

Article

Designing Translingual and Transmodal Scaffolding and VR Pair Programming for Supporting Multilingual Learners' Participation in Scientific Sensemaking

Ai-Chu Elisha Ding ^{*}, Jorge Hernandez Cervantes, Katherine Martin and Kexin Zhang

Department of Workforce Education and Instructional Technology, University of Georgia, 850 College Station Road, Athens, GA 30605, USA; jh05726@uga.edu (J.H.C.); katherine.martin@uga.edu (K.M.); kexin.zhang@uga.edu (K.Z.)

^{*} Correspondence: ading@uga.edu

Abstract

This single case study examines the implementation of a co-designed fifth-grade science unit enhanced by using Virtual Reality (VR) and integrating translingual and transmodal scaffolding strategies to support students' participation and quality of talk during scientific sensemaking. The co-designed science unit covered physical and chemical changes as part of the fifth-grade science curriculum. The research involves a fifth-grade science teacher and her class of 22 students comprising multilingual learners (ML) and English monolingual learners (EML). This study examines the learning experience of 3 student pairs grouped as ML-ML, EML-ML and EML-EML. Using content analysis, we analyzed 911 min of video data on the six students' learning in this unit. The results indicate that when the teacher used translingual and transmodal scaffolding strategies introduced during the co-design process, equal participation across MLs and EMLs was observed. The VR pair programming worked well for student pairs in increasing active participation regardless of the pairing, although active participation did not necessarily lead to high quality science talk. Findings of this study provide implications and recommendations for leveraging the scaffolding from teachers, materials, and VR pair programming activity to support the equal participation and quality of talk among all learners during scientific sensemaking.

Keywords: translanguaging; transmodaling; scaffolding; virtual reality; scientific sensemaking; collaborative learning; multilingual learners



Academic Editors: Victoria Lowell and Paula MacDowell

Received: 30 June 2025

Revised: 4 September 2025

Accepted: 10 September 2025

Published: 17 September 2025

Citation: Ding, A.-C. E., Hernandez Cervantes, J., Martin, K., & Zhang, K. (2025). Designing Translingual and Transmodal Scaffolding and VR Pair Programming for Supporting Multilingual Learners' Participation in Scientific Sensemaking. *Education Sciences*, 15(9), 1236. <https://doi.org/10.3390/educsci15091236>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Scientific sensemaking, with its increasing attention in science education ([National Science Teaching Association, 2025](#)), is a collaborative and dialogic activity where individuals work together to understand scientific phenomena and solve problems ([Miller & Reigh, 2020](#)). Scholars have pinpointed the importance of engaging students in collaboratively making sense of scientific phenomena through essential science and engineering practices, such as creating and using models, to explain how and why climate change is occurring ([Zangori et al., 2017](#)). Sensemaking supports learners by pooling their knowledge and skills to tackle complex scientific concepts and tasks that would have otherwise been difficult to complete individually.

However, studies have shown that **multilingual learners (MLs)**, learners who speak more than one language and speak a named language other than English at home in the US context ([Grabin et al., 2023](#)), tend to be marginalized participants in group work

and gain little from the collaborative process when their participation is not carefully supported in monolingual instructional contexts (Cohen & Lotan, 2014; Turner et al., 2013). This is partially due to the inequitable power dynamics caused by the narrowly defined means of communication: English-medium verbal-focused communication. English is typically the only language used in US science classrooms. Although visuals and models are essential elements in scientific communication (Jewitt et al., 2001; Tardy, 2004), the English-medium verbal-focused language output remains the primary form of assessing learners' science learning outcomes (Ding, 2024; Jiang et al., 2024). Without the opportunities to use multilingual and non-verbal linguistic resources as forms of engaging in group work, MLs with limited English language proficiency would therefore feel less confident in participating in the sensemaking process (Pérez Fernández, 2024).

To that end, this study orients to the translanguaging and transmodaling perspectives (García, 2017; Newfield, 2017) to co-design sensemaking activities with elementary science teachers in the hope of fostering more equitable group participation and science talk among MLs and their **English monolingual learner (EML)** peers. Collaborating with two elementary science teachers, we re-designed a “physical and chemical change” unit derived from their initial instructional materials. The re-designed unit engaged students in creating multimodal representations (Prain & Tytler, 2022; Tang et al., 2014) of physical and chemical reactions. We also intentionally incorporated various translanguaging and transmodaling scaffolding strategies into the unit and integrated a virtual reality science game to engage students in making meanings through visual-focused and gestural-focused meaning-making (Ding, 2023). And in considering the potential marginalization of MLs in group work when role assignment is used, the researchers also utilized pair programming strategy (X. Wei et al., 2021; Williams et al., 2002) where one student serves as driver and another serves as navigator to collaboratively complete the VR learning task. With our intentional translanguaging and transmodal scaffolding design, we ask two research questions:

- Q1: How did the teacher use translanguaging and transmodal scaffolding to support ML students' participation and talk?
- Q2: How did MLs and EMLs participate in scientific sensemaking through the intentional translanguaging and transmodal scaffolding design of the unit, including the VR pair programming activity and teacher scaffolding?

