Original Research Article

Open Access

A Rasch Model-Based Study on the Transition of Chemistry Instruction between Junior and Senior High Schools: A Case Study of Redox Reactions

Li Li[1], Wolin Chen[1], Xiaofeng Chen[1], Xinyi Liang[1], Tairong Huang[2], Xingyuan Gao[1,*]

[1] School of Chemistry and Materials Science, Guangdong Second Normal University, Guangzhou, Guangdong 510303
[2] Jiangmen No.1 Middle School, Jiangmen, Guangdong 529080

***Corresponding author:** Gao Xingyuan, Ph.D. in Chemical Engineering from the National University of Singapore, M.Sc. in Education from University College London, and Head of the Chemistry (Teacher Training) Department at the School of Chemistry and Materials Science, Guangdong Second Normal University, No.351, Xingang Middle Road, Haizhu District, Guangzhou, Guangdong Province, 510303, China, Email: gaoxingyuan@gdei.edu.cn

Funding: Guangdong University of Education 2024 "Open Competition" Research Project "Innovative Research on Smart Education System for Chemistry Normal Students in the Context of 'New Normal' Education" (2024JBGS005); Guangdong University of Education 2024 Teaching Achievement Cultivation Project "Exploration and Practice of 'Human-Machine Collaborative' Pre-service Education for Chemistry Normal Students in the Context of Educational Informatization" (PX-107241186); 2023 Guangdong Province Undergraduate Higher Education Teaching Quality and Teaching Reform Engineering Construction Project "Research on the Construction and Practice of Technology-Empowered Blended Teaching and Evaluation System for Chemistry Normal Students" (SJJG-57231142); 2025 Guangdong University of Education University-level Teaching Quality and Teaching Reform Engineering Project (2025jxgg22); Guangdong University of Education Digital Excellent Course Construction Project: Online and Offline Blended Course (Key Project) (PX-117251568); 2025 Jiangmen City Primary and Secondary School Teachers' Educational Research Ability Enhancement Plan Project "Research on Chemistry Concept Teaching and Evaluation Based on Handheld Technology Digital Experiments" (JME24005); 2025 Guangdong Province Educational Science Planning Project (Higher Education Special Project), "Research on Collaborative Cultivation Pathways for Core Competencies and Teaching Academic Ability of Chemistry Normal Students under the Background of Guangdong's New College Entrance Examination Reform" (2025GXJK0477). 2026 Education and Teaching Research and Reform Project of the Online Open Course Alliance for Universities in the Guangdong-Hong Kong-Macao Greater Bay Area (WGKM2026090); 2026 Higher Education Teaching Reform Research Project under the '15th Five-Year Plan' of the Guangdong Higher Education Teaching Management Association: Research on Intelligent Evaluation and Teaching-Feedback Loop of Normal Students' Teaching Ability Driven by Digital Intelligence (YB202602043).

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, sharing, adaptation, distribution and reproduction in any medium or format, for any purpose, even commercially, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Abstract: In the context of the new curriculum reform, a notable discontinuity exists in chemistry instruction between junior and senior high schools. In frontline teaching, Grade 10 students generally struggle with the conceptual progression of redox reactions, and existing research lacks multi-dimensional analysis and assessment to guide instruction. Based on the Rasch model, this study constructed a three-dimensional transition system encompassing knowledge, ability, and competency, and developed an assessment instrument. The instrument demonstrated an item reliability of 0.87, good fit, and acceptable reliability and validity. A controlled teaching experiment was conducted with Grade 10 classes of similar academic backgrounds. Data showed that the experimental class achieved significantly higher transition levels, with a statistically significant difference from the control class. These findings indicate that the Rasch model-based three-dimensional transition system is scientific and feasible, and that transition-focused instruction can bridge the discontinuity between educational stages and enhance students' comprehensive chemistry competency.

Keywords: Rasch model; junior–senior high school transition; educational measurement; redox reactions

1. Research Background

1.1. Stage Differences and Transition Challenges in Chemistry Instruction between Junior and Senior High Schools

The Chemistry Curriculum Standards for Compulsory Education (2022) [1] and the Chemistry Curriculum Standards for Senior High School (2017) [2] both explicitly emphasize strengthening the transition between junior and senior high school instruction. Regarding differences in educational orientation and knowledge structure across stages, chemistry at the compulsory education stage is oriented toward scientific enlightenment, delivering knowledge through a macro-level and concrete teaching paradigm. Conceptual representations are appropriately simplified, and content is accessible and easy to understand, with an emphasis on memorization and cognitive accumulation of foundational knowledge through figurative thinking. In contrast, chemistry at the senior high school stage, as advanced basic education content, exhibits significantly enhanced abstraction, logicality, and systematicness. It emphasizes in-depth theoretical exploration, integrated application of knowledge, and cognitive construction that integrates macro and micro perspectives, placing more rigorous demands on students' higher-order thinking skills, including abstract logical reasoning, knowledge transfer and application, and data analysis and processing [3][4]. Significant discontinuities exist between the two stages in terms of knowledge, ability, and competency, which can readily lead to learning adaptation difficulties among Grade 10 students.

