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Role-Playing as a Teaching Strategy in IB Chemistry: A Mixed-Method Study

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Abstract

Drama pedagogy, particularly role-playing, offers promise for making abstract chemical concepts tangible through embodied learning. However, evidence for its effectiveness across different age groups remains limited, especially in multilingual International Baccalaureate (IB) contexts. This mixed-methods study investigated when and how role-playing effectively supports learning of abstract chemical concepts, examining developmental readiness as a critical factor. Seventy-eight students (66 Grade 9, 12 Grade 12) from an international school in Shenzhen, China participated. A between-subjects design with Grade 9 students compared role-playing (n=44) against conventional instruction (n=22) for chemical reaction types. A within-subjects design with Grade 12 students examined role-playing for nucleophilic substitution mechanisms. Data included achievement tests, motivation/engagement surveys, 30 student interviews, and 10 systematic lesson observations. For Grade 9, the experimental groups who received role-playing showed negligible achievement gains compared to the control group who received conventional instruction ($d = 0.022$), despite high behavioural engagement and enjoyment. For Grade 12, where all students served as their own controls in a pre-post design, role-playing produced very large improvements in understanding reaction mechanisms (Cohen's $dz = 1.209$, $p = .002$). English proficiency significantly predicted achievement ($\eta^2 = .220$) but did not moderate

intervention effects. The two cohorts are not directly comparable due to differences in topic, design, sample size, and assessment. The Zone of Pedagogical Receptivity (ZPR) is presented only as a speculative hypothesis for future investigation; it is not a finding of this study. Findings challenge assumptions that engaging pedagogies necessarily improve outcomes, offering evidence-based guidance for implementing drama in chemistry education.

Keywords: drama pedagogy, chemistry education, developmental readiness, mixed-methods, SDG 4 (Quality Education)

1. Introduction

Chemistry learning requires students to navigate cognitively between macroscopic observations, submicroscopic processes, and symbolic representations. This is what Johnstone (1991) called the chemistry triplet. Students consistently struggle with visualising molecular-level processes, particularly reaction mechanisms where electron movement, spatial arrangements, and dynamic interactions occur at the same time (Talanquer, 2011). Traditional instruction that relies on two-dimensional diagrams often fails to convey the three-dimensional nature of molecular interactions, leading to rote memorisation rather than conceptual understanding (Eichler & Peeples, 2016). This challenge is made worse in linguistically diverse classrooms where students must process unfamiliar scientific vocabulary and abstract chemical concepts through an additional language.

The gap between the cognitive demands of chemistry and the representational tools available to students has significant consequences for science education. Research has consistently shown that students who fail to develop strong mental models of molecular interactions in secondary school still have those misconceptions when they reach tertiary education (Taber, 2013). Despite the fact that reforms over the past decades have pushed for inquiry-based and student-centred approaches, most chemistry classrooms worldwide still rely on teacher-centred instruction and static visual representations.

Drama Pedagogy as a Potential Solution

Drama pedagogy, particularly role-playing, offers a promising alternative based on constructivist principles (Piaget, 1972; Vygotsky, 1978). When students physically enact chemical reactions, abstract concepts become easier to understand through physical experience (Braund, 2014; Dorion, 2009). Embodied cognition theory suggests that physical engagement enhances cognitive processing by creating multiple memory pathways (Wilson, 2002). This is relevant because traditional chemistry instruction typically relies on two-dimensional diagrams to teach concepts that are three-dimensional and dynamic in nature.

Drama-related activities have generally achieved high participation rates and positive student attitudes, but evidence that they actually improve conceptual understanding has been mixed. Otter (2020) conducted a focused role-playing study in A-level chemistry and found statistically significant gains in student understanding of organic mechanisms. Abed (2016) showed that dramatisation improved science achievement among primary students, and Najami et al. (2019) reported positive effects on student attitudes toward science. However, none of these studies examined whether the same approach works equally well across different age groups. There is

also limited research on role-playing in linguistically diverse IB contexts, where students learn content through an additional language.

The Research Gap

While existing studies show that drama pedagogy has potential, most do not specify whether they involve redesigning the entire curriculum or simply adding drama activities into existing lessons. This distinction matters for teachers who want to use drama but need to work within their current curriculum structure. The IB context, with its emphasis on inquiry-based learning and international-mindedness, is therefore a suitable context for investigating these questions, since linguistic diversity is built into these settings.

