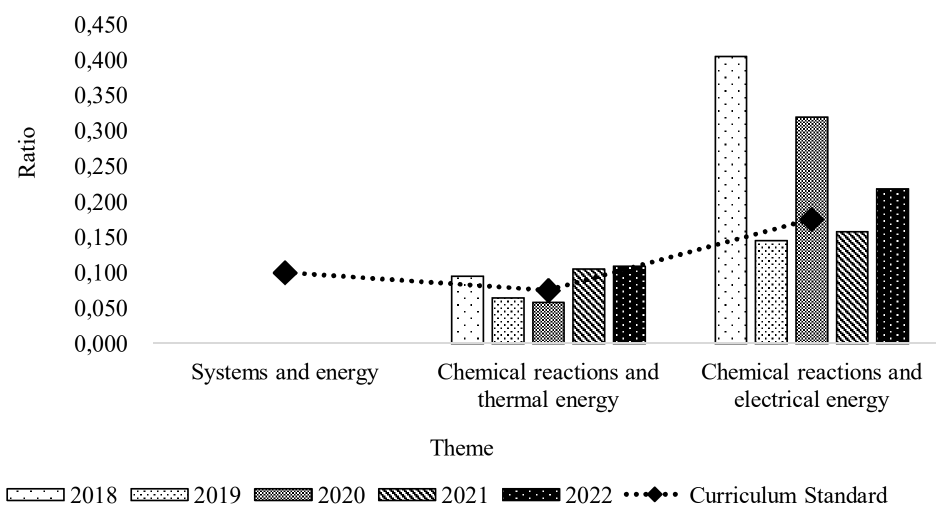
As can be seen from Figure 1, NCEE averages are higher than the requirements of the HSCCS for five themes: 'Chemical Reactions and Thermal Energy', 'Chemical Reactions and Electrical Energy', 'Directions and Limits of Chemical Reactions', 'Precipitation Dissolution Equilibria' and 'Applications of Ionic Reactions and Equilibria', while the remaining six themes are lower than the requirements of the HSCCS. Across all themes, the absolute ratio differential for 'Systems and Energy', 'Chemical Reactions and Electricity', 'Directions and Limits of Chemical Reactions', 'Ionization Equilibria and Applications of Ionic Reactions and Equilibria' were higher than 0.05, indicating that these five parts of the examination showed significant deviations from the HSCCS, with the largest deviations being in 'Systems and Energy' and 'Application of Ionic Reactions and Equilibria', with the absolute value of the ratio difference between them exceeding 0.1.

1. Dimension of 'Chemical Reactions and Energy'

An analysis of the alignment of the dimension of 'Chemical Reactions and Energy' (Figure 2) shows that the theme with the highest degree of alignment is 'Chemical Reactions and Thermal Energy', and the distribution of NCEE each year does not vary much from the requirements of the HSCCS. The greatest overall difference was in the 'Systems and Energy', which was not examined in any of the five years' NCEEs. For 'Chemical Reactions and Electrical Energy', the actual NCEEs in 2019, 2021, and 2022 were less different from the HSCCS, while the NCEEs in 2018 and 2020 exceeded the requirements of the curriculum standards.

Figure 2
Comparison of the Thematic Dimensions on 'Chemical Reactions and Energy' in the 2018–2022 NCEEs and HSCCS



2. Dimension of 'Direction, Limits, and Rates of Chemical Reactions'

For dimensions of 'Directions, Limits, and Rates of Chemical Reactions', as can be seen from Figure 3, the gap between the HSCCS and the NCEEs is relatively large compared to 'chemical Reactions and Energy', and there are significant gaps for all three themes. For 'Directions and Limits of Chemical Reactions', all five years of the NCEEs exceeded the requirements of the HSCCS, while for 'Regulation of Chemical Reactions', the requirements of the HSCCS were largely missed. For 'Rates of Chemical Reactions', the 2018 and 2019 NCEEs do not differ significantly from the HSCCS, while in the latter three years' NCEEs, they are largely unexamined, which is a significant gap from the HSCCS.