1.2. Assessment Advantages of the Rasch Model

Current research on the transition of chemistry instruction between junior and senior high schools still exhibits notable shortcomings at the measurement and evaluation level. The dimensions assessed are mostly limited to single knowledge tests, lacking a three-dimensional systematic diagnostic framework of "knowledge–ability–competency" [5]. Instruments developed under Classical Test Theory (CTT) have item difficulty and student ability parameters that are highly dependent on the tested sample, and the division of proficiency levels is highly subjective [6], making it difficult to precisely identify students' transition weaknesses and impossible to achieve cross-stage longitudinal comparison and dynamic tracking.

Item Response Theory (IRT) can effectively address these deficiencies by using mathematical models to achieve precise quantification of test-takers' ability levels [7]. The Rasch model, as a typical form of the one-parameter model in IRT, possesses strict parameter invariance, which overcomes the sample-dependence problem of traditional measurement theory [6]. It is well-suited to small-scale, precision-oriented learning assessment scenarios in subject areas [7] and can provide scientific data support for assessing chemistry transition between junior and senior high schools, thereby achieving objective classification of students' transition levels [5].

2. Construction of a Three-Dimensional System for Chemistry Instructional Transition between Junior and Senior High Schools

2.1. Theoretical Basis for the Assessment Framework Construction

This study draws primarily on Wilson's four building blocks framework [10]. Integrating the transition points

in knowledge, ability, and competency between junior and senior high schools, it constructs an assessment instrument for transition levels through construct maps, item design, outcome space, and a measurement model.

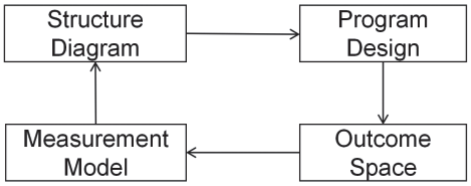


Figure 1. Wilson's four building blocks framework

2.2. Design of a Progression Model for Knowledge–Ability–Competency Transition Points between Junior and Senior High Schools

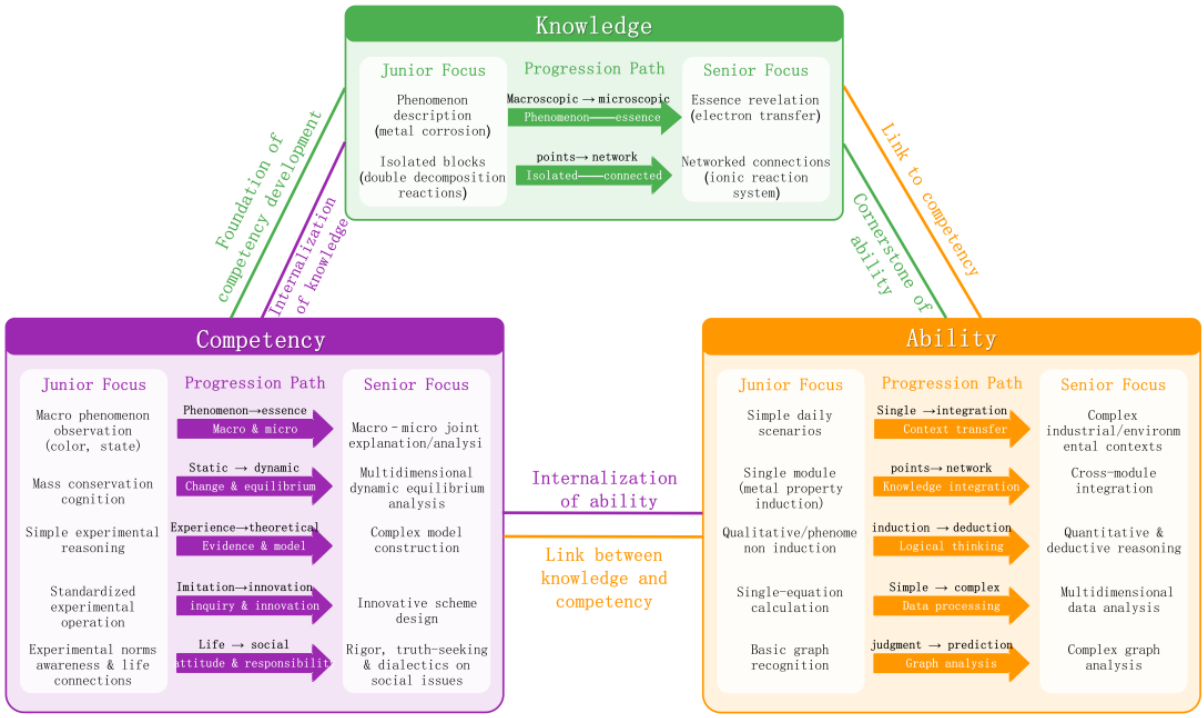


Figure 2. Overview of the Three-Dimensional Progression Model of Transition Points between Junior and Senior High Schools

3. Practical Case of Transition Instruction: Transition Teaching of "Redox Reactions" between Junior and Senior High Schools

Learning Progression Theory describes the pathway through which cognition develops from naive and fragmented understanding toward scientific and integrated understanding, and it can address the questions of "what to teach, in what sequence to teach, and how to transition"[11]. Taking "redox reactions" as an example, constructing a complete cognitive pathway spanning junior and senior high schools, identifying transition discontinuities and progression nodes, and integrating guided instruction with tiered design can overcome the shortcomings of traditional instruction. A transition pathway between junior and senior high schools is established: macro-level phenomena (gain and loss of oxygen) →intermediate features (changes in elemental valence) → micro-level essence (electron transfer) →systemic connections and value dialectics. This pathway progressively overcomes the difficulties in conceptual upgrading, achieves three-dimensional development in knowledge, ability, and competency, integrates core competency cultivation throughout the entire teaching process, and facilitates a smooth transition in both knowledge and thinking. The instructional phases of this lesson are presented in the

following table.