Much of the available literature focuses on single age groups. The lack of comparative studies across different developmental stages is a significant gap in science education research. Piaget's cognitive development theory (Piaget, 1972) and research on embodied cognition (Barsalou, 2008) suggest that age-related differences in cognitive processing should affect how well embodied teaching methods work, but this has not been empirically tested in chemistry education. This study therefore addresses these gaps.

Research Questions

This study addressed four research questions:

How does role-playing compare to conventional teaching in improving student understanding of chemical reaction types (Grade 9) and reaction mechanisms (Grade 12) in IB Chemistry?

What impact does role-playing have on student motivation and engagement?

How does English language proficiency influence role-playing effectiveness?

What implementation challenges emerge, and what strategies address them?

2. Literature Review

Drama Pedagogy in Science Education

Drama-based instructional strategies have gained increasing attention in science education as researchers seek pedagogies that engage students more deeply with abstract content (Ødegaard, 2003). The application of drama in science ranges from brief kinaesthetic activities to full theatrical productions. Role-playing, which places students as active participants representing scientific entities or processes, sits between these extremes as a practical approach with enough depth to be useful (Dorion, 2009). In chemistry, role-playing has been used to teach topics ranging from states of matter at the primary level to organic reaction mechanisms at advanced secondary and university levels. Braund (2014) conducted a comprehensive review of drama in science education and found that there is still a gap between what embodied learning promises in theory and what the evidence actually shows in practice. While drama activities consistently produced high student engagement and positive attitudes, evidence of improved conceptual understanding was uneven.

Otter (2020) addressed this gap through a focused study of role-playing in A-level chemistry, finding statistically significant improvements in students' understanding of organic mechanisms.

However, Otter's study examined only one age group, leaving questions about developmental readiness unanswered.

Embodied Cognition and Chemistry Learning

Embodied cognition theory suggests that cognitive processes are shaped by the body's interactions with its environment (Wilson, 2002; Barsalou, 2008). In chemistry education, this suggests that physical enactment of molecular processes may help students form better mental models than visual or verbal instruction alone. Kontra et al. (2015) provided neuroscientific evidence for this, showing through functional magnetic resonance imaging that students who physically manipulated angular momentum apparatus showed greater activation in sensorimotor brain regions during subsequent problem solving, compared to students who merely observed.

This is directly relevant to chemistry education. Molecular processes such as nucleophilic substitution involve three-dimensional spatial transformations that are difficult to represent through static diagrams (Eichler & Peeples, 2016). When students physically enact these processes, they create mental models that show the dynamic and spatial nature of molecular interactions in ways that arrow-pushing notation on paper cannot show.

Developmental Readiness and Pedagogical Approaches

Piaget's (1972) theory of cognitive development distinguishes between concrete operational thinking (ages 7 to 11) and formal operational thinking (ages 11 and beyond). Formal operational thinkers can reason abstractly, consider hypothetical scenarios, and coordinate multiple variables at the same time. While research has modified Piaget's original age ranges, recognising that the

transition to formal operations is gradual and context-dependent (Kuhn, 2008), the fundamental distinction between concrete and abstract reasoning capacity remains empirically supported. For drama pedagogy, this raises an important question: does effective embodied learning of abstract concepts require consolidated formal operational thinking, or can it support the development of such thinking in transitional learners?

The existing literature does not directly address this question. Studies of drama in science education typically examine either primary-age students with concrete concepts (Abed, 2016) or senior secondary and university students with abstract concepts (Otter, 2020), without examining multiple age groups within the same study. This gap motivated this study's dual-cohort design, which examines role-playing with two different age groups studying different chemistry topics. While this cross-sectional design does not track the same students over time, it allows for observation of how role-playing functions with students at different points in their schooling, with different levels of prior knowledge and different curricular demands.

