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Analyzing the Representation of Chemical Thinking in the Gaokao Chemistry Exam in China

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1 Introduction

The concept of "chemical thinking" is increasingly being highlighted in international reforms and research related to chemistry education Global standards for science and chemistry education underline the crucial role of this concept in helping students learn how to formulate and answer questions, and resolve issues. However, the problem is that students who have only accumulated unrelated, random scientific knowledge tend to struggle with identifying and solving real-life problems. This issue can be attributed to curricula and teaching methods that prioritize delivering information over fostering thinking and problem-solving abilities oblem. "Chemical thinking" delineates the questions that are central to the field of chemistry and offers the thinking tools needed to organize and search through chemical knowledge to answer these questions . Therefore, as a core competency in the discipline, chemical thinking promotes question-asking and problem-solving among students. Given that summative assessments in China greatly influence the classroom teaching behaviors of chemistry teachers, incorporating "chemical thinking" into these assessments is crucial.

This study aims to examine how chemical thinking is represented in the Gaokao chemistry subject in Mainland China. This study contributes to the field by providing empirical evidence to reveal how chemical thinking is represented in the Gaokao chemistry subject. Moreover, this study provides guidance and implications for chemistry education researchers and practitioners to understand how to incorporate chemical thinking into the analysis of Gaokao chemistry subject questions and classroom teaching.

2 Theoretical Framework

2.1 Disciplinary Essential Questions and the Corresponding Perspectives in Science Education

One of the fundamental aims of science disciplines is to characterize and differentiate research objects in the particular domain. Moreover, scientists not only recognize the diversity of the world but also strive to explore the order underlying the natural world by constructing theoretical models to explain and predict phenomena. Additionally, practitioners of chemistry demonstrate a keen interest in the investigation of matter ' s transformation and synthesis processes.

In this sense, scholars in the field of education posit that chemistry encompasses a domain which not only seeks to advance scientific comprehension, but also actively engages in the

implementation of technological applications. The hybrid or dual nature of chemistry, which has been emphasized by many philosophers and historians of science, underscores its important role in both basic research and applied science.

Based on the above discussions, we argued that authentic approaches to chemical inquiry should be presented in school science education, that is, teachers and students need to be exposed to the three fundamental subject areas of chemistry and their corresponding tasks and perspectives. In this way, school science education could enable both teachers and students to comprehend the various methods of obtaining data, for example, by taking into account the specific analytical perspectives that embody the distinctive features of the chemistry discipline. Moreover, is has been explicitly advocated by the learning outcomes at each grade level to convey a pluralistic orientation to these chemical inquiry approaches. In this regard, science education ought to promote the idea that not one method or particular line of evidence, but rather the convergence from various sources, can support chemical theoretical claims, thus leading to scientific explanations. Hence, we take the diversity of perspectives to chemical inquiry as the basic stance in this study.

2.2 Chi's Essential Questions-perspectives Framework(EQ-P framework)

As delineated in the introduction of this paper, Ming Chi, through an integration of literature review and a mixed-methods approach combining qualitative and quantitative research, proposes the Chemical Disciplinary Essential Questions-Perspectives Framework(EQ-P framework)(see Table).

Table 1 The Essential Questions-Perspectives Framework

Chemical Disciplinary Essential Questions	Purpose	Chemical Education Perspectives
What is the substance?	Description and Identification	Physical characteristics,Reaction characteristics, Composition,Structure
Why do the properties or behaviors of substances emerge?	Explanation and Prediction	Particles,Interaction,Thermodynamics,Kinetics
How do we transform and make the substance?	Transformation and Synthesis	Target molecule,Starting material,Addition-removal,Process control

2.3 Research Questions

The current research seeks to investigate the representation of essential questions-perspectives in college entrance chemistry examination papers. The specific research question addressed in this study is as follow: How are the twelve corresponding perspectives to the essential questions invoked in the design of chemistry examination questions?

2.4 Methodology

In this study, content analysis was employed as the research methodology, seeking to uncover and delineate the phenomena of interest by considering extensive textual data into a smaller number of content categories, following explicit coding rules.

Utilizing the previously mentioned analytical framework, the investigation aimed to furnish evidence addressing the research questions posited earlier in the academic context.

2.5 Context

The NCEE, a highly influential national assessment in China, serves as a selective prerequisite test

for higher education admission, taken by high school graduates or individuals with equivalent educational backgrounds.

Due to regional disparities in educational development, China administers college entrance examination papers in two ways: one overseen by the Ministry of Education's education examination authority, and the other autonomously administered by provincial or municipal education examinations authorities with higher education levels, granted by the Ministry of Education for local use.

Considering the examination's importance, the education examinations authority meticulously selects exam writers each year. These teams comprise subject experts and educational specialists, including university professors and teaching supervisors. The examination question designers for each subject rotate annually, and the education examinations authority reviews the compiled examination paper for validity. Recent studies have confirmed the reliability and validity of Chinese college entrance examination papers.

To ensure examination fairness, test papers are kept strictly confidential before the exam. Examination question designer must participate in centralized test paper design at a designated location under closed off management. They are prohibited from leaving until the conclusion of the college entrance examinations and must sign a non-disclosure agreement to guarantee the secrecy of the test paper design members, processes, and details.

The proposition for Chinese college entrance chemistry examination is based on the *Chinese Chemistry Curriculum Standards*(CCCS).