2. Literature Review

2.1. Translanguaging and Transmodal Scaffolding

Translanguaging and transmodaling encourage students to use various languages and presentation modes to make sense of the learning contents. Translanguaging honors the diversity of language uses, encouraging the moves between named languages (García, 2017), formal academic language and informal everyday speech (Jensen & Thompson, 2019), and different forms of expression such as visual, auditory, gestural modes, or spoken and written language (Canagarajah, 2018; Kress, 2009). Transmodaling emphasizes transmodal moments, which are instances when students intentionally transduce and transform meanings across different modes of communication (e.g., sound, static and moving images, movement, and language) and even different scientific models (e.g., a drawing model and a math equation). This purposeful shift in meaning between communicative modes and models is deemed crucial and productive to students' science learning (Ding & Cha, 2024). Translanguaging and transmodaling both seek to expand the channels of meaning-making in classrooms, liberating learners from monolingual and monomodal standards. This approach aims to create a more equitable and dynamic learning experience for all students.

Translanguaging and transmodal scaffolding further refers to the scaffolding strategies that enable translanguaging and transmodaling practices in the classroom. Originating

from sociocultural learning theories (Wood et al., 1976), scaffolding refers to the support structures that teachers provide to help learners bridge the gap between their current learners' capacity and the desired academic performance. To enhance translanguaging pedagogies, especially in classrooms where only English is typically used, educators should provide support for translanguaging activities to help students understand its advantages for their school-based learning (Daniel et al., 2019). For instance, Daniel et al. (2019) proposed that instructors can scaffold students' translanguaging using macro-level planning (e.g., launching translanguaging through discussions) and micro-level planning (e.g., transliterating words, borrowing terms, using opposites, and identifying cognates). Similarly, transmodaling scaffolds create spaces for students to represent what they learn using modes beyond traditional verbal-focused means. For example, teachers can adopt the transmodal framework developed by Mina (2021) where they can implement scaffolding activities such as creating storyboards and rhetorical choice memos.

The use of translanguaging and transmodaling scaffolding strategies generates multiple benefits in teaching and learning. It enhances bilingual learners' comprehension and participation, particularly in whole-class discussions (Cenoz & Gorter, 2020). It also promotes a more equitable learning environment for MLs and provides substantial learning benefits for both MLs and EMLs (Ding & Cha, 2024). Furthermore, translanguaging validates students' home and community languages as meaningful resources for learning, supporting identity affirmation, cognitive flexibility, and deeper engagement with academic content (García & Wei, 2014).

2.2. Affordances of Immersive Virtual Reality to Support Science Learning

Virtual Reality (VR) simulates physical environments by providing students with a sense of reality through vivid interactions by means of stereoscopic, high-resolution environments (Froehlich et al., 2024). This engages the learner through sensory, auditorial, and visual modes that correlate particularly well with transmodal instructional methods (Ding, 2024; Mills et al., 2022). Through high-fidelity virtual scenarios, VR creates opportunities in science learning that can reduce and shift the cognitive load required of students. For instance, students can experience real environments that may not be easily accessible such as conducting experiments in a research science lab or traveling on the International Space Station (Adžgauskaitė et al., 2020; Seedhouse, 2022). Students are also afforded the opportunity to experience scenarios that were impossible to explore. For example, students can learn about the components of a cell by removing and interacting with different parts of one in a virtual environment (Froehlich et al., 2024; Parong & Mayer, 2021).

VR also uniquely affords transmodal meaning-making opportunities. Ding (2023, 2024) found that students engaged in visual- and gestural-based meaning-making during VR-based activity and that students heavily engaged in transforming visual or written representations into gestural movements or oral utterances. These transmodal meaning-making patterns are uniquely found during VR-based activities more than other activities in the science learning unit. These transmodal meaning-making opportunities are considered particularly beneficial for supporting both EMLs and MLs' participation and learning in the science classrooms. This is demonstrated through the students' use of non-verbal modalities to communicate their understanding of relevant and specialized scientific concepts related to unit phenomena that may have otherwise been inhibited through verbal modes of communication alone.

Despite the potential benefits of VR, integrating VR into K-12 education presents challenges for educators, primarily due to the cost of the devices and the complexity of managing and facilitating their use simultaneously. Consequently, VR individual play is not a viable or sustainable method for integration within K-12 settings. To leverage this

emerging technology, collaborative learning should be considered to reduce the number of devices needed in classrooms while enhancing meaningful student interactions. However, the current study by [Ding et al. \(2025\)](#) indicates that poorly designed VR group work can negatively impact MLs who only observe other students' VR activities, resulting in their suboptimal performance. Author A suggests that this is due to the absence of role assignments during group tasks, which would encourage MLs to overcome language barriers and actively contribute to discussions. Consequently, structuring VR collaboration tasks is a critical pedagogical consideration to ensure equal participation from both MLs and EMLs.

2.3. Supporting Group Participation Through the Pair Programming Strategy

Collaborative learning is rooted in social interdependency theory, which states that the performance of individuals is affected by their own and that of others involved ([Johnson & Johnson, 2009](#)). The responsibility of being engaged in group roles gives place to a positive interdependence, presenting group work as a dynamic whole where members are made interdependent through common goals. And as collective goals are identified, motivation to persist arises. Collaborative learning can be hard to achieve, and in group learning activities between MLs and EMLs, multilingual learners may fall into the marginalized group and have their ideas and contributions dismissed by their peers. It is crucial to effectively challenge and redefine status to foster an inclusive and equitable learning environment where all learners are perceived as valuable members of the learning community ([Monteiro et al., 2024](#)). Group roles can be effective in increasing student participation in heterogeneous classrooms when used with other strategies to promote collaborative learning ([Cohen & Lotan, 2014](#)). [Stoeckel \(2024\)](#) presents group roles as a strategy to communicate with students that all learners can and should contribute to group work, enabling productive collaboration and engagement with one another.