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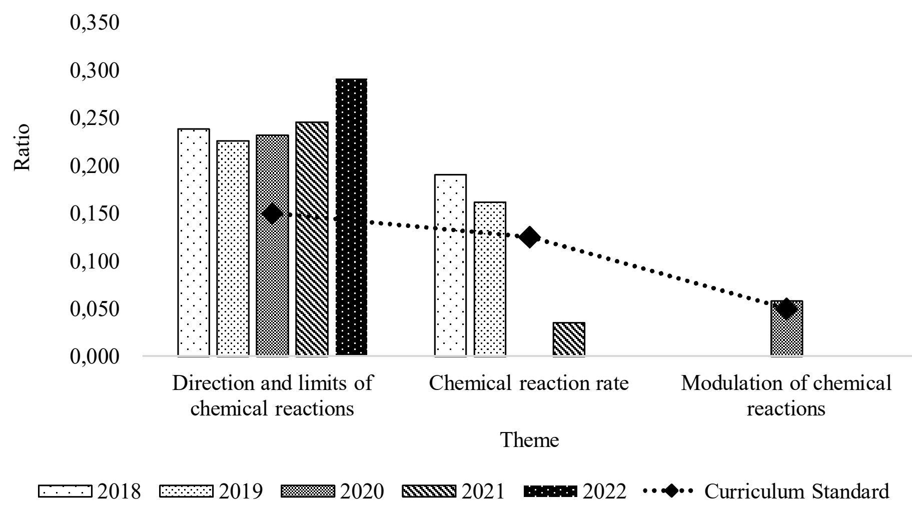
Figure 3

Comparison of the Thematic Dimensions on 'Direction, Limits, and Rates of Chemical Reactions' in the 2018–2022 NCEEs and HSCCS

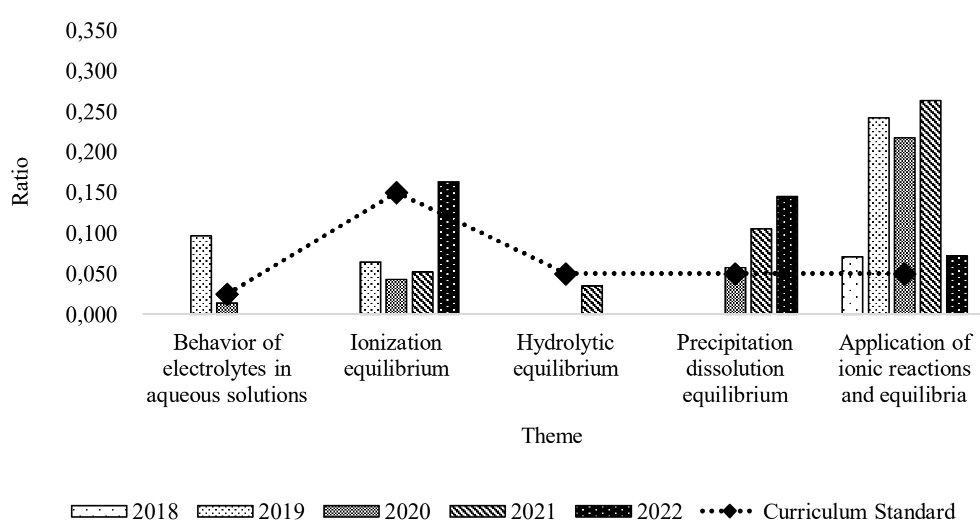


3. Dimension of 'Ionic Reactions and Equilibria in Aqueous Solutions'

For dimensions of 'Ionic Reactions and Equilibria in Aqueous Solutions', there were relatively large differences between the NCEEs and the HSCCS (Figure 4). For the 'Ionic Reactions and Equilibria in Aqueous Solutions', the five-year NCEEs were generally above the requirements of the HSCCS, while for the other four themes, the NCEEs did not meet the requirements of the HSCCS in all years except for a few years when the requirements of the HSCCS were slightly exceeded.