Table 1. Transition-Oriented Instructional Phases

Teaching Phase	Teacher Activity	Student Activity	Knowledge	Ability	Competency	Junior–Senior High Transition
Phase 1: Contextual Introduction—From Everyday Phenomena to Chemical Questions	1. Show images of iron rusting; ask about the essence of the reaction and junior high school reaction classification. 2. Present the reaction of carbon reducing copper oxide to create a classification conflict. 3. Guide students to review oxidation and reduction from the perspective of oxygen gain/loss. 4. Ask whether the two occur simultaneously.	Review the four basic reaction types and give examples; discover that the old classification cannot cover new reactions; analyze substance changes based on oxygen gain/loss and initially summarize the concept of redox reactions.	Junior high school definitions of oxidation and reduction from oxygen gain/loss; recognize that oxidation and reduction accompany each other.	Review of prior knowledge, context transfer, identifying cognitive conflict.	Macroscopic identification: uncovering chemical essence from macroscopic phenomena.	Activate prior knowledge of the oxygen gain/loss criterion from junior high school; create cognitive conflict through special reactions to naturally introduce new knowledge of redox reactions in senior high school.
Phase 2: Macroscopic Perspective—Valence Change Characteristics	1. Present the reaction between iron and copper sulfate; have students determine the reaction type. 2. Point out that this reaction is a redox reaction to trigger cognitive conflict. 3. Guide students to label valence states and explore change patterns. 4. Summarize: valence change is a universal criterion for judging redox reactions.	Determine reaction type and experience cognitive doubt; label valence states, compare and analyze changes, and summarize macroscopic judgment patterns.	Correspondence between valence changes and redox reactions; consolidate common valence rules.	Logical reasoning, valence calculation, comparative induction.	Evidence-based reasoning: derive reaction patterns from evidence of valence changes.	Compare junior high school oxygen gain/loss and senior high school valence change criteria, helping students appreciate the universality of the senior high criterion and achieve cognitive upgrading.
Phase 3: Microscopic Perspective—Essence of Electron Transfer	1. Ask about the microscopic cause of valence changes; show atomic structure diagrams. 2. Use animations to demonstrate reactions of sodium and hydrogen with chlorine; analyze electron gain/loss and electron pair shift. 3. Summarize that the essence of the reaction is electron transfer. 4. Construct a core judgment model for redox reactions. 5. Guide students to analyze classic junior high school oxygen-generation reactions using new knowledge.	Explore electron changes based on atomic structure; watch microscopic animations to establish links between electron transfer and valence; construct knowledge models in groups and apply new knowledge to analyze junior high school chemical equations.	The essence of valence change is electron gain/loss or shift; master concepts of oxidant and reductant and basic analytical models.	Microscopic analysis, knowledge transfer, model construction and application.	Microscopic analysis and model cognition: understand redox reactions from the microscopic essence.	Use junior high school atomic structure knowledge to explain the causes of valence changes, upgrade shallow junior high cognition to essential senior high understanding, and consolidate new knowledge through familiar junior high reactions.
Phase 4: Summary—Discussion of Advantages and Disadvantages	1. Guide students to sort out the cross-classification relationship between the four basic reaction types and redox reactions. 2. Using combustion as an example, guide students to dialectically analyze the pros and cons of redox reactions.	Draw a cross-classification diagram of reactions; discuss in groups the positive and negative values of redox reactions and develop dialectical understanding.	Improve the chemical reaction classification system; recognize the dual nature and practical value of redox reactions.	Knowledge integration and induction, dialectical thinking, applying learning to practice.	Scientific attitude and social responsibility: develop dialectical thinking in chemistry.	Integrate junior high school reaction classification with senior high school redox classification, build a structured knowledge network, and promote students' shift from single-minded to dialectical thinking.

4. Evaluation of Teaching Effectiveness of the Rasch Model-Based Three-Dimensional System

4.1. Development of an Assessment Instrument for Three-Dimensional Transition Levels between Junior and Senior High Schools

This study used the transition model described above as the basis for item development. Following pilot testing and refinement, 20 multiple-choice items of graded difficulty were developed for the redox reactions unit and administered as pre- and post-tests in both traditional instruction and junior–senior high school transition instruction. Participants were randomly selected from two parallel classes of Grade 10 students with similar academic levels at the same school: Class A was designated the experimental group (n = 37), and Class B was designated the control group (n = 34), yielding a total sample of 71 students. Parallel classes refer to groups of classes within the same grade or instructional stage that have been balanced in terms of student quality, teacher allocation, curriculum design, teaching progress, and evaluation criteria, such that no systematic differences exist between them and they are comparable. The pre-test assessed students' baseline transition levels. Subsequently, the same teacher implemented transition-oriented classroom instruction in Class A and traditional classroom instruction in Class B, with each lesson lasting 40 minutes. The post-test compared improvements in students' transition levels under the two instructional modes, evaluated the effectiveness of transition instruction, and informed instructional optimization. The assessment comprehensively examined students' transition levels across the three dimensions of knowledge, ability, and competency, providing a basis for improving instructional implementation.