In this study, we turn to pair programming as a strategy to assign roles to students in completing the VR activity. Pair programming is a collaboration strategy initially used in programming and computer science education ([X. Wei et al., 2021](#)). This strategy involves one student acting as the navigator who gives commands and one as the driver who executes the commands and rotates the roles during the collaboration process. In our case, we also have students paired up to complete the VR activity, one as navigator and one as driver. The navigator utilizes an iPad with a more objective point of view to guide the driver and provide directions, commands, and instructions to accomplish the goal; the driver uses the VR equipment (an immersive VR headset and two hand-held controllers) and follows the navigator's commands to complete tasks. During the learning, students take turns to serve as navigators and drivers. Through presenting responsibility and accountability for the group work, the pair programming strategy potentially can offer equal-status participation among EMLs and MLs to complete group work and collectively achieve a mutual goal.

3. Materials and Methods

3.1. Research Design and Participants

This study is a single case study ([Yin, 2003](#)) occurred at the Kingsley Elementary School (pseudonym), a Title 1 school located in an exurban county in the southeastern United States. The unit of analysis of the case study is the translingual and transmodal VR-enhanced science unit, which the research co-designed with the participating teacher (see description below), noting how the participants interacted with each other and with the materials within this bounded system.

Participants are a 5th-grade science teacher, Elle (pseudonym), and her students who consented to participating in the research project. In Elle’s class of 22 students, the ratio of MLs to EMLs is 26.7% to 73.3% with the majority of MLs speaking Spanish as the home language. The research team worked with Elle to intentionally pair 22 students into 10 pairs and in 4 groups, distributing MLs and EMLs evenly across the four groups. We zoom in on one group of six students to examine qualitatively their participation and quality of science talk. The six students in this group were further paired as follows: ML (Dominique)—ML (Alonso), ML (Marrisa)—EML (Morene), and EML (Nancy)—EML (James) (all in pseudonyms). The variations in pairing MLs and EMLs were intentionally designed in the hope of observing how the impact of translangual and transmodal design might differ among different pair dynamics as research has shown that the pair or group assignment between ML and EML could impact their engagement (Langeloo et al., 2021; Miller & Reigh, 2020).

3.2. The Focal Science Unit

The focal unit covered the topic of physical and chemical change (NGSS Lead States, 2013), which is a part of the teachers’ general science curriculum. The research team met with the two fifth-grade teachers at Kinsley from October 2024 to February 2025 to co-design and revise the unit to encourage more phenomenon-based and model-based learning activities (Achieve, 2017; Zangori & Forbes, 2016; Schwarz et al., 2017), the integration of VR activities, and translangual and transmodal strategies. The final unit is composed of eight 50 min sessions (see Table 1). Activities in this unit purposefully sequenced students to move from macro-level and observation-based model construction to molecule-level construction. By the end of the unit, students revised their models to include molecule representations with written explanations, demonstrating a deeper and more scientifically grounded understanding of the physical and chemical reactions.

Table 1. Learning Activities of the Eight Sessions in the Focal Science Unit.

Session Number	Learning Activities
1	• Video demonstration of the two investigative activities: Coke and mentos; vinegar and baking soda. • Developed multimodal word wall with bilingual vocabulary in Spanish and English with students. • Students independently construct the first model (a drawing model representing their initial hypothesis on why putting coke and mentos together causes eruption and why mixing vinegar and baking soda causes eruption).
2	• Model construction continues. • Teacher synthesis session (The teacher honors and uses students’ drawing models and languages to teach key scientific concepts).
3	• Teacher synthesis session continues. • VR pre-training.
4	• Station Day 1 ○ Station 1: VR game (Group 1 and 2) (The focus group was Group 2). ○ Station 2: labs (Coke and candy experiment AND baking soda and vinegar experiment) (Group 3 and 4).
5	• Station Day 2 ○ Station 1: VR game (Group 3 and 4). ○ Station 2: labs (Coke and candy experiment AND baking soda and vinegar experiment) (Group 1 and 2) (The focus group was Group 2).

Table 1. Cont.

Session Number	Learning Activities
6	• Second-round model construction: create molecular models using playdough to explain how Coke and mentos interact and how baking soda and vinegar interact to determine whether the eruption is a physical or chemical reaction.
7	• Second-round model construction continues. • Students write their model explanation. • Teacher synthesis session.
8	• Write short science report using the Claim, evidence, and reasoning (CER) structure and sentence stems to synthesize the findings and explain the anchoring phenomena.

This sequential progression is observed in each of the tasks conducted throughout the individual sessions. In Session 1, Elle introduced the anchoring phenomenon through whole-class discussion and videos on the physical and chemical changes explored in the unit. She would consistently employ teacher questioning to check for students’ understanding and engaged students in building the multimodal vocabulary word wall together to prepare them for describing properties of changes (e.g., rough to describe texture). Elle introduced the key vocabulary and concepts (such as physical and chemical change) in both English and Spanish to elicit the aid of her Spanish-speaking students. The students also began individually creating their first models to represent their original hypotheses for each reaction.

During Session 2, Elle prompted students to continue writing down their initial observations and hypotheses on what would happen if putting Mentos into Coke or mixing baking soda and vinegar through model creation. Elle would encourage students to use the sentence stems and discourse moves for discussing and completing the tasks together and modeled using those resources. Translingual scaffolding strategies were utilized with ML students. Elle had students share their models in their table groups and encouraged students to guess and discuss their peer’s hypothesis based on the drawn model.

