Translanguaging as a Scaffold in Bilingual Science Classrooms: Supporting Students' Construction of the Particle Model of Matter and Language Learning

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Abstract

In response to the dual challenges posed by Taiwan's Curriculum Guidelines of 12-Year Basic Education and the "Bilingual 2030" policy, this study designed a science curriculum integrating Model-Based Instruction and bilingual education, with "translanguaging strategies as a scaffold in the bilingual science classroom" as its core perspective. It explores how sixth-grade students employed translanguaging strategies when constructing the Particle Model of Matter (PMM) and how these strategies were distributed across different instructional designs. Participants were 40 sixth-grade students from an elementary school in Taipei City, matched by pretest performance and randomly assigned to four instructional contexts. A qualitative analysis identified five major strategy types: direct imitation; diagram-plus-short-explanation; self-selected language, gestures, or diagrams to convey ideas; switching between forms; and fully integrated multimodal explanations. Among these, "diagram-plus-short-explanation" was the most common, while fully integrated multimodal explanations were the least frequent. Bilingual groups exhibited a greater variety of expressions and more frequent mode-switching, particularly in the bilingual modeling group, where students addressed both conceptual and linguistic challenges and connected everyday experiences to microscopic explanations. The findings highlight the feasibility of combining modeling with bilingual instruction to support the learning of abstract scientific concepts. Integrating modeling with translanguaging scaffolds effectively links macroscopic phenomena to microscopic explanations, expands students' multilingual and multimodal expressive resources, and fosters progression from single representations to integrated explanations. This approach not only deepens students' conceptual understanding but also offers practical design directions for bilingual science instruction, transforming language use from mere vocabulary input into a key tool for supporting scientific reasoning and knowledge construction.

Keywords: Translanguaging Strategies, Bilingual Science Classroom, Model-Based Instruction, Particle Model of Matter

1. Introduction

In recent years, Taiwan has actively promoted the "Bilingual Nation 2030" policy to enhance citizens' English communication skills and global competitiveness. The Ministry of Education in Taiwan further encourages using English as the medium for certain subjects. In classroom practice, bilingual education is not only about language integration but also about helping students understand and express science concepts in ways that support disciplinary learning.

Taiwan's Curriculum Guidelines of 12-Year Basic Education first listed "constructing models" as a science learning performance for elementary students, extending microscopic concepts, such as "matter consists of tiny particles in constant motion," to upper grades [1]. For topics such as the Particle Model of Matter (PMM), this change has prompted the need for teaching designs that bridge students' everyday experiences and abstract chemical concepts.

In bilingual science classes, students must acquire scientific knowledge while switching languages, creating a dual burden. One practical approach for supporting such learning is to integrate bilingual explanations with multiple representations, so that students can link new scientific terms with visual and experiential references. When dealing with microscopic concepts, students often rely on language and complementary representations to reason with models. These multimodal transformations can help reduce language barriers and enhance students' ability to apply concepts in both science and language learning contexts [2].

This paper reports a classroom-based study in which model-based instruction and bilingual elements were integrated into teaching PMM. The focus here is on how the instructional designs were implemented, what kinds of multimodal and cross-language practices were observed, and what implications these offer for chemistry teaching in elementary settings.

2. Literature Review

2.1 Challenges in Students' Learning of the Particle Model of Matter

In Taiwan's Curriculum Guidelines of 12-Year Basic Education [1], the concept that matter is composed of particles was introduced at the elementary school level. However, this concept involves multiple dimensions: including particle volume, shape, motion, and interactions, whose highly abstract nature poses challenges for both students and teachers. Chen and Lin [3] noted that even experienced teachers often hold vague understandings of the particle-related concepts covered in the curriculum.

The PMM is a scientific concept at the microscopic level, which cannot be directly observed and is not easily constructed naturally from students' everyday experiences [4]. Lin [5] proposed eight core particle propositions to help clarify teaching priorities and strengthen connections among concepts. Chen and Lin [3] also pointed out the high potential of analogical modeling in PMM instruction. Through the mapping of familiar situations onto particle-level ideas, students can more easily connect prior experiences with new chemistry-related concepts.