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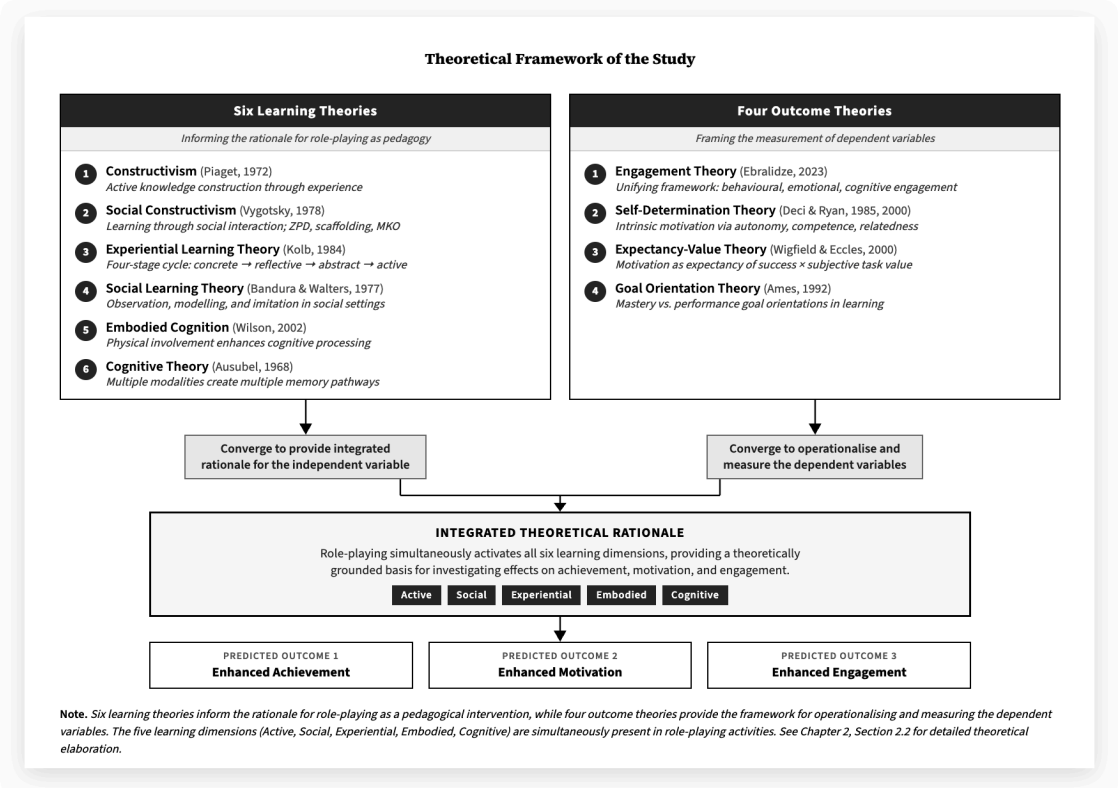
3. Theoretical Framework

This study integrates multiple theoretical perspectives that together support drama pedagogy as a suitable instructional approach for chemistry education. The framework draws on six foundational learning theories and four outcome theories to provide a basis for investigating role-playing's effectiveness. Constructivist foundations (Piaget, 1972) describe learners as active participants who build knowledge through experience. In role-playing, students must actively manipulate concepts rather than receiving information passively. Social constructivist extensions

(Vygotsky, 1978) explain how peer collaboration and teacher guidance during role-playing enable students to accomplish tasks beyond individual capacity through the Zone of Proximal Development (ZPD). Experiential Learning Theory (Kolb, 1984) maps onto well-designed role-playing activities where students enact reactions, reflect on their representations, connect to chemical principles, and apply understanding to new contexts through a cyclical process of concrete experience, reflective observation, abstract conceptualisation, and active experimentation.



Note. *Six learning theories inform the rationale for role-playing as a pedagogical intervention, while four outcome theories provide the framework for operationalising and measuring the dependent variables. The five learning dimensions (Active, Social, Experiential, Embodied, Cognitive) are simultaneously present in role-playing activities. See Chapter 2, Section 2.2 for detailed theoretical elaboration.*

Figure 1. Convergence of Theoretical Perspectives Underpinning the Study

Embodied Cognition (Wilson, 2002; Barsalou, 2008) argues that how people think is connected to how their bodies physically interact with the environment. Physical representation of abstract concepts creates richer, more memorable learning experiences, as demonstrated by Kontra et al. (2015) who provided direct evidence that physical experience enhances science learning. Social Learning Theory (Bandura and Walters, 1977) further supports the approach through observational learning and modelling, while Cognitive Theory explains how multisensory input creates multiple memory pathways, which helps students to remember and recall information better (Atkinson & Shiffrin, 1968).

The study draws on three complementary motivation theories. Self-Determination Theory (Deci & Ryan, 2000) proposes that when students feel a sense of autonomy, competence, and relatedness, their intrinsic motivation increases. Expectancy-Value Theory (Eccles & Wigfield, 2002) explains motivation as a product of how likely students think they are to succeed and how much they value the task.