Session 3 included a 20 min teacher-led review session combined with a 40 min VR orientation and pair programming practice session led by two of the research team members. During the teacher-led review practice, Elle used the worksheet she designed along with teacher questioning scaffolding to solidify students’ understanding of the differences between physical and chemical changes. Afterwards, during the VR orientation and pair-programming practice, the first and second authors used a tutorial guide accompanied by a VR pair programming worksheet with bilingual vocabulary and a practice activity to teach students how to use the VR headsets and engage in pair programming, respectively. Students engaged in hands-on practice and physically moved around during the pre-training. The first and second authors also employed several translingual and transmodal scaffoldings during the pre-training (e.g., teaching students how to give a command in both English and Spanish and connect the verbal command with bodily movements). In Session 4, students played the VR game following the pair programming technique. The VR game and the pair programming technique appeared to successfully prompt all students to actively participate in the learning activity. The research team also facilitated students’ VR play through translanguaging and teacher questioning scaffolding.

During Session 5, students were able to engage in a student-led hands-on learning experience. The students conducted the Coke and Mentos experiment, baking soda and vinegar experiment, collected data on the weight of the substances, measured geyser heights, and recorded the temperature of the substances to determine whether a physical

or chemical change had occurred. After the initial instruction from Elle, the six students carried out the experiments as a group while Elle floated between groups for check ins. The student-led hands-on experiments seemed to afford the most opportunities for students to use the specialized terms.

Returning to model construction, however this time through playdough modeling, Session 6 guided students in building molecular models that represented the physical and chemical changes from each experiment. Students were guided by bilingual worksheets and permitted to model their playdough molecule after the reaction of their choice. This continued into Session 7, where students were asked to draw their models on their respective worksheets and explain why the molecule was the result of a physical or chemical reaction. The group of six students followed during this study were encouraged by Elle to write their responses in Spanish or English, or to draw models expressing their understanding of the phenomena observed from each student’s reaction of choice. The teacher would check in with each group and ask students to explain their models.

Concluding the unit, in Session 8, students participated in a whole class claim, evidence, reasoning (CER) writing activity. Through the research team’s developed CER worksheet with sentence stems, the teacher facilitated step by step development of a paragraph that synthesized each student’s hypothesis, findings, and explanations of the unit’s anchoring phenomena. In keeping with previous sessions, the teacher encouraged students, through translanguaging and teacher questioning, to use English or Spanish to write their responses.

3.3. The Translingual and Transmodal Scaffolds

In the unit, we specifically developed or adopted hard and soft scaffolding (Saye & Brush, 2002) materials based on relevant science education and translingual and transmodal literature (Celic & Seltzer, 2013; He & Lin, 2022; MacDonald et al., 2014; Zheng et al., 2025). Table 2 summarizes the scaffolding materials provided in this unit and provides examples of the instances where each scaffold was employed.

Table 2. Translingual and Transmodal Scaffolds.

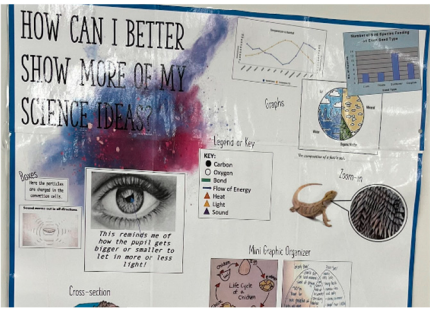
Hard Scaffolds	Features	Examples
Bilingual Vocabulary Teaching	The teacher provided opportunity for whole classroom engagement in translation of the relevant terminology using translanguaging strategies to teach vocabulary in English and Spanish.	Elle: In English, the next one is atom. All students: atom. Elle: Como se dice? Alonso: átomo. Elle: átomo? All students: átomo.
Multimodal Representation Poster	This poster utilized transmodaling to demonstrate the various modes students could use to respond to problems and questioning during the unit.	

Table 2. Cont.

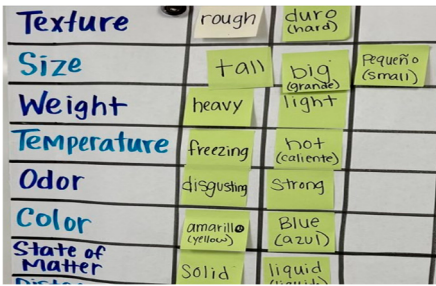
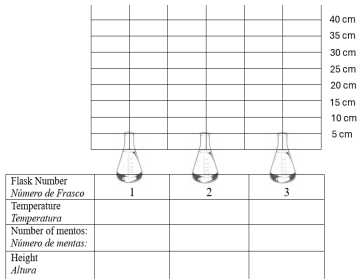
Hard Scaffolds	Features	Examples
Multimodal Vocabulary Wall	A poster for students to share words that can be used to describe properties of an object/phenomenon; students were encouraged to share words in English or Spanish using transmodal scaffolding strategies.	
Sentence Stems	Sentence stems as optional resources for students to use to develop their scientific writing.	- The data supports/does not support _____. (El dato apoya/no apoya _____.) - The reason I think in this way is based on_____. - The data table/graph shows _____.
Activity Worksheets	Worksheets created to intentionally encourage students' translingual and transmodal practices in the unit. This includes the Pair-Programming practice worksheet, Bi-lingual Playdough Modeling activity worksheet, data collection worksheets during station activities and the CER writing worksheets	 Observations/Observaciones: What changed from one flask to another? What stays the same? Draw or describe your observation!
Soft Scaffolds	Features	Examples
Teacher Discourse Moves	A list of bilingual discourse moves provided by the research team for teachers to support one of the seven functions during conversations: (1) help a student clarify his/her thinking, (2) make ideas and thinking public, (3) mark a particular idea, (4) help students listen carefully and think about other's ideas, (5) help students deepen their reasoning, (6) help students apply their thinking to other's ideas, and (7) help students translanguaging and honoring students' cultural knowledge.	Elle: OK. So do you think that there's some sort of reaction happening inside of that? Do you think there's a reaction happening in there? Other student: I think it might be a physical or chemical reaction. . .
Student Discourse Moves	A list of bilingual discourse moves provided by the research team for students to engage in meaningful science talk with each other during group work.	Tell or explain an idea: "I know it will work because _____." Sharing each other's languages and experiences: "This reminds me of a story/a saying in my family. . ."