2.2 Application of Translanguaging in Science Education

While model-based instruction supports conceptual understanding, students may still encounter difficulties when learning in a bilingual setting. In such contexts, teachers and students often combine languages, visuals, gestures, and other modes to make meaning. García and Lin [6] note that these practices help address language needs, clarify concepts, and enhance comprehension.

García and Li [7] define translanguaging as the flexible use of language resources, not limited to code-switching between languages but also including multimodal integration. Cenoz and Gorter [8] emphasize that it is learner-centered and promotes meaning-making. Lu and So [9] identified functions such as guiding inquiry, giving praise, and explaining content. Lemmi and Pérez [10] likewise recognize its supportive role in science learning. In chemistry teaching, such strategies can help students connect symbolic, particulate, and macroscopic representations.

Lemke [11] stressed that language is a key medium for constructing concepts. In bilingual science education, integrating purposeful translanguaging with visual and hands-on resources can create an environment where language use directly supports chemistry concept learning.

2.3 Multimodal Learning in Science Education

Multilingual and multimodal resources can promote students' participation in inquiry and facilitate scientific knowledge construction [9]. For PMM, this includes linking particle diagrams, animations, and everyday analogies to chemical phenomena. Kress et al. [12] pointed out that beyond verbal language, teachers use oral explanations, images, gestures, physical models, and writing to convey meaning.

Ainsworth [13] noted that multiple representations can deepen understanding if closely aligned with the learning task. For abstract concepts such as particle motion or energy transformation, multimodality can enhance motivation and comprehension [14]. Pierson et al. [15] pointed out that multimodal resources are essential for engaging in scientific practices, especially when abstract or microscopic concepts are involved. Bolger et al. [16] found that model construction itself is a multimodal learning process.

Xue and Sun [2] emphasized that models and modeling offer significant benefits in chemistry learning, playing important roles in describing phenomena and developing scientific knowledge. Analogies can reduce the difficulty of modeling instruction by connecting prior experiences to new chemical concepts, making microscopic processes more tangible for students.

3. Research Methods

3.1 Research Design and Participants

This study employed a qualitative classroom-based approach to examine how different instructional designs influenced students' participation and expression when learning the PMM, a topic that often challenges elementary learners due to its microscopic and abstract nature. The intervention was implemented across four class periods, with some groups experiencing model-based activities and others receiving more traditional instruction, and with language modes varying between bilingual and Chinese-only contexts.

In the first class, a pre-test was conducted to assess students' baseline PMM understanding, science-related language skills, and familiarity with modeling activities. The "tiny mover" analogy was introduced in a diffusion scenario, together with selected English vocabulary related to the PMM, as a bridge to later instructional activities.

The instructional activities were developed by crossing two factors: teaching strategy (Modeling vs. Traditional) and language mode (Bilingual vs. Chinese), producing four groups:

- Bilingual Analogical Modeling Group (BA): Bilingual instruction with modeling activities, guiding students to construct concepts through a variety of language and visual supports.
- Bilingual Traditional Group (BT): Bilingual instruction using inquiry and lecture-based methods.
- Chinese Analogical Modeling Group (CA): Modeling activities conducted entirely in Chinese.
- Chinese Traditional Group (CT): Traditional inquiry and lecture-based teaching in Chinese.

All lessons were delivered by the same trained team of teachers to ensure consistency. They followed lesson scripts, observed each other's instruction, and engaged in post-lesson reflections to review classroom implementation.

The participants were forty sixth-grade students from a public elementary school in Taipei with bilingual learning experience but no prior exposure to modeling instruction. These students were selected from a larger cohort based on comparable pre-test performance, ensuring similar starting points across the four groups.

3.2 Data Collection

Multiple sources of qualitative data were gathered to document classroom processes and student participation:

(1). Classroom Video and Audio Recordings: All lessons were recorded and transcribed to capture teacher–student interactions and the ways students expressed their ideas.
(2). Instructional Materials and Worksheets: Lesson materials and student work were collected for evidence of concept representation and language use.
(3). Classroom Observation Records: Notes were taken during lessons, aligned with the corresponding pages of instructional materials.
(4). Team Meetings: The research team met regularly to ensure lesson fidelity and reflect on classroom implementation.
These data were coded by lesson type (BA, BT, CA, CT) and linked to student identifiers for later analysis. For example, a student with the identifier 60119 in the Bilingual Modeling group was labeled as BA60119.