Goal Orientation Theory (Dweck, 1986) distinguishes mastery goals from performance goals. Engagement encompasses behavioural, emotional, and cognitive dimensions (Fredricks et al., 2004), and these are interconnected. For example, when a student is emotionally engaged, they are more likely to put in cognitive effort, which can then lead to better achievement.

4. Conceptual Framework

The conceptual framework describes the relationships among the study's variables. The independent variable, drama pedagogy through role-playing, is implemented through structured activities for chemical reaction types (Grade 9) and reaction mechanisms (Grade 12).

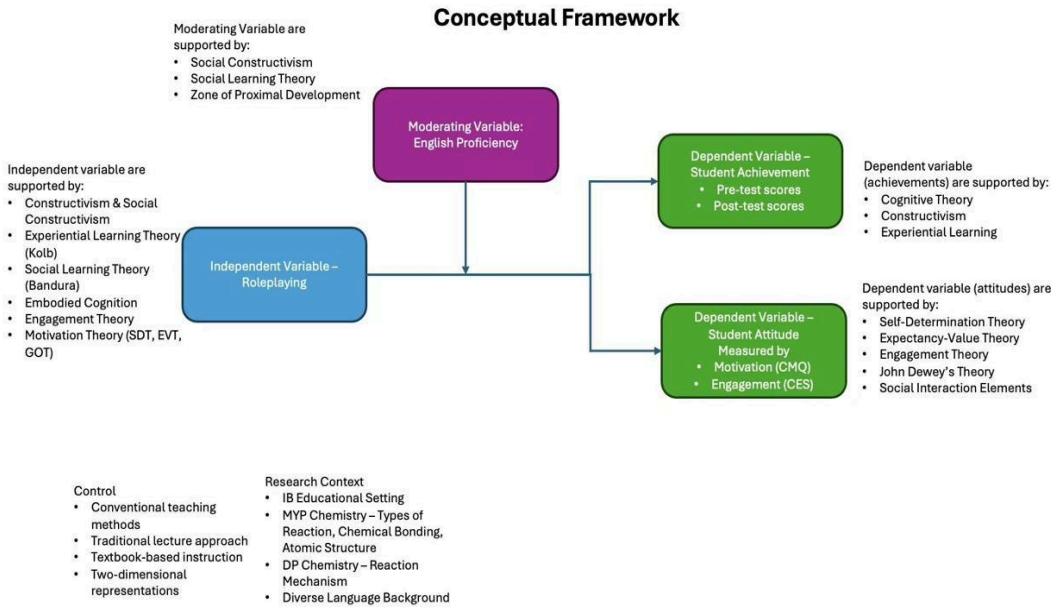


Figure 2. Conceptual Framework: Variables and Relationships in the Study

The dependent variables are student achievement, measured through pre- and post-tests, and student attitudes toward the subject, measured through standardised motivation and engagement

surveys. English language proficiency serves as a moderating variable that may influence how effective role-playing is in this multilingual setting. The control group received conventional instruction, i.e. lectures, diagrams and textbook exercises.

The framework also accounts for implementation challenges through strategic topic selection and professional development. Rather than requiring a complete overhaul of the course, role-playing activities were fitted into the existing IB structure. The framework hypothesises that embodied pedagogy may interact with language proficiency in complex ways: physical enactment could potentially compensate for linguistic barriers by giving students physical ways to show meaning without relying on words, or conversely, the additional verbal demands of collaborative role-playing could add to challenges for lower-proficiency students. Testing this moderation effect is important in order to understand whether drama pedagogy works in internationally diverse classrooms.

5. Methodology

Research Design and Philosophy

Grounded in critical realism (Bhaskar, 1975), this study employed a convergent mixed-methods design (Creswell & Plano Clark, 2017). A between-subjects experimental design with Grade 9 students compared role-playing against conventional instruction for chemical reaction types, with Class A serving as the control group and Classes B and C as experimental groups. A within-subjects pre-post design with Grade 12 students examined role-playing for nucleophilic

substitution mechanisms, with each student serving as their own control. The two cohorts studied different chemistry topics, received different role-playing activities, and were assessed with different achievement tests appropriate to their respective curricula. The Grade 9 topic (chemical reaction types) involved concrete, observable phenomena, while the Grade 12 topic (nucleophilic substitution mechanisms) involved abstract spatial and temporal reasoning. These differences reflect authentic curricular distinctions between the grade levels and mean that direct comparison of effect sizes across cohorts should be interpreted with caution. Qualitative data collection (interviews, observations) ran concurrently to explain quantitative patterns and document implementation processes. The convergent design enabled triangulation of findings across data sources, strengthening the validity of the conclusions.