Table 2. Cont.

Soft Scaffolds	Features	Examples
Teacher Questioning	The most frequently utilized discourse move used to engage students during whole class discussion. The question functions not on the teacher discourse moves prompts are listed under this category.	Elle: And we kind of have already been talking about that, right? About how what, what 2 substances have we mixed together that make a new substance? Alonso: Vinegar and baking soda. Elle: Vinegar and Baking soda, yes, that creates what? Alonso: A chemical. Elle: It’s a chemical reaction. What new substance do we get? Alonso: Carbon dioxide. Elle: Carbon dioxide, Good.
Teacher elicits student contribution	The teacher prompted students to read the worksheets in English or Spanish for participation in the class conversation. The elicited student output is only the repeating of the materials.	Elle: All right, the third bullet. Who can read the last one under “think about”? One more volunteer. All right, [Student E]. Other student: Whether or not mixing two or more substances makes a new substance.

3.4. VR Pair Programming Activity

The VR game was developed through the first author’s previous projects. The game introduces students to making observations and inferences and simulate the Coke and Mentos experiment following the steps of scientific method (see [Ding, 2024](#), for more description of the game). In this iteration, students worked in pairs using the Meta Quest 2 equipment and iPads to cast and play the VR game based on the pair programing design (see Section 2.3).

During Session 3, students participated in a VR orientation and pair programming practice session lasting approximately 40 min. Members of the research team introduced students to the VR equipment allowing them to try on the VR headsets and practicing by using the equipment, giving commands and directions and acting out the movements of such commands. Students were then introduced to bilingual vocabulary using a word bank as part of a pair programming worksheet that listed commonly used commands in both English and Spanish (see Figure 1). The first and second authors explained pair programming and the roles of a navigator and a driver. Students performed hands-on practice tasks using the VR equipment and giving commands and directions to each simulating being in the virtual space and practicing pair programming (See Figure 2).

Bilingual Word Bank

Derecho (Right)	Izquierda (Left)	Arriba (Above)	Entre (Between)
Mueve (Move)	Abajo (Underneath)	Dentro (Inside)	Detras (Behind)
Teletransportate (Teleport)	Alcanza (Reach)	Abre (Open)	
Cierra (Close)	Agarra (Grab)	En frente (In front)	

1.

2.

3.

4.

5.

6.

Now follow the instructions you have completed and draw the route Alberto must

Figure 1. Bilingual Word Bank—Pair Programming Worksheet.

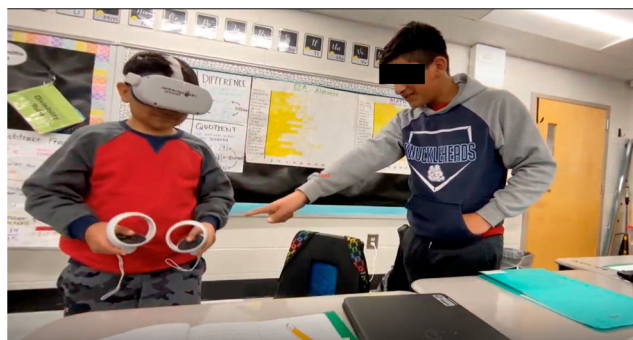


Figure 2. Students practicing pair programming and using VR equipment during VR orientation.

The VR pair programming activity took place during Sessions 4 and 5 during stations. One group completed the VR pair programming while the other group completed hands-on experiments led by Elle in the classroom, and then the groups would switch stations the next day (See Table 1). The VR station was set up in the hallway outside of the classroom, and the VR sessions were facilitated by members of the research team (See Figure 3). Our six focal students completed the VR activity during Session 4 in their respective pairs. During the VR session, each pair also used a data collection sheet designed by the research team to take notes of the scientific experiment performed in the VR space, and annotate any relevant observations and information related to the completed VR tasks.



Figure 3. VR stations located in the hallway outside of the classroom.

3.5. Data Sources

The primary data sources of this study were the video recordings of the classroom interactions accompanied by audio transcription files. The video data, recorded through three iPads, centered on the six students grouped into three pairs based on their learner characteristics (see Section 3.1). Each iPad is used to track one pair's interactions and talk. Thus, one session would yield three angles of data to analyze. These six students were followed throughout the entire Physical and Chemical Change unit. The data documented followed the students' interactions with their partners and their table group members. A total of 21 videos with a combined length of 911 min of video data were collected and saved in a password-protected shared drive accessed by the research team.

The videos were later transcribed verbatim using a combination of artificial intelligence software and professional transcription services. The research team then reviewed each transcript, correcting transcribed items and translated sections. The research team also added information about the non-verbal actions (e.g., turning and paying attention to Elle while she provided activity instruction) into the transcripts. The transcribed conversations

and interactions were then separated into codable segments ($n = 552$) that were analyzed based on a developed coding scheme that documented each student's participation, the types of interactions, and the types of conversation each student engaged in. Each segment was first identified based on the type of interaction taking place (e.g., teacher-whole class, pair or small groups, teacher-student) before identifying the participation, talk, scaffolding, translanguaging, transmodaling, and in vivo codes. The documents were uploaded to the qualitative research software, ATLAS.ti version 25.0.1, for collaborative coding.