Figure 4

Comparison of the Thematic Dimensions on 'Ionic Reactions and Equilibria in Aqueous Solutions' in the 2018–2022 NCEEs and HSCCS



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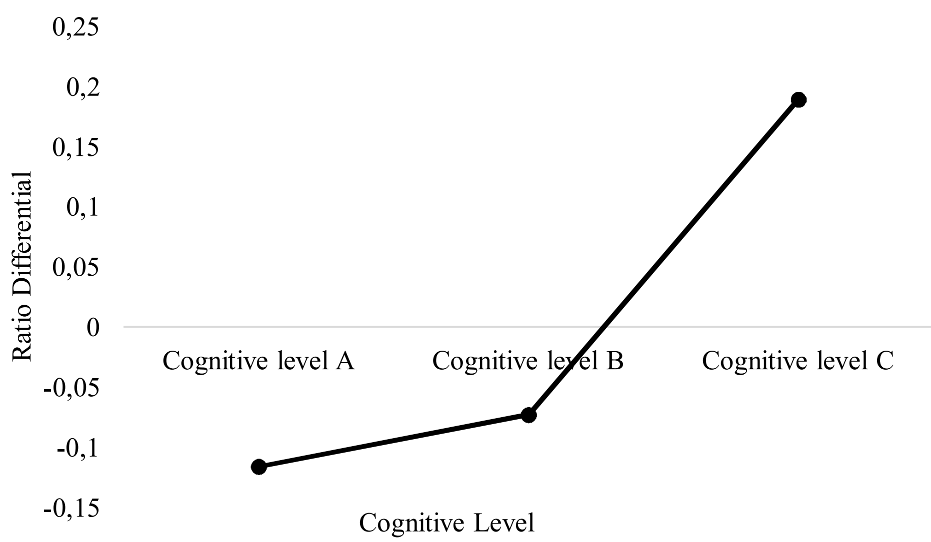
Alignment Result of Cognitive Levels

The mean ratio differential between the HSCCS and the distribution of the last five-year NCEEs for each cognition level were also analyzed. Overall, there is a wide gap between the average examination of students' cognitive levels in the recent 5-year NCEEs and the HSCCS, with the absolute ratio difference between the two being above 0.05 (Figure 5). A relatively good alignment is found at Level B, followed by Level A, with Level C showing the poorest. At Level C, the NCEEs were tested well above the requirements of the HSCCS.

Figure 5

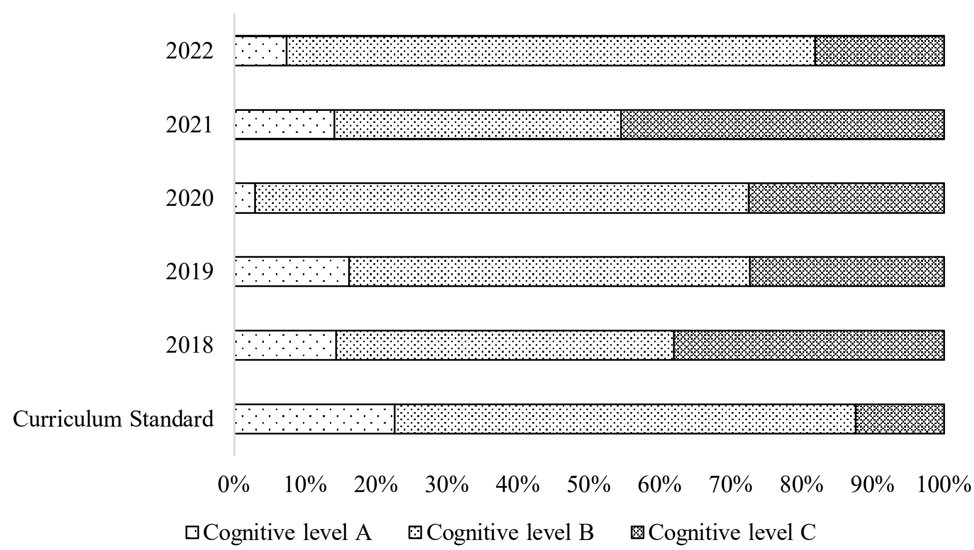
Difference Between the Average Examination Rate of NCEEs and the HSCCS Requirement Rate for Each Cognitive Level



Further Analysis of the differences in cognitive level of examination between the NCEEs and the HSCCS for each year was carried out, and the results are shown in Figure 6.