Participants and Context

This study was conducted at an IB continuum international school in Shenzhen, China. Participants comprised 78 students: 66 Grade 9 students (ages 14–15) and 12 Grade 12 students (ages 17–18). Grade 9 students were organised into three intact classes of 22 students each, pre-assigned by school administration to ensure balanced demographics.

Table 1. Participant Demographics

Demographic Variable	Grade 9 (n=66)	Grade 12 (n=12)
Gender		
Female	32 (49%)	7 (58.3%)
Male	34 (51%)	5 (41.7%)
Student Background		

Chinese (Hong Kong)	43 (65.2%)	5 (41.7%)
Chinese (Taiwan/Macau)	10 (15.2%)	0
American/Canadian	6 (9.1%)	3 (25%)
Other	7 (10.6%)	4 (33.3%)
English Proficiency		
Level 1–2	9 (13.6%)	0
Level 3	23 (34.8%)	0
Level 4–5	34 (51.5%)	12 (100%)

Interventions

Grade 9 Intervention (Weeks 3–8): Experimental groups (Classes B and C) received role-playing instruction for Atomic Structure, Chemical Bonding, and Chemical Reactions. Activities included "Electron Hotel" for electron configuration, "Electron Transfer Ceremonies" for ionic bonding, and "Atomic Speed Dating" for synthesis reactions. Each activity was designed to turn abstract concepts into physical, embodied experiences. The control group (Class A) received conventional instruction covering identical content through lectures, diagrams, and textbook exercises, ensuring content equivalence across conditions.

Grade 12 Intervention (Weeks 1–4): All students received conventional instruction for nucleophilic substitution (SN1 and SN2) mechanisms during Weeks 1–2, followed by role-playing instruction during Weeks 3–4. Activities included "Synchronised Molecular Dance" for the SN2 concerted mechanism and "Two-Step Drama" for the SN1 stepwise mechanism with

carbocation intermediate. Students physically enacted nucleophilic attack, bond breaking, and stereochemical inversion, translating arrow-pushing notation into physical movement.

Achievement tests for Grade 9 (50 marks) assessed Periodic Table, Atomic Structure, Chemical Bonding, and Chemical Reactions. Grade 12 tests (50 marks) assessed nucleophilic substitution mechanisms. All tests underwent expert validation by an experienced IB educator and were moderated systematically through independent marking, with disagreements resolved by consensus. The modified Chemistry Motivation Questionnaire II (CMQ-II) measured intrinsic motivation, career motivation, self-determination, self-efficacy, grade motivation, and English language integration using a 5-point Likert scale ($\alpha > .80$ for all subscales).

Data Collection Instruments

Chemistry Engagement Survey (CES), with Cronbach's alphas ranging from .76 to .84, measured cognitive, emotional, and behavioural engagement. Qualitative data were collected through semi-structured interviews with 30 students selected using maximum variation sampling, along with 2 teacher-observers and 10 lessons documented using structured observation protocols.

Data Analysis

Quantitative analysis employed independent samples t-tests, ANCOVA, paired samples t-tests, and linear mixed models. Effect sizes (Cohen's d, partial eta-squared) were calculated with 95% confidence intervals to provide practical significance measures alongside statistical significance. Qualitative analysis followed Braun and Clarke's (2006) thematic analysis procedure, through collaborative coding by the researcher and an independent Teacher-Observer using Atlas.ti

software. Integration occurred through joint displays and meta-inference development, consistent with best practices for convergent mixed-methods designs.

Ethical Considerations

Informed consent was received from all participants in this study; for students under 18 years, consent was also obtained from a parent or guardian. Participation was voluntary, and participants could withdraw at any time without penalty. All data were anonymised using alphanumeric codes (e.g., G9B17, G12A04) and stored securely with restricted access. The researcher's dual role as teacher-investigator was acknowledged and addressed through reflexive journaling, independent coding verification, and transparent reporting of potential bias.