4.2. Three-Dimensional Assessment Instrument Constructed Based on the Rasch Model and Transition Level Classification

4.2.1. Overall quality analysis of the assessment instrument

The analysis results showed that the MNSQ values of the items in both tests were close to 1.0, and the ZSTD values approached 0, indicating good fit between the items and the Rasch model. The item separation index was 2.97 > 2.0, and the item reliability was 0.87 > 0.85, indicating that the instrument could effectively distinguish item difficulty and student ability levels. The person separation index was 2.18 > 2.0, and the person reliability was 0.8, placing reliability at the threshold of excellence. The person separation and reliability were slightly lower than the item separation and reliability, which is consistent with the research design because the Grade 10 participants had

similar academic backgrounds and small individual differences. All overall indicators fell within acceptable ranges, demonstrating that the quality of the assessment instrument was stable. Unidimensionality analysis showed that the first eigenvalue of both the pre-test and post-test was less than 2.0, with no obvious second dimension, meeting the unidimensionality requirement.

4.2.2. Evaluation criteria and level classification for junior–senior high school transition levels

This study relied on the Logit difficulty parameters output by the Rasch model. Integrating the characteristics of junior–senior high school transition content in chemistry and the requirements of the curriculum standards, the attribution of items was predetermined: items focusing on essential junior high school foundations and oriented toward the junior–senior high transition were defined as Transition Level 1, while items emphasizing higher-order thinking and comprehensive competency application at the senior high school level were defined as Transition Level 2. On this basis, using the item difficulty Logit values calibrated by the Rasch model, the average difficulty of Level 1 and Level 2 items was calculated separately, serving as the objective basis for classifying junior–senior high school transition levels. Specifically, Level 1 focuses on core junior high school concepts, basic memorization, and simple application—shallow transition content—to diagnose how well students have consolidated the essential knowledge required at the junior high school stage. Level 2 emphasizes knowledge transfer, logical reasoning, and the comprehensive application of core chemistry competencies at the senior high school level—higher-order transition content—to identify students' level of cognitive leap and ability improvement in chemistry between junior and senior high schools.

Table 2. Junior–Senior High School Transition Test Items and Their Difficulty

Test Type	Transition Dimension	Mean	Level	Overall Level (three dimensions)	
				M	SD
Pre-test	Knowledge	-0.55	Level 1	Level 1: -0.52; Level 2: 0.47	Level 1: 0.070; Level 2: 0.005
		0.48	Level 2		
	Ability	-0.54	Level 1		
		0.47	Level 2		
	Competency	-0.48	Level 1		
		0.46	Level 2		
Post-test	Knowledge	-0.64	Level 1	Level 1: -0.66; Level 2: 0.72	Level 1: 0.044; Level 2: 0.065
		0.72	Level 2		
	Ability	-0.63	Level 1		
		0.65	Level 2		
	Competency	-0.71	Level 1		
		0.78	Level 2		

Table 3. Three-Dimensional Competency Transition Progression Model for Junior and Senior High Schools and Logit Score Classification of Development Levels

Level Classification	Knowledge	Ability	Competency	Logit Score Range
Below Level 1 (Junior High)	1. Understand oxidation/reduction from gain/loss of oxygen, only at surface features; 2. Know reactions of substances with oxygen are oxidation; 3. Cannot systematically propose the concept of "redox reaction".	1. Judge whether common reactions are oxidation based on gain/loss of oxygen; 2. Describe oxidation phenomena with examples; perform simple observation, comparison, and induction; 3. Conduct basic experiments and observe macroscopic changes such as combustion.	1. Establish macroscopic identification awareness; recognize changes at the phenomenal level; 2. Form basic ideas that "change requires conditions and is accompanied by energy"; 3. Appreciate links between chemistry, life, and environment; develop safe and eco-friendly experimental awareness.	Pre-test: < -0.52; Post-test: < -0.66

Continuation Table:

Level Classification	Knowledge	Ability	Competency	Logit Score Range
Level 1 (Junior–Senior High Transition)	1. Initially link "valence change" with redox reactions; 2. Recognize redox reactions are not limited to gain/loss of oxygen but extend to reactions with valence changes; 3. Encounter typical examples (metals with acids, etc.).	1. Judge whether a reaction is redox by valence changes; 2. Compare junior high "gain/loss of oxygen" and senior high "valence change" perspectives to achieve cognitive transition; 3. Classify reactions and build structured cognition of reaction types.	1. Achieve macro-micro-symbolic transition (phenomena → valence → symbolic expression); 2. Develop evidence-based reasoning using valence change as evidence for redox; 3. Establish the idea that the same concept can be understood from multiple perspectives, paving the way for abstract learning in senior high.	Pre-test: -0.52 to 0.47; Post-test: -0.66 to 0.72
Level 2 (Senior High)	1. Define redox reactions from the essence of electron transfer; 2. Systematically learn core concepts such as oxidant, reductant, oxidation product, reduction product; 3. Master balancing redox equations by valence change method; 4. Learn redox reactions in galvanic cells; understand energy conversion and electron conservation.	1. Analyze reaction mechanisms of redox reactions from electron transfer; 2. Independently balance redox equations and perform related calculations; 3. Design and analyze electrochemical experiments; explain electron flow and energy conversion; 4. Comprehensively apply redox rules to solve practical problems in substance inference, industrial processes, environmental chemistry, etc.	1. Complete macro-micro integrated thinking (macroscopic phenomena—valence changes—electron transfer essence); 2. Ideas of change and balance; understand universality and regularity of redox reactions; 3. Scientific inquiry and innovation awareness; design experiments based on electrochemical principles; 4. Scientific attitude and social responsibility; explain real-world issues such as corrosion prevention, environmental protection, and energy using redox knowledge.	Pre-test: > 0.47; Post-test: > 0.72