Figure 6

HSCCS Requirement and Percentage Distribution of 2018–2022 NCEEs Across Cognitive Levels



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As can be seen from Figure 6, at the 'Level A' cognitive level, the 2019 NCEE has the highest percentage of questions at 0.161, which is also the most consistent with the curriculum standard but still slightly below the curriculum standard of 0.225, while the 2020 NCEE has the lowest percentage of questions at 0.029. At the 'Level B' cognitive level, the 2022 NCEE has the highest percentage of questions at 0.745, and the 2020 NCEE also has a high percentage at 0.696. The remaining three years' NCEEs are at a rate lower than the curriculum standard, with the 2021 NCEE being the lowest at 0.404. At cognitive level C, the 2021 NCEE is the most tested at a rate of 0.456, followed by the 2018 NCEE at 0.381. The 2022 NCEE is the smallest, with a ratio of 0.182. In addition, 2018–2022 NCEEs all tested the 'Chemical Reaction Principles' section at a ratio exceeding the curriculum standards for cognitive level C.

Discussion

Using the SEC alignment analysis method, this study coded the HSCCS and the 2018-2022 NCEEs into six matrixes and compared their alignment levels from the dimensions of overall alignment, content alignment, and cognitive level alignment.

For the overall alignment level, the findings of this study indicate that there is a lack of significant alignment between the HSCCS and the NCEEs in China. This is consistent with previous research findings, which have also shown similar misalignment issues between the NCEEs, textbooks, and curriculum standards in the field of biology in China (Lu & Liu, 2012; Sun & Li, 2021; Yu et al., 2022). This study extends this issue to the field of chemistry and further confirms the existence of such misalignment problems in multiple subjects. This may result from several reasons. Firstly, the examination system may emphasize the assessment of student's knowledge, while educational objectives of standards may focus on cultivating students' comprehensive qualities and practical application abilities (Hong et al., 2019). This may cause some differences between the examination system and educational objectives. Secondly, the updating of textbooks and curriculum standards requires time and resources, while the development of examination questions may be faster and more flexible (Solomon, 2009). This can also result in misalignment between examinations and the latest educational requirements. Additionally, because of time, resources, and other limitations, the examination may have difficulties in comprehensively covering all aspects of the educational curriculum, thereby leading to misalignment with curriculum standards (Weir, 2005).

Regarding the year comparison, the study also finds the overall alignment between the HSCCS and NCEEs varies over time. Although the overall alignment levels are not high, the alignment between the two has progressively improved as the years have passed. This can be attributed to the curriculum reforms undertaken in China in recent years, as well as the revisions made to the curriculum standards based on the lessons learned from these reforms (Yao & Guo, 2018). The latest version of the curriculum standards was issued in 2017 and revised in 2020 (Ministry of Education of China, 2020). The 2018 NCEE was the first examination conducted after the release of the new curriculum standards, and it is possible that question writers may not have been fully acquainted with the updated standards at that time (Liang & Yuan, 2008; Liu et al., 2009; Lu & Liu, 2012). However, since then, the NCEEs have been gradually aligning with the curriculum standards, except for a possible deviation in 2020, which suggests the success of the Chinese national training for NCEE question proposers. In the future, it is crucial to continue providing training activities in various areas to ensure that question proposers have a deep understanding of the curriculum standards, can accurately assess students' knowledge, and improve the quality of the NCEEs (Flowers et al., 2006; Lu & Liu, 2012).

For the comparison of the content level, the average distribution of the five-year NCEE questions is closer to the curriculum standard for the theme of 'Behavior of electrolytes in aqueous solutions', with only a minimal absolute difference of 0.003. On the other hand, the biggest differences were observed in the themes of 'Application of ionic reactions and equilibrium' and 'Systems and energy', with absolute ratio differences exceeding 0.1. The NCEEs fell significantly short of the curriculum standard requirements for 'Systems and energy', while the examination questions for 'Ionic reactions and applications of equilibrium' went beyond the curriculum standard requirements. Moreover, the study categorized the themes of each dimension into three categories and further analyzed the specific gaps between the questions of each year and the curriculum standards. This analysis provides valuable insights for future improvements in the quality of examination questions.