6. Findings

Achievement Outcomes

Independent samples t-test revealed no significant difference between control and experimental groups in Grade 9. The negligible effect size (d = 0.022) indicated that performance was virtually identical across the conditions, suggesting that role-playing did not enhance chemistry achievement for this age group.

Table 2. Grade 9 Achievement Test Results by Group (Scores range 0–50)

Group	n	Pre-Test M (SD)	Post-Test M (SD)	Gain	d

Control (A)	22	33.23 (9.60)	34.36 (9.63)	+1.14	—
Experimental B	22	33.18 (9.25)	34.32 (9.36)	+1.14	—
Experimental C	22	33.27 (9.40)	34.86 (9.42)	+1.59	—
Combined Exp	44	33.39 (9.17)	34.57 (9.16)	+1.18	0.022

ANCOVA with pre-test scores and English proficiency as covariates confirmed no treatment effect ($F(2,61) = 0.047$, $p = .954$, partial $\eta^2 = .002$). Pre-test scores dominated the model (partial $\eta^2 = .982$), indicating that prior knowledge was the main factor determining achievement regardless of instructional approach. In contrast, for Grade 12 students, a paired samples t-test demonstrated significant improvement with a very large effect size.

Eleven of 12 students (91.7%) improved from pre-test to post-test, indicating that gains were consistent at the individual level. Qualitative findings helped to explain the quantitative contrast. Grade 9 students demonstrated what one teacher-observer termed "busy hands, empty minds", suggesting that students were engaged but not necessarily learning.

Table 3. Grade 12 Pre-Post Achievement Comparison

Measure	Value	95% CI

Pre-Test Mean (SD)	36.25 (7.11)	[31.73, 40.77]
Post-Test Mean (SD)	38.75 (7.44)	[34.02, 43.48]
Mean Difference	2.50 (2.07)	[1.19, 3.81]
Paired t-test	t(11) = 4.190, p = .002	—
Cohen's dz	1.209	[0.440, 1.949]

Student G9B17 shared: "When we did that precipitation reaction role-play, I was focused on remembering my lines and when to move and not bumping into people. The actual chemistry concept got kind of lost." In contrast, Grade 12 students showed a qualitatively different type of engagement. Student G12A04 explained: "The pause between steps, that's when it clicked. For the first time, I understood WHY it's two steps, not just that it IS two steps."

Motivation and Engagement

Linear mixed models revealed significant cognitive engagement increases for Grade 12 students (+14.2%, p = .018) but minimal changes for Grade 9. Emotional engagement showed no significant changes across groups, which challenges the assumption that drama automatically increases enjoyment.

Table 4. Chemistry Engagement Mean Scores by Factor and Time (1–5 Likert scale)

Class	Cog Pre	Cog Post	Emo Pre	Emo Post	Beh Pre	Beh Post
A (Control)	2.94	3.05	2.92	3.01	2.89	2.98
B (Exp)	2.76	2.87	2.77	2.89	2.72	2.83
C (Exp)	2.56	2.68	2.59	2.72	2.53	2.65

D (Gr 12)	2.95	3.37	2.96	3.25	2.92	3.21

CMQ-II results showed significant self-efficacy gains ($F(1,74) = 7.89$, $p = .006$, $\eta^2 = .096$) and intrinsic motivation increases ($F(1,74) = 5.23$, $p = .025$, $\eta^2 = .066$), primarily driven by Grade 12 students. Change in motivation correlated with change in achievement for Grade 12 ($r = .31$, $p = .006$), suggesting that the motivational benefits of embodied learning led to actual improvements in academic results for the older students.

Language Proficiency Moderation

English proficiency significantly predicted achievement ($F(1,61) = 17.19$, $p < .001$, partial $\eta^2 = .220$), accounting for 22% of variance in post-test scores after controlling for pre-test performance. However, the Group × English proficiency interaction was non-significant ($F(2,59) = 0.683$, $p = .509$, partial $\eta^2 = .023$), indicating role-playing neither amplified advantages for high-proficiency students nor compensated for challenges faced by lower-proficiency learners. Qualitative data also showed that students used translanguaging successfully. Student G12A08 explained: "We'd quickly check our understanding in Chinese, '这是反转吗?' (Is this inversion?). It helped having someone to verify my thinking in my native language before trying to act it out in English."