5. Discussion of Research Data

5.1. Overall Statistical Analysis of Transition Levels

Figure 3 presents the overall statistical results of junior–senior high school transition levels measured by Logit scores. In the pre-test, participants at Level 1 constituted the majority of the research sample. In contrast, participants at Level 2 accounted for only 29.33%, while those below Level 1 accounted for an even smaller proportion, indicating that the class as a whole remained at the foundational cognitive level of junior high school and exhibited clear deficiencies in the abstract thinking and quantitative analysis abilities required at the senior high school level. Compared with the pre-test, 71.43% of participants in the post-test had progressed to Level 2, and the proportion of students below Level 1 decreased significantly relative to the pre-test, indicating that some students had advanced to Level 1 or above. Overall, the results demonstrate that after transition-oriented instruction, participants made significant progress in junior–senior high school transition levels, gradually moving from macroscopic phenomenon identification to essential understanding, thereby achieving the unification of knowledge understanding, ability development, and competency enhancement.

In the pre-test, the low score on Q19 reflected students' insufficient information processing and transfer application abilities, deficiencies in triple representation and cognitive model construction, and a lack of quantitative analysis awareness, contrasting with the qualitative thinking of conservation of mass developed in junior high school. This suggests that teachers should use visualization tools to strengthen triple representation training, build cognitive models, compare junior and senior high school thinking differences through worked examples, design electron transfer conservation exercises, cultivate quantitative awareness, and enhance students' model cognition and microscopic analysis competencies.

Teachers guided students through progressive question chains to break through the limitations of macroscopic phenomena, probe into the essence of ionic reactions, understand the intrinsic relationship between electron gain/loss and valence changes, and master the double-line bridge and single-line bridge

analysis methods. Post-test assessment data showed that students further strengthened the logic chain of "structure–property–application." However, for complex reactions (T20: industrial preparation of SF4), the error rate in oxidation number determination in SF4 preparation was high, indicating that participants still had biases in oxidation number determination. It is recommended that teachers integrate real processes with scaffolded tasks: first, use simple sulfur compounds such as SO2 to consolidate the basic rule that fluorine is -1; then, use intermediate-valence compounds such as SCl2 as a transition to reinforce the logic of oxidation number calculation; and finally, incorporating the SF4 preparation process, guide students to label valence states step by step and determine electron transfer, thereby reducing cognitive load and improving quantitative analysis ability in complex contexts.

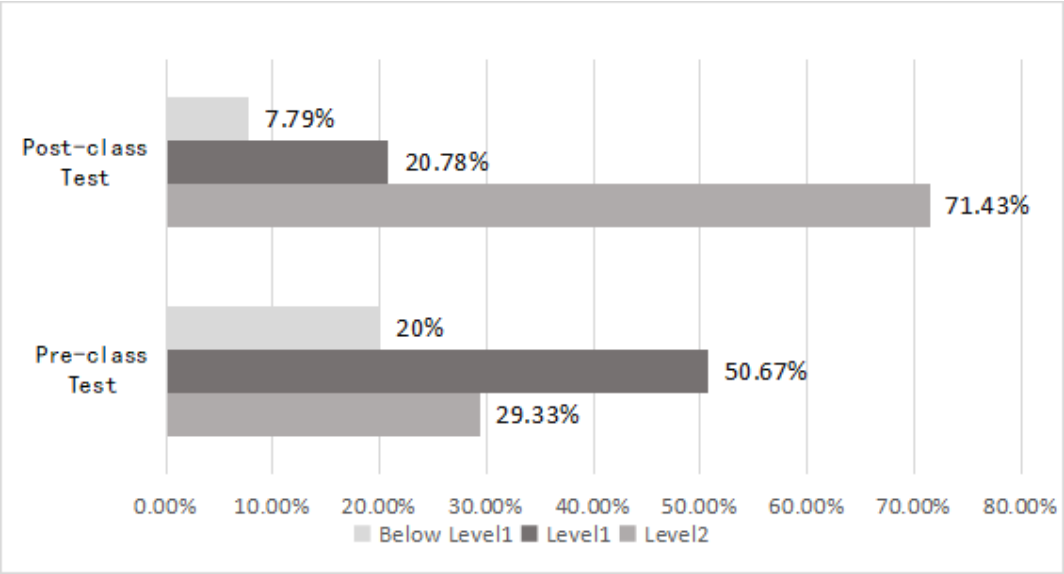


Figure 3. Proportions of Students at Each Junior–Senior High School Transition Level Based on Logit Scores

5.2. Branch-Level Progression Across Dimensions of Junior–Senior High School Transition Levels

Items corresponding to the three dimensions of knowledge, ability, and competency in the pre-test and post-test were identified separately. The same processing approach as that used for overall levels was then applied to delineate the Logit score range corresponding to each transition level within each dimension, as shown in **Figure 4**.