In terms of cognitive levels, there are also significant differences in the distribution between the NCEEs and the HSCCS. Compared to the curriculum standards, the NCEEs tend to focus more on higher cognitive levels while neglecting a comprehensive assessment of students' foundational knowledge. Previous research also found the same results in mathematics education (Hong et al., 2019). This may be attributed to the purpose and role of the NCEEs. As a college entrance examination, the NCEEs aim to evaluate students' comprehensive abilities and ap-

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plication skills at a higher level, selecting outstanding talents (Wang, & Rao, 2022). Therefore, the examination questions are often designed to emphasize higher cognitive skills such as analysis, synthesis, and evaluation (Zou, 2018). In contrast, the curriculum standards place more emphasis on students' mastery of foundational knowledge and core concepts, laying a solid foundation for their future learning and career development.

Conclusions and Implications

Using the coded data from the curriculum standards and the 2018–2022 NCEEs as the sample of the study, the knowledge involving 'Chemical Reaction Principles' was divided into two dimensions, vertical in terms of themes and horizontal in terms of cognitive level, to construct an alignment analysis framework, and the alignment between the two was analyzed, resulting in the following conclusions. The 'Chemical Reaction Principles' section had no statistically significant alignment between the NCEEs and the curriculum standards. The NCEEs differed significantly from the curriculum standards in terms of themes, on average, being more consistent for 'ionic reactions and equilibria in aqueous solutions'; the examination of 'Application of ionic reactions and equilibria' and 'Systems and energy' deviated significantly from the curriculum standard, falling far short of or exceeding the requirements of the curriculum standard. The examination of each dimensional topic was not well balanced from year to year. The chemistry NCEEs also varied relatively markedly regarding cognitive level with the curriculum standard. Compared with the curriculum standards, the NCEEs have raised the cognitive demands on students.

The findings of this study have implications for the field of chemistry education. Firstly, the alignment analysis framework used in this study provides theoretical references for future alignment studies in other disciplines and fields. The methodology and insights gained from this study can be applied to examine the alignment between examination questions and curriculum standards in subjects beyond chemistry. This expands the potential impact of the study and contributes to the broader field of educational research. Secondly, the results of this study serve as a reference for future reforms in classroom teaching and examination practices. By aligning the examination questions with the curriculum standards, educators can ensure that the teaching and assessment methods are more closely aligned with the requirements of the curriculum. This alignment will help create a more effective learning environment for students, meeting their cognitive needs and promoting a deeper understanding of the subject matter. Thirdly, for teachers, these findings guide teachers in terms of the direction and focus of their teaching. By understanding the gaps and inconsistencies between the examination questions and curriculum standards, teachers can better prioritize and emphasize critical knowledge and concepts in their teaching. This will enhance the quality of instruction and improve student learning outcomes. Finally, for students, the findings of this study benefit them directly by helping them master the relevant critical knowledge more effectively. By aligning the examination questions with the curriculum standards, students will have a clearer understanding of what is expected of them and can focus their efforts on acquiring the essential knowledge and skills. This alignment will ultimately contribute to improved student performance and achievement. In summary, this study informs classroom teaching and examination reforms, guiding teachers in their instructional practices, enhancing student mastery of critical knowledge, and providing theoretical references for alignment studies in other disciplines. These implications contribute to the advancement of chemistry education and have broader implications in the field of educational research.

Limitations and Future Study

This study has certain limitations. Firstly, due to time and resource constraints, the study only focused on the module "Chemical Reaction Principles" in high school chemistry and did not analyze other modules. Therefore, future research will address these limitations and explore other modules in chemistry to gain a more comprehensive understanding of the gaps and inconsistencies between examination questions and curriculum standards. By doing so, researchers can provide valuable insights for future reforms of examination questions, ensuring that the questions align more closely with the curriculum standards and promote a deeper understanding of the subject matter. Additionally, this study only focused on the analysis of standards and entrance examination questions, without extending to other elements of the education system for a comprehensive alignment assessment. Future research will expand the study of alignment to other essential elements of the education system, such as high school chemistry curriculum standards, textbooks, and teachers' teaching methods, to conduct a comprehensive and systematic analysis of alignment. By analyzing the alignment between these elements, researchers can examine the curriculum from a broader perspective and identify areas that require further reform.

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Declaration of Interest

The authors declare no competing interest.