3.6. Data Analysis

We answered our research questions by analyzing video data with content analysis (Vaismoradi et al., 2013). We organized and analyzed our data using ATLAS.ti Web. After the initial coder training, each team member coded 10% of the data (166 min) individually based on the initial coding scheme developed by the first author. After multiple rounds of coding, discussion, and recoding, a final coding scheme (see Table 3) was derived. We calculated the inter-coder reliability with Krippendorff's α and received high reliability for the final coding scheme ($\alpha = 0.967$). Research team members later used this final coding scheme to code the remaining data.

Table 3. Coding Scheme on interaction, participation, and talk used in this study.

Code Name	Definition	Examples
Interaction Types		
Teacher-whole-class	The interactions involve the teacher standing in the front, addressing the whole class without directing to specific students.	Elle: Your hypothesis should say something like, I hypothesize that _____ happens because _____. Use the sentence stems.
Pair or small groups	Two or more students interact with one another during pair or small group work.	Dominique: ¿Cómo se dice (use pencil to point to one discourse move), Alonso: Coca Cola, Espuma (geyser)?
Teacher-student	The teacher interacts with specific students during pair, small group, or individual practice time.	Elle: Do you know which one is carbon and which one is oxygen? Morene: Carbon? Elle: So, look at the board, how many carbons do we have?
Participation Levels		
Active	The student initiates the discussion or leads the task within the group. The student frequently shares ideas and opinions, asks questions, or clarifies concepts. The student actively listens to others and builds on others' contributions.	Dominique asks Alonso: "¿qué opinas de la número cuatro?" (What do you thinking about number four?) "¿tú piensas que es physical?" (Do you think it is physical?)
Contributing	The student participates occasionally with relevant comments or questions. The student contributes ideas when prompted or asked directly. The student listens attentively to group discussions.	[Following Dominique's question above] (Alonso looks down on his paper) Alonso: esperate (wait) Alonso: (responds in Spanish saying "C")

Table 3. *Cont.*

Code Name	Definition	Examples
Passive	The student primarily listens to others without actively contributing. The student participates minimally, like nodding or agreeing with others. The student may not be fully engaged in the group discussion or task.	Elle to the whole class: We are going to walk through one of these (writing tasks) together. It says through the Coke and candies experiment. I would say that if we mix Coke and _____ together, we will make a mess at home. What could we put in that first blank? OTHER STUDENT: 13:44 Mentos. (Marissa and Morene did not mouth the word, but they were writing)
Non-Participant	The student appears disengaged or withdrawn from the group. The student does not actively participate in discussions or group activities and may be doing something else.	Elle: I am going to pause you there, ask you to fill in the next sentence with the word. . . . Other Student: Oh, in the model, it showed that there is no change to the particles (Alonso was staring blankly; Dominique was yawning without looking at the other student)
Talk Quality		
Specialized	The student uses specialized science vocabulary (e.g., physical and chemical change, carbon dioxide, observation, inference, height, centimeters) that was specifically introduced in the unit to explain a concept or engage in a science practice.	(kids doing the Baking soda and vinegar experiment) Nancy: What's the height for #2? (Morene took the meterstick, bended down and did the measurement of the height) Morene: about 7 Nancy: ?? 7 inches? Morene: Centimeters
Relevant-Verbal	The student uses plain words to explain a concept or engage in a science practice.	(kids working on the steps of scientific method puzzle in the VR) Marissa: Yeah. Get the question one, and put a number one. James: Get question and put number one where Marissa: Get one of the plates that says question, and put it on the number one.
Relevant-Nonverbal	The student makes sense of a concept through non-verbal actions or performs a science practice.	See Morene's non-verbal actions in the "specialized" example.
Irrelevant	The student's talk was irrelevant to the focus of the unit.	(Kids working on creating a model to represent chemical change using play-dough) Marissa: This is how I make tortilla (shows the flat play-dough to Alonso and Morene)

As shown by the coding scheme (Table 3), we coded the interaction types (teacher-whole class, teacher-individual student or small group, student-student), the participation patterns (active, contributing, passive, non-participant), and the quality of the science talk (talk with specialized vocabulary or science concept, relevant-verbal, relevant-nonverbal, and irrelevant). We also coded the teachers' translingual and transmodal practices performed through carrying out the scaffolding. After coding was completed, coding frequencies and co-occurrence analyses were conducted in ATLAS.ti to identify patterns of ML and EML participation and talk, along with their relationships with translingual and transmodal scaffolding strategies afforded through the design.

4. Results

4.1. RQ1: The Teacher's Translingual and Transmodal Scaffolding for Supporting MLs' Participation and Talk

We coded a total of 684 translingual and transmodal scaffoldings during the science unit (each codable segment could have more than one scaffolding strategy). A total of 299 observed instances where the teacher provided soft scaffolding identified, and 385 of hard scaffolding were found. Overall, we observed that the incorporation of translanguaging and transmodaling strategies from the teacher worked well in creating active teacher-student interactions and promoting both MLs and EMLs meaningful scientific sense-making.

For instance, during Session 1, Elle first showed the class videos illustrating the type of reactions that occur when mixing vinegar and baking soda or putting mentos in coke. Then, she guided the class to get familiar with key vocabulary and then distributed a worksheet for students to record their observations and hypotheses where sentence stems were provided. Through this instructional sequence, Elle purposefully prompted students to transform meanings from audio-visual materials (video) and verbal explanation of concepts to produce written meanings. The worksheet with step-by-step guiding questions and sentence stems supported this transmodal meaning-making process (see Figure 4).