Implementation Challenges

Time was the main constraint, with setup, execution, and cleanup requiring 30–45 minutes per session. Space limitations in chemistry laboratories, designed for bench work rather than movement, created safety concerns. Teacher-Observer 1 noted: "A 10-minute explanation

became 30 minutes with role-play. Space constraints, not designed for movement activities! Nearly knocked over the Bunsen burners."

Behavioural management challenges included Grade 9 students treating activities as "free play." Student G9B20 observed: "Some people didn't take it seriously, others were too shy to participate properly." Successful adaptations included pre-arranged furniture, student leadership roles, differentiated participation options, and explicit connections between embodied activities and assessment requirements. Teachers reported that establishing clear routines over the first two sessions significantly reduced setup time and behavioural disruptions in subsequent sessions, suggesting that spending time on setting up clear procedures early on leads to better efficiency later. These findings show that successful implementation of drama pedagogy requires careful attention to logistics and classroom management, not just pedagogical design.

7. Discussion

Interpreting the Contrast Between Grade 9 and Grade 12 Outcomes

The contrast between Grade 9 ($d = 0.022$) and Grade 12 ($dz = 1.209$) outcomes requires careful interpretation given that the two cohorts studied different topics, received different treatments, and were assessed with different tests. Several explanations are possible: the difference may reflect topic difficulty, the nature of the role-playing activities, sample size differences, or differences in the students' cognitive readiness for embodied instruction. **These two cohorts are not directly comparable** due to the following methodological differences:

Feature	Grade 9	Grade 12
Design	Between-subjects (control vs. experimental)	Within-subjects (pre-post, no control)
Topic	Chemical reaction types (concrete, observable)	Nucleophilic substitution (abstract, spatial, temporal)
Treatment duration	6 weeks	2 weeks
Sample size	66	12
Statistical power	Adequate for medium effects	Underpowered for small effects
Prior knowledge	Low (novices)	High (advanced)

Given these differences, the contrast **cannot be attributed solely—or even primarily—to developmental readiness**. Alternative explanations include topic difficulty × pedagogy interaction, statistical artefacts from the small Grade 12 sample (95% CI for dz: 0.44–1.95), regression to the mean in within-subjects design, practice effects, and different outcome measures.

The Zone of Pedagogical Receptivity (ZPR): A Speculative Hypothesis, Not a Finding

Drawing on these observations alongside the qualitative data, the Zone of Pedagogical Receptivity (ZPR) framework (Figure 3) is proposed only as a tentative hypothesis that identifies possible conditions under which embodied learning may be more or less effective. This framework is not a confirmed finding of the study but rather a conceptual tool generated from the pattern of results that requires further empirical testing.

Figure 3. The Zone of Pedagogical Receptivity Model (original figure retained)

ZPR comprises three interrelated components. First, formal operational thinking (Piaget, 1972) requires students to coordinate concrete actions with abstract concepts simultaneously. Grade 9 students, typically in the concrete-to-formal operational transition, struggled with this dual processing, managing the demands of performing while trying to understand the chemistry. Grade 12 students, with consolidated formal operations, were better able to connect the physical actions to the chemical concepts. Second, metacognitive awareness (Flavell, 1979) enables students to think about how the physical representations relate to the chemical principles. Grade 12 students were able to explain on their own how the physical acting helped them understand the mechanisms, whereas Grade 9 students focused on performance logistics rather than conceptual connections. Third, epistemic maturity (Hofer & Pintrich, 2012) requires students to recognise embodied exploration as legitimate scientific practice rather than play. Grade 9 students' perception of role-playing as "fun but not real learning" meant that there was a gap between what the students were doing and what they were supposed to be learning.

However, it is important to acknowledge that this study did not track the same students over time, and the different topics and treatments used for each cohort mean that the observed contrast cannot be attributed solely to cognitive readiness. The framework is offered as a starting point for future longitudinal research that could test these ideas more rigorously by following the same students across age groups or by comparing different topics within the same age group. It identifies cognitive abilities that may need to be in place for embodied pedagogy to work, but further research is needed to confirm whether these factors are indeed the ones responsible for the pattern observed here. Readers should not treat ZPR as an empirically supported model.