3.3 Data Analysis

This study adopted Codebook Thematic Analysis as the primary qualitative data analysis method. The thematic analysis combined predetermined analytical dimensions with inductive theme generation, aligning with analytical principles while facilitating collaborative operations and cross-checking among multiple researchers. In practice, the research team first conducted repeated readings and open coding of all students' written responses in the learning sheets and the verbatim transcripts of the recorded instructional process. Based on theoretical foundations and pilot studies, four preliminary analytical dimensions were established: analogy type, language style, modality integration, and regulation strategies. These four main codes formed the first-level coding framework. Subsequent steps involved defining detailed coding categories, identifying representative statements, constructing classification logic, and performing cross-checking to enhance the reliability and reproducibility of the analysis. Our coding categories are Analogy type, Language style, Mode integration, and Regulation strategies.

This coding framework provided the logical foundation for thematic analysis, supporting both the generation and comparison of themes, as well as serving as the basis for interpreting the relationship between translanguaging strategy types and students' learning performance. All modifications were documented in detail, with complete records of the analytical procedures and corresponding original excerpts to ensure transparency, validity, and reliability of interpretation [17].

To enhance coding consistency and reliability, the research team conducted training and example-based discussions for each category in the codebook. Two researchers independently coded a sample dataset from the Bilingual Traditional group, using the teaching material from the observation records as the primary unit of analysis, supplemented with video recordings, teaching materials, and students' worksheets. Coding was performed for each student, and the results were cross-checked. The Kappa values for all major codes exceeded .78, indicating high inter-coder agreement [18]. Any discrepancies were resolved through negotiation with a third researcher. This framework thus served as the basis for developing, reviewing, and refining preliminary themes.

4. Results

4.1. What translanguaging strategies did students use when learning the PMM?

When learning the PMM, students displayed a range of ways to combine language, visuals, and other resources to explain abstract and microscopic ideas. Five main patterns of expression were observed:

- ●Pattern 1: Direct imitation of the teacher's or peers' wording or diagrams.
- ●Pattern 2: Combining diagrams with brief written or spoken explanations to illustrate a phenomenon.
- ●Pattern 3: Actively using self-selected words, gestures, or diagrams to convey an idea.
- ●Pattern4: Switching between different forms of expression when encountering difficulty in explanation.
- ●Pattern 5: Integrating multiple modes and personal analogies to create a more comprehensive explanation.

In terms of frequency, the second pattern, combining diagrams with brief explanations, was the most common and accounted for 51% of all instances. It was followed by the third pattern, using self-selected language, gestures, or diagrams to convey ideas, at 32%, Pattern 1, direct imitation accounted for 12%, Pattern 4, switching between modes for 3%, and Pattern 5, integrating multiple modes into a personalized explanation, for 2%.

For example, in the Bilingual Traditional group, a student (BT60415) was asked, "*Do hot particles move faster than cold particles?*" The student wrote "*YES*" in English and drew two cups (Figure 1), one labeled "*hot*" and the other "*cold.*" Wavy lines were added to each cup to represent food coloring spreading in water, with shorter, denser lines in the cold cup and more spread-out lines in the hot cup. This visual-text combination clearly illustrated the faster and wider diffusion in hot water, showing how students could use a simple blend of scientific vocabulary and diagrams to convey a chemical concept.

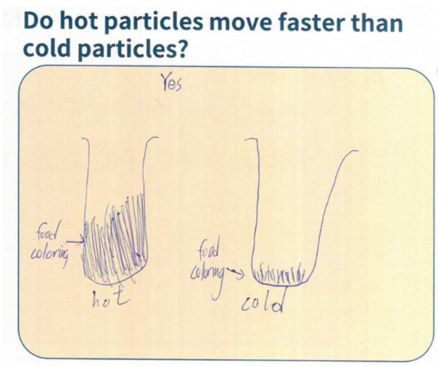

Figure1. BT60415's response in the instructional material

4.2 Under different instructional designs, what patterns do translanguaging strategies exhibit?

The four instructional designs appeared to create different opportunities for students to combine language, visuals, and other resources in explaining PMM concepts. The results were as Table 1. While all groups made use of diagrams and short explanations, the extent and variety of these combinations varied notably.