Form your initial explanation. Forma tu explicación inicial.

1. What are your observations (Observaciones) on both experiments?

it looked like a small volcano but once you throw the mento it looked like it was staged.

when he put the mentos in it looked like a jachozy with soap.

2. What are your hypotheses (Hipótesis) right now?

You may use a sentence stem such as "If I change the candy, then I will _____ Hypotesis," or "I hypothesize that _____ happens because you" to form your hypotheses.

Coke and Mentos: _____

Vinegar and baking soda: I feel like if you poured less its not gonna fizz so much

Figure 4. An example of the worksheet and student response.

In another example, Elle used translingual soft scaffolding to encourage MLs' active participation and engaging them in science talk. For instance, during Session 1 when going through the worksheet, Elle asked the class for the Spanish translation of vocabulary words, and for the first time, active participation was observed from Dominique, the ML with limited English proficiency, during whole-class discussion. Elle asked: "How do you say observation in Spanish?" to which both Alonso and Dominique responded saying: "Observación (Observation)." Elle further prompted the students to write down their observations for both experiments saying: "So what are your observación? Observations on both experiments? Write them down." In this instance, both MLs actively engaged in class discussion and used specialized terms through leveraging the bilingual linguistic resources they possessed.

Elle's translingual soft scaffolding was particularly powerful for supporting Dominique. In another instance during a teacher-student interaction, Elle encouraged Dominique to use translanguaging. Elle asked: "so, why did you put physical change"? To which Dominique responded: "because it can come back?" Elle reassured him saying: "You are right, it can be reversed. ¿Cómo se dice it can be reversed en español? (How do you say it can be reversed in Spanish?)" Dominique replied: "Puede ser reversivo" and Elle applauded him and encouraged him to use Spanish if preferred, reminding him that it was acceptable for him to write in Spanish when completing his assignment. She told Dominique: "Hey if you want to write it in Spanish, you can. If you can say more in Spanish, say it, put it in Spanish."

4.2. RQ2: MLs and EMLs' Overall Participation and Quality of Talk

Our data show similar levels of participation among all six students, regardless of whether they are ML or EML (see Table 4). Levels of participation of student pairs also show to be very similar between each student in each pair, regardless of pairing. For instance, in the ML-ML pair, both students demonstrated active participation of 45.4% and 41.9%, the ML-EML pair presents active participation at 37.2% and 42.9% and the EML-EML pair showed active participation at 42.9% and 35.7%. The similar levels of participation indicate that translingual and transmodal design encouraged all three groups to actively engage or contribute for the majority of the recorded interaction time.

Table 4. Frequencies and Percentage of Students' Participation Levels.

Pair	Student Name	Active	Contributing	Passive	Non-Participant	Total
Pair 1	Alonso (ML)	134	90	57	14	295
		45.4%	30.5%	19.3%	4.7%	100%
	Dominique (ML)	111	44	89	21	265
		41.9%	16.6%	33.59%	7.9%	100%
Pair 2	Marissa (ML)	89	58	80	12	239
		37.2%	24.3%	33.5%	5.0%	100%
	Morene (EML)	102	58	72	6	238
		42.9%	24.37%	30.3%	2.5%	100%
Pair 3	James (EML)	63	45	37	2	147
		42.9%	30.6%	25.2%	1.7%	100%
	Nancy (EML)	50	39	43	8	140
		35.7%	27.9%	30.7%	5.7%	100%

In terms of the quality of talk observed in this unit, our analysis shows that, overall, the six students' relevant talk (including specialized, relevant-verbal, and relevant-nonverbal) ranged from 88.8% to 92.1%. In contrast, irrelevant talk shows the lowest levels across all three pairs, ranging from 7.9% to 11.2%. The high percentages of relevant talk across students indicate that they maintained relevant communication during the majority of the interaction time recorded (see Table 5).

As we zoom in on the frequency of using specialized talk (e.g., using topic-relevant vocabulary), we found that Pair 1 (ML-ML) showed a drastic difference between the proficient ML (25.8%) and the emerging ML with limited English proficiency (8.9%). Pair 2's (ML-EML) specialized talk levels were closer together, with 17.5% ML and 18.4% EML, respectively. The levels of specialized talk for Pair 3 (EML-EML) were also very similar,

with levels of 31.4% and 28%. However, Pair 3 had a much higher frequency of specialized talk (28~31.4%) compared to Pair 1 or 2.

Table 5. Frequencies and Percentages of Students' Quality of Science Talk.

Pair	Student Name	Specialized	Relevant-Verbal	Relevant-Non-Verbal	Irrelevant	Total
Pair 1	Alonso (ML)	60	106	48	19	233
		25.8%	45.5%	20.6%	8.1%	100%
	Dominique (ML)	17	67	91	15	190
		8.9%	35.3%	47.9	7.9%	100%
Pair 2	Marissa (ML)	28	69	48	15	160
		17.5%	43.1%	30%	9.4%	100%
	Morene (EML)	33	71	55	20	179
		18.4%	39.7%	30.7%	11.2%	100%
Pair 3	James (EML)	37	39	29	13	118
		31.4%	33.1%	24.5%	11%	100%
	Nancy (EML)	33	41	34	10	118
		28%	34.7%	28.8%	8.5%	100%

4.3. RQ2: MLs and EMLs' Participation and Talk During Different Scaffolded Activities

While the overall participation and talk patterns are similar among students, different scaffolded activities seem to yield different levels of participation and talk quality. We calculated the frequency of active participation on eight days of the unit to identify the two most active days and the two least active days for the students. Our analysis showed that the two most active days were the third and fourth sessions ($n = 97$ and 129), both of which the students were using VR (see description in Section 3.2 for the scaffolded activities students went through). On the other hand, we observed the least active participation during the first and second sessions ($n = 13$ and 41), both of which involved a great amount of teacher-led activities and whole-class discussions. In these activities, the teacher was typically the one initiating an interaction to elicit student responses, especially during Session 1. Thus, while students might be contributing to the conversations, they had fewer opportunities to take the initiative and lead the conversations.