Theoretical Implications

The findings challenge the assumption that engaging, active pedagogies necessarily improve learning outcomes (Kirschner et al., 2006). The Grade 9 results suggest that behavioural activity does not automatically equate to cognitive processing. This could be due to what cognitive load theory (Sweller, 1988) describes as extraneous load: students who do not yet have strong background knowledge may find it too mentally demanding to handle the performance aspects of role-playing (remembering lines, coordinating movements, managing social interactions), leaving not enough mental capacity for actually learning the chemistry. Conversely, Grade 12 students' existing knowledge schemas may have had enough mental capacity left over to think more deeply through the physical activities. This is consistent with the expertise reversal effect in instructional design research, where methods that benefit advanced learners can be ineffective or even counterproductive for novices.

The language proficiency findings offer specific implications for multilingual science education. The significant main effect of English proficiency ($\eta^2 = .220$) confirms that language facility has a strong effect on chemistry achievement. However, the absence of moderation effects reveals that role-playing pedagogy neither amplifies advantages for high-proficiency students nor compensates for challenges faced by lower-proficiency learners. This suggests that embodied pedagogy works together with language demands, not as a replacement for them. The physical aspects of role-playing (gesture, movement, spatial positioning) add to but do not replace the language-heavy parts of chemistry learning (Paivio, 1990). Language scaffolding remains necessary regardless of pedagogical approach.

Practical Implications

For Grade 9–10 educators, role-playing should be used cautiously with simple, concrete concepts. Activities should be brief (10–15 minutes), heavily scaffolded, and immediately connected to chemical principles through explicit reflection. For Grade 11–12 educators, role-playing can greatly improve understanding of complex mechanisms. Extended activities (30–45 minutes) allow deep exploration, and student-directed elements and peer teaching can be incorporated successfully. Across all levels, implementation recommendations include differentiated roles to accommodate diverse comfort levels, clear behavioural expectations to maintain academic focus, pre-arranged furniture to reduce time lost to logistics, and explicit links between embodied activities and assessment criteria to ensure learning transfer.

Limitations

Several limitations must be acknowledged. The single-school context limits generalisability to other educational settings and curricula. The Grade 12 sample size (N = 12), while yielding large effect sizes, restricts statistical power and the strength of conclusions for that cohort. Teacher-rated English proficiency, while it reflects real classroom conditions, is not as precise as standardised language tests. The absence of a delayed post-test means retention durability cannot be assessed. Finally, the researcher's dual role as teacher-investigator introduces potential bias, though this was mitigated through reflexive practices, independent coding verification, and transparent reporting.

Critical limitation specific to cross-cohort comparison: This study was not designed to test developmental differences. The two cohorts differ in topic, design, treatment length, and assessment—confounding any developmental interpretation. The ZPR framework is withdrawn

as a finding of this study and is presented only as a speculative hypothesis requiring independent validation.

8. Conclusion

This study examined role-playing as a teaching strategy with two different cohorts studying different chemistry topics. For Grade 9, role-playing for chemical reaction types produced negligible achievement gains compared to conventional instruction, despite high engagement. For Grade 12, role-playing for nucleophilic substitution mechanisms produced very large pre-post gains, with students reporting that physical enactment helped them understand spatial and temporal aspects that had been difficult to grasp through conventional diagrams alone. The contrasting results across the two cohorts led to the proposal of the Zone of Pedagogical Receptivity (ZPR) framework only as a speculative hypothesis suggesting that cognitive factors such as formal operational thinking, metacognitive awareness, and epistemic maturity may influence how well students benefit from embodied pedagogy. This hypothesis requires further testing through longitudinal or more tightly controlled comparative designs. ZPR is not a finding of this study.

For educators, the findings suggest that engagement alone should not be taken as evidence of learning. The null result for Grade 9 is just as informative as the positive result for Grade 12, though the different topics and treatments used mean that these results should not be directly compared as if all other variables were equal. What can be said is that role-playing worked well for Grade 12 students studying abstract reaction mechanisms but did not produce measurable

learning gains for Grade 9 students studying chemical reaction types. Educators considering drama pedagogy should therefore attend carefully to how well the specific activity matches the cognitive demands of the topic and the readiness of the students.

Future research should look at whether the ZPR framework applies to scientific disciplines beyond chemistry, and how embodied learning may work differently at different developmental stages from a neurocognitive perspective. There is also a need for assessment approaches that can capture what students learn through multiple modes, not just written tests. Longitudinal studies that follow students through developmental transitions would help to clarify exactly when and how pedagogical receptivity develops. Cross-cultural replication studies are also needed to test whether the ZPR framework holds in educational systems with different curricular structures and language contexts.

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