Compared with the pre-test, significant progress was observed across all dimensions in the post-test. The proportion of students at Level 1 and below decreased to varying degrees across all three dimensions, while the proportion at Level 2 increased by approximately 30% in each dimension, with all exceeding half. In the knowledge dimension, students who initially had weak foundations made notable progress, and most students established a structured knowledge system. In the ability dimension, the initial proportion of Level 2 students was relatively substantial, and the focus of transition instruction fell on enhancing multiple abilities among students at other levels. In the competency dimension, almost no students remained below Level 1 in the post-test, demonstrating the significant remedial effect of transition-oriented instruction—integrating Learning Progression Theory with guided instruction—on students with learning difficulties.

5.3. Class Differences in Junior–Senior High School Transition Levels

In this study, the class that received the transition-oriented instructional design was designated the "experimental group," while the class that received traditional instruction was designated the "control group." Based on participants' Logit values and level classifications, **Figure 5** was generated. Although no significant difference existed between the two classes before the intervention, the experimental group demonstrated significantly greater improvement than the control group in the post-test data. In contrast, the control group, lacking targeted transition

reinforcement, showed little change in ability levels in the post-test, with the proportion of Level 2 students remaining almost unchanged from the pre-test and only a slight increase in the proportion of Level 1 students. In summary, the transition-oriented instruction on redox reactions between junior and senior high schools proved effective to a certain extent, helping students advance from quantitative accumulation to qualitative transformation in the transition of knowledge, ability, and competency.

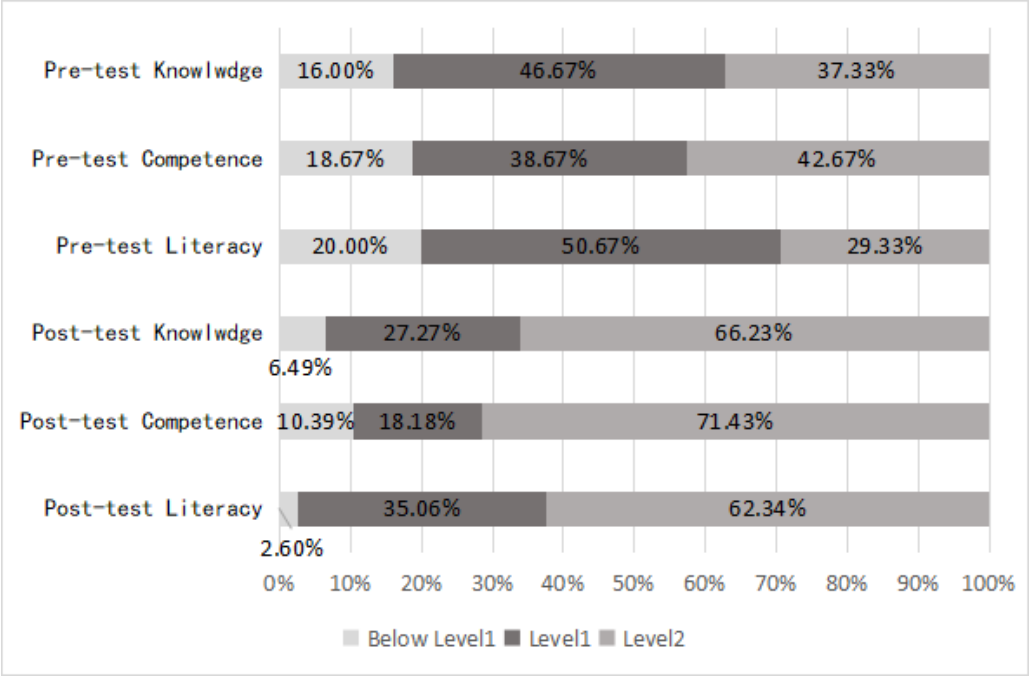


Figure 4. Comparison of Student Level Distributions across Knowledge, Ability, and Competency Dimensions before and after Transition-Oriented Chemistry Instruction between Junior and Senior High Schools