In the Bilingual Analogical Modeling group (BA), students produced the widest range of expression types, including direct use of scientific vocabulary, switching between Chinese and English, and drawing analogies from everyday experiences to illustrate particle behavior. This group also showed more instances where diagrams, gestures, and verbal explanations were integrated in the same response.

The Bilingual Traditional group (BT) also displayed variety, though most responses combined textbook diagrams with brief bilingual explanations. Occasional analogies and language switching were observed, but these were less frequent than in the Bilingual Modeling group.

In the Chinese Analogical Modeling group (CA), most responses involved diagrams plus short written explanations in Chinese, sometimes enriched with analogies related to everyday phenomena. The range of expression was narrower than in bilingual settings, but the visual explanations were often clear and accurate.

The Chinese Traditional group (CT) relied heavily on reproducing diagrams from the materials, with short labels or captions. This approach conveyed the basic concept but offered fewer opportunities for students to extend or personalize their explanations.

Overall, bilingual instruction appeared to encourage more varied forms of expression, while modeling activities, whether in bilingual or monolingual settings, tended to prompt students to create their own diagrams and connect them to explanations of particle behavior. The richest combinations of modes and language were observed when bilingual instruction and modeling were combined, suggesting that these elements together can create a more dynamic space for students to articulate their understanding of chemical concepts.

Table1. Distribution of translanguaging strategies under different instructional designs

Strategy	BA	BT	CA	CT
Pattern 1	★★	★★		
Pattern 2	★★	★★★	★★★★★★★★ ★★	★★★★★★★★ ★★
Pattern 3	★★★★★★	★★★★		
Pattern 4	☆	☆		
Pattern 5	☆			

Note: ★ indicates the proportion of translanguaging strategy use across the four instructional design groups.
☆ indicates a proportion below 10%.

5. Conclusions and Implications

This study examined how students in different instructional settings expressed their understanding of the PMM, focusing on the ways they combined language, visuals, and other resources. Across the four groups, five main patterns of expression were observed: direct imitation, diagram-plus-short-explanation, self-selected language, gestures, or diagrams to convey ideas, switching between forms, and fully integrated multimodal explanations. These patterns appeared with different frequencies—diagram-plus-short-explanation was by far the most common, while fully integrated multimodal explanations were rare.

The distribution of these patterns varied across instructional designs. Bilingual settings encouraged greater variety, with students more often switching between languages, drawing on analogies, and combining multiple modes. Modeling activities, whether conducted in bilingual or monolingual contexts, can encourage students to independently produce diagrams and relate them to explanations of particle behavior, sometimes integrating everyday experiences to enrich their microscopic-level interpretations. The richest and most flexible combinations occurred in the Bilingual Modeling group, where students navigated both conceptual and linguistic challenges.

From these findings, several teaching insights emerge:

Use modeling to anchor abstract concepts

Incorporating analogy-based modeling can prompt students to work with both visual and verbal representations, helping them connect macroscopic observations (e.g., diffusion in hot vs. cold water) to microscopic particle behavior.

Leverage bilingual elements to expand expressive resources

Alternating between Chinese and English in a supportive way can encourage students to reframe and refine their explanations, fostering more precise use of scientific terms.

Encourage movement across modes

Providing opportunities to draw, gesture, and write about chemical phenomena can deepen understanding, especially for concepts that cannot be directly observed.

Support gradual progression toward integrated explanations

Teachers can prompt students to move from reproducing diagrams or repeating terminology toward combining multiple resources into personalized, coherent explanations.

In chemistry teaching, particularly for topics like PMM, integrating modeling with bilingual scaffolding can create a learning environment where students actively construct both conceptual and linguistic understanding. Such integration shifts bilingual science instruction from simply adding English terms to strategically using language as a tool for deepening disciplinary learning.

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