2.6 Data Analysis

In order to classify the items in the exam papers, it is essential to first determine the unit of analysis for this study. For multiple-choice items, each item was treated as a unit of analysis; for non-multiple-choice items, considering that an item typically contains several sub-items addressing different essential questions and the corresponding perspectives, each sub-item was considered a unit of analysis. Based on establishing the unit of analysis, we employed the following operational procedures for coding.

3 Results

3.1 Analysis Outcomes of National Papers Over the Past Decade

In the National Papers, the proportion of items anchoring the 12 perspectives related to the essential questions in the EQ-P framework is 48.76%, as depicted in Figure 1.

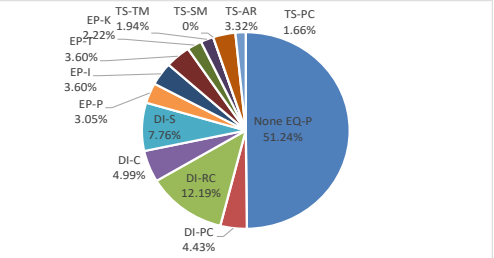
The data can be broken down into two distinct periods. From 2014 to 2020, the proportion stands at 37.15%, while the period from 2021 to 2023 sees the proportion at 80.99%.

Following this, a detailed evaluation of these twelve analytical categories tied to the disciplinary essential questions is performed (see Figure 2). It is obvious that DI-RC stands as the most dominant category, representing 12.19% of the total distribution.

This is closely followed by DI-S, contributing 7.76% to the overall content. However, the proportions of the remaining ten categories fail to cross the 5.00% mark. Particularly striking is TS-SM, which holds a marginal position with a zero percentage.

Therefore, it can be inferred that the National Papers display a significant emphasis towards DI-CR and DI-S categories, while completely neglecting TS-SM.

This illuminates certain prevalent trends and biases in the approach to these categories within the education system.



Note: "none-EQ-P" refers to the items that do not reflect the perspectives in the EQ-P framework

Figure 1 The proportion of the twelve basic perspectives in the National Papers over the past decade

3.2 Addressing Essential Questions without Anchoring Corresponding Perspectives: A Predicament in National Papers

In National Papers of the past decade, within the 51.24% of items that did not anchor to the corresponding perspectives of the essential questions, some attempted to address the essential question of "What is the substance?". However, they did not design a context that would invoke the students' corresponding perspectives for describing or identifying substances. Taking the 35(3) item of the 2020 National Paper 2 as an example: "*The crystal cell of $CaTiO_3$ is shown in Figure 2. What is the order of electronegativity of its constituent elements? What is the force between the metal ions and oxygen ions? What is the coordination number of calcium ions?*" This item uses the crystal structure of calcium titanate as a context, directly testing students' (1) ability to recall the electronegativity of elements; (2) capacity to discern the type of interionic forces; (3) capability to determine particle coordination numbers. Each of these questions instructs students to describe and identify substances from a structural perspective explicitly, without creating contexts that could potentially invoke their perspectives on material structure for description and identification of substances. However, items attempting to address the other two essential questions of "Why do the properties and behaviors of substances emerge?" and "How do we transform and make the substances?" are all anchored in their corresponding perspectives.

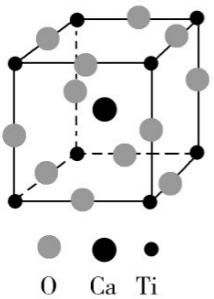


Figure 2 The crystal cell of $CaTiO_3$

4 Conclusion and Discussions

This study utilized Chi's Disciplinary Essential Questions and Perspectives framework to analyze the representation of these questions and perspectives in Chinese college entrance chemistry exams over the past decade, focusing on the shift from the 2003 to the 2017 curriculum standards. We also examined the contexts in which these perspectives were invoked in the chemistry questions.

For the first time, we provided operational illustrations for the twelve perspectives corresponding to the essential questions and applied this framework to the Chinese high-stakes testing system. This study serves two main purposes: offering insights into the nature of Chinese college entrance chemistry exams to an international audience and providing a novel analytical framework for examining practical chemistry items.

Our findings indicate that nearly half of the questions in recent exams engage students' chemical thinking, especially after adopting the 2017 curriculum standards. These questions focus on the essential questions: "What is the substance?", "Why do the properties or behaviors of substances emerge?", and "How do we transform and make the substance?" The 2017 curriculum emphasizes understanding substances' properties and behaviors, their composition and structure, and their transformation and synthesis, aligning well with Chi's framework.

Over the past decade, the exams have primarily focused on students' abilities to describe and identify substances, rather than on interpreting properties or synthesizing substances. The 2017 curriculum's emphasis on macro recognition, micro-analysis, and balance thinking highlights the need to describe and identify substances and interpret and predict their properties and behaviors.

The Chinese education system, heavily influenced by high-stakes exams, often focuses on these aspects, possibly due to the limited implementation of experimental teaching in schools. This may explain the limited emphasis on transformation and synthesis in the exams.

From 2021 onwards, there has been a notable increase in questions designed to invoke students' chemical perspectives to solve real-world problems. However, questions involving the "Starting material perspective" remain scarce. Future exam designers should consider including more questions that reflect this perspective.

This study highlights the need for more contextually rich questions that engage students' chemical thinking across all essential questions and perspectives. Further research should explore the practical application of Chi's framework in classroom teaching to enhance chemistry education.