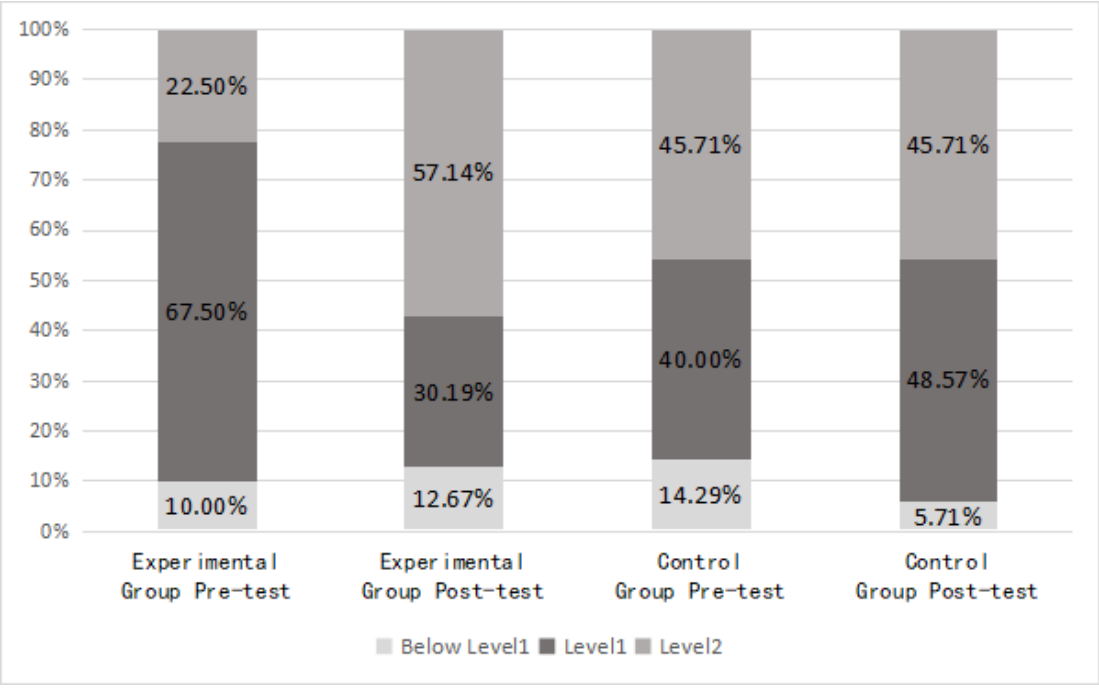


Figure 5. Comparison of Student Level Distributions between the Experimental Group and the Control Group in Junior–Senior High School Chemistry Transition Instruction

6. Implications and Suggestions for Junior–Senior High School Transition Instruction

6.1. Knowledge Transition: Progressing from Surface to Depth, with Knowledge Structuring and Concept Reconstruction in Parallel

Drawing on specific test items, microscopic mechanisms were made concrete and core concepts were structured, thereby accomplishing concept reconstruction and knowledge integration simultaneously. Based on the pre- and post-test items and assessment score data, for Q1 on ionic reactions, students tended to confuse the ionic equations for reactions of excess versus limited CO2 with alkalis, and frequently overlooked details such as acetic acid being a weak electrolyte and calcium carbonate being a solid that cannot be dissociated into ions. Q7 and Q8, which concerned changes in conductivity and pH during reactions of Ba(OH)2 with H2SO4 and NaHSO4, exposed students' lack of understanding that "changes in ion concentration determine the essence of the reaction." To address such problems, instruction on ionic reactions can use microscopic animations to demonstrate the stepwise reaction of CO2 with OH^-, comparing the particle changes when limited CO2 produces $CO3^{2-}$ versus excess CO2 produces $HCO3^-$. Conductivity sensor experiments can visually present the process in which Ba^{2+} combines with $SO4^{2-}$ and H^+ combines with OH^-, leading to decreased ion concentration. T1 and T4 focused on the essence of redox reactions and the two-dimensional valence-category diagram; students often equated "valence changes" with the essence of redox reactions. In teaching redox reactions, teachers can start from the junior high school concept of "gain and loss of oxygen," incorporate post-test T12 on the reaction of magnesium with oxygen, and use electron transfer diagrams to label electron gain and loss, clarifying that "electron transfer is the essence, while valence change is the characteristic." Using the two-dimensional valence-category diagram for iron as a tool, teachers can integrate junior high school Fe and Fe2O3 with senior high school Fe2+ and Fe3+, forming a structured knowledge system. At the same time, with ionic reactions and redox reactions as core hubs, junior high school double displacement and single displacement reactions can be incorporated into the senior high school reaction classification framework, thereby completing the reconstruction of the knowledge network.

6.2. Ability and Competency Progression: Focusing on Higher-Order Thinking and Problem Solving

Grounded in item contexts, instruction should strengthen context transfer and evidence-based reasoning, enabling a leap from lower-order thinking to higher-order problem solving. Based on pre- and post-test and assessment score data, Q2 and Q12 involved simple contexts such as coal combustion, nitrogen fertilizer use, and daily cooking, requiring only phenomenon association, and participants scored relatively high. In contrast, complex STSE contexts in the post-test—such as T5 restoration of "lead return" in oil paintings, T14 denitrification of wastewater, and T16 preparation of soda ash—required microscopic analysis and principle application, and participants scored relatively low. In instruction, teachers can draw on the theme of metal corrosion and protection. Using Q12 "drying an iron wok to prevent rust" as an entry point, they can upgrade from the junior high school idea that "iron rusts when exposed to oxygen and water" to senior high school redox-based corrosion analysis, and design comparative experiments to explore microscopic differences among different protection methods. Q11 and Q13 focused on analogical reasoning about metal reactivity and controlled-variable experiments. Assessment results indicated that students tended to overlook the boundaries of analogy and variable control. In teaching metal reactivity, teachers can use the Q11 analogy judgment item as an example to clarify that "similarity of active metals ≠ consistency," verify through experiments that Ca reacts with water first rather than displacing Cu^{2+}, and establish an "evidence–reasoning–conclusion" thinking pathway.