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Appendix A 2018-2022 NCEEs Coding Results (2-D Matrix)

2018 NCEE Content (Rate) Matrix

Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
1	1.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	1.2	0(0.000)	0(0.000)	2(0.095)	2(0.095)
	1.3	0(0.000)	4(0.190)	4.5(0.214)	8.5(0.405)
2	2.1	0(0.000)	5(0.238)	0(0.000)	5(0.238)
	2.2	3(0.143)	1(0.048)	0(0.000)	4(0.190)
	2.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
3	3.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.2	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.4	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.5	0(0.000)	0(0.000)	1.5(0.071)	1.5(0.071)
Summation		3(0.143)	10(0.476)	8(0.381)	21(1.000)

2019 NCEE Content (Rate) Matrix

Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
1	1.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	1.2	0(0.000)	1(0.032)	1(0.032)	2(0.065)
	1.3	0(0.000)	4.5(0.145)	0(0.000)	4.5(0.145)
2	2.1	0(0.000)	7(0.226)	0(0.000)	7(0.226)
	2.2	5(0.161)	0(0.000)	0(0.000)	5(0.161)
	2.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
3	3.1	0(0.000)	3(0.097)	0(0.000)	3(0.097)
	3.2	0(0.000)	2(0.065)	0(0.000)	2(0.065)
	3.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.4	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.5	0(0.000)	0(0.000)	7.5(0.242)	7.5(0.242)
Summation		5(0.161)	17.5(0.565)	8.5(0.274)	31(1.000)

2020 NCEE Content (Rate) Matrix

Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
1	1.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	1.2	0(0.000)	0(0.000)	2(0.058)	2(0.058)
	1.3	0(0.000)	11(0.319)	0(0.000)	11(0.319)

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Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
2	2.1	1(0.029)	7(0.203)	0(0.000)	8(0.232)
	2.2	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	2.3	0(0.000)	2(0.058)	0(0.000)	2(0.058)
3	3.1	0(0.000)	0.5(0.014)	0(0.000)	0.5(0.014)
	3.2	0(0.000)	1.5(0.043)	0(0.000)	1.5(0.043)
	3.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.4	0(0.000)	2(0.058)	0(0.000)	2(0.058)
	3.5	0(0.000)	0(0.000)	7.5(0.217)	7.5(0.217)
Summation		1(0.029)	24(0.696)	9.5(0.275)	34.5(1.000)

2021 NCEE Content (Rate) Matrix

Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
1	1.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	1.2	0(0.000)	2(0.070)	1(0.035)	3(0.105)
	1.3	0(0.000)	0(0.000)	4.5(0.158)	4.5(0.158)
2	2.1	3(0.105)	4(0.140)	0(0.000)	7(0.246)
	2.2	1(0.035)	0(0.000)	0(0.000)	1(0.035)
	2.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
3	3.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.2	0(0.000)	1.5(0.053)	0(0.000)	1.5(0.053)
	3.3	0(0.000)	1(0.035)	0(0.000)	1(0.035)
	3.4	0(0.000)	3(0.105)	0(0.000)	3(0.105)
	3.5	0(0.000)	0(0.000)	7.5(0.263)	7.5(0.263)
Summation		4(0.140)	11.5(0.404)	13(0.456)	28.5(1.000)

2022 NCEE Content (Rate) Matrix

Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
1	1.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	1.2	0(0.000)	0(0.000)	3(0.109)	3(0.109)
	1.3	0(0.000)	6(0.218)	0(0.000)	6(0.218)
2	2.1	2(0.073)	6(0.218)	0(0.000)	8(0.291)
	2.2	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	2.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)

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Theme		Content encoding (ratio value)			
		Cognitive level A	Cognitive level B	Cognitive level C	Summation
	3.1	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.2	0(0.000)	4.5(0.164)	0(0.000)	4.5(0.164)
3	3.3	0(0.000)	0(0.000)	0(0.000)	0(0.000)
	3.4	0(0.000)	4(0.145)	0(0.000)	4(0.145)
	3.5	0(0.000)	0(0.000)	2(0.073)	2(0.073)
Summation		2(0.073)	20.5(0.745)	5(0.182)	27.5(1.000)

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