6.3. Improving the Evaluation System: Implementing the Integration of Teaching, Learning, and Assessment

At the instructional evaluation level, a full-process, precision-oriented integrated teaching–learning–assessment system should be constructed, using assessment data to guide transition instruction. Based on pre- and post-test items and assessment score data, teachers can use the pre-test to conduct diagnostic assessment before class, accurately identify the zone of proximal development, and design targeted

cognitive conflict situations accordingly. Taking redox reaction instruction as an example, teachers can first focus on high-frequency error items such as Q15 on the concept of electrolytes and Q16 on NaHSO4 ionization to identify students' pain points, including "dissociation of weak electrolytes" and "confusion between conductivity and the concept of electrolytes." During class, formative assessment can be implemented through classroom questioning and exercises centered on the T4 two-dimensional valence-category diagram to track cognitive progression. After class, the post-test can be used for summative assessment, with tiered items following a "basic–advanced–comprehensive" structure, corresponding to test points of varying difficulty such as T1 on the essence of redox, T9 on ionic equations, and T14 on chemical engineering contexts. At the same time, targeted interventions should be implemented based on diagnostic data. For example, in response to the error in Q15 that "liquid hydrogen chloride does not conduct electricity, while aqueous SO2 conducts electricity but is not an electrolyte," specialized instruction should be conducted to differentiate "electrolyte/non-electrolyte" and "conductivity and ionization," thereby supporting efficient transition through precise assessment.

Instructional evaluation needs to be integrated with scientific modeling tools in the field of educational measurement (the Rasch model) to overcome the empirical and ambiguous limitations of traditional assessment. Through data support, teachers can accurately grasp students' degree of knowledge mastery, level of ability development, and state of competency progression, achieving scientific diagnosis and precise positioning of junior–senior high school transition learning conditions. This effort aims to make instructional evaluation precise and scientific, promote the concrete implementation of the "competency-based" philosophy, and foster the orderly and sustainable development of students' core competencies.

References

[1] Ministry of Education of the People's Republic of China. (2020). Putong gaozhong huaxue kecheng biaozhun (2017 nianban 2020 nian xiuding) [Chemistry curriculum standard for senior high school (2017 edition, 2020 revision)]. People's Education Press.

[2] Wang, L. (2022). Yiwu jiaoyu huaxue kecheng biaozhun (2022 nianban) jiedu [Interpretation of the Chemistry Curriculum Standards for Compulsory Education (2022 edition)]. Chinese Journal of Chemical Education, *43*(17), 1–8.

[3] Ministry of Education of the People's Republic of China. (2022). Yiwu jiaoyu huaxue kecheng biaozhun (2022 nianban) [Chemistry curriculum standard for compulsory education (2022 edition)]. Beijing Normal University Press.

[4] Yang, Y. Q. (2017). Huaxue hexin suyang zhi "moxing renzhi" nengli de ceping yanjiu [Research on the assessment of "model cognition" ability in chemistry core competency]. Chemistry Teaching, (07), 9–14.

[5] Xie, Y. Z., & Li, Y. R. (2020). Jiyu Rasch moxing de gaozhong huaxue xueke hexin suyang ceping yanjiu——Yi "bianhua guannian yu pingheng sixiang" weili [Research on the assessment of senior high school chemistry core competency based on the Rasch model: A case study of "ideas of change and balance"]. Chinese Journal of Chemical Education (Chinese and English), *41*(21), 7–15.

[6] Yang, Q., He, W. J., & Wang, H. L. (2021). Dancanshu danduowei Rasch moxing de youshi yu yiyi [Advantages and significance of the one-parameter unidimensional Rasch model]. Journal of Psychological Science, *44*(06), 1491–1498.

[7] Sun, X. M., & Guan, D. D. (2009). Jingdian celiang lilun yu xiangmu fanying lilun de bijiao yanjiu [A comparative study of Classical Test Theory and Item Response Theory]. China Examinations (Research Edition), (09), 10–17.

[8] Li, M., Zhang, F. Y., Du, S. T., et al. (2025). Chuzhongsheng huaxue "kexue tanjiu yu shijian" suyang shuiping ceping ji qishi [Assessment and implications of junior high school students' competency level in "scientific inquiry and practice" in chemistry]. Educational Measurement and Evaluation, (03), 76–88.

[9] Sun, X. Q. (2022). Jiyu xueke hexin suyang de chugaozhong huaxue jiaokeshu neirong de xianjiexing fenxi ji jiaoxue jianyi [Analysis of the continuity of junior and senior high school chemistry textbook content based on disciplinary core competency and teaching suggestions]

[Master's thesis, Inner Mongolia Normal University]. https://doi.org/10.27230/d.cnki.gnmsu.2022.000089

[10] Li, Z. Y. (2023). Jiyu Rasch moxing ceping gaozhongsheng huaxue xueke nengli [Assessing senior high school students' chemistry disciplinary ability based on the Rasch model] [Master's thesis, Yan'an University]. https://doi.org/10.27438/d.cnki.gyadu.2023.000419

[11] Qian, Z. N. (2023). Jiyu fazhan "moxing renzhi" de huaxue gainian jinjie xuexi——Yi "yanghua huanyuan fanying" danyuan jiaoxue weili [Progressive learning of chemistry concepts based on developing "model cognition": A case study of the "redox reactions" unit]. Chemistry Teaching, (04), 44–51.