In terms of the frequency of specialized science talk, we also noted a different pattern across the scaffolded activities. Our analysis revealed that students had the most specialized science talk during the fifth session (the hands-on experiments session) ($n = 48$) and had the second most specialized talk during the first and the sixth session ($n = 35$ for both sessions), both of which involved teacher lecture presenting videos as instructional materials to illustrate experiments and a model construction activity using play doh where more disciplinary-focused science words and concepts were introduced. This indicates that teacher-led activities and model-based activities could potentially afford more science talk. On the other hand, students had the least specialized science talk during the third and fourth sessions (the VR-related sessions) ($n = 15$), even though these two sessions afforded the most active participation for the six students. This is partially due to the fact that students were making meanings via non-verbal actions during VR activities. In the meantime, this also indicates that the design of the VR-based learning tasks could be improved to further prompt students to use specialized talk.

When zooming in on how MLs and EMLs performed during the three sessions with the most specialized science talk, we noted additional patterns and relationships among

students' talk and the scaffolding strategies. First, during Session 5, the frequencies differed drastically, with Nancy (EML) contributing 19 times, to Dominique (ML with low English proficiency) contributing only 1 specialized talk. The possible reason why the fifth session had the highest number of specialized science talks could be because of the student-led, content-focused, hands-on nature of the activity. Through engaging in the essential science and engineering practices in this activity, students were actively making meaning on their own and producing science talk. Thus, this activity design seemed to show great potential for engaging students in high-quality science talk. However, the English-focused student-centered activity was potentially the reason why a drastic difference between ML and EML's specialized talk was observed. Mainly, despite the teachers' efforts in modeling translingual discourses, we noticed that the EML students have never really used the bilingual discourse moves once. They continued to use English as the main communication channel with their peers. This was fine for Alonso and Marissa, who were MLs with higher English proficiency. They were still able to participate in pair or group work meaningfully, but for Dominique, his participation and quality of talk dropped significantly during the six-person group work, where English is the only channel of communication. This is drastically different from other sessions where he engaged in pair work with Alonso and was able to converse in Spanish or take other non-verbal actions.

Second, in Session 1, where the teacher introduced the anchoring phenomenon, key vocabulary, and engaged students in a modeling task, all six students were using specialized terms to some degree (4~7 times). In Session 1, we observed that students' specialized talk mainly occurred during the teacher-led lecture and discussion in the form of "responding", "fill in the blank", or "read-out-loud" the text. For example, during Session 1, Elle asked the class the essential question, and James responded with the specialized word "carbon dioxide".

Elle: OK, our essential questions, number one, which everyday objects should we not mix together to avoid making a mess at home?

James: (raised hand, and Elle called on him) Elephant toothpaste.

Elle: OK, what gets mixed together to make elephants toothpaste.

James: I know it was like, carbon dioxide and something!

Elle: OK. Right now we're just, we're being scientists right now. We're just having a hypothesis, an educated guess.

In Session 6, students' specialized talk differed again from Alonso (ML), contributing 12 times, while Marissa (ML) contributed only once. Similarly to Session 1, we also found that students' specialized talk mainly occurred during the teacher-led lecture and discussion instead of the paired modeling tasks. In Session 6, besides engaging students in discussion, Elle also asked for volunteers to read the anchoring phenomenon and questions out loud when introducing the modeling task to students. For example,

Elle: So let's review the procedure sheet and some diagram examples. ... Who can read the anchoring phenomenon? You can read it in English or Espanol. We're looking at this paper right here. Okay. Will you read it, Nancy?

Nancy: How even when heating, cooling or mixing substances, the total weight of matter is conserve, conserved.

Elle: Conserved. What does conserved mean?

Alonso: It's still the same.

Additionally, Elle also employed translanguaging discourse moves and asked her MLs to help with reading the Spanish instruction, which engaged active MLs like Alonso to speak in class with specialized terms:

Elle: Step #2 who can read that? Go ahead. (picked someone, and the student read the question). OK, so physically or chemically, can anyone translate that?

Alonso: fisical y quimical (physical and chemical).

Elle: Can you read the whole thing like como cambiaran Ingrediente a ingrediente durante la reacción. (Elle tries to read the text in Spanish).

Alonso: Como cambiara el ingrediente durante la reacción (how will the ingredient change during the reaction).

5. Discussion and Conclusions

5.1. Translingual and Transmodal Scaffolding Supports Equal Participation of MLs and EMLs

This study explores how an elementary teacher in collaboration with researchers co-designed a VR-enhanced science unit providing translingual and transmodal scaffolding to students. This study also investigates how MLs and EMLs participated in scientific sensemaking in the co-designed translingual and transmodal VR-enhanced unit.

Our findings showed that the translingual and transmodal scaffolding design supported MLs and EMLs' equal participation in this unit. The six students we observed, regardless of their pairing, showed similar distribution of participation level during this unit and remained engaged for the majority of the instructional time, i.e., they remained at the active or contributing participation levels for most of the time. Two main factors seem to support the equal active participation of MLs and EMLs in this study. First, the teacher, Elle, adopted several translingual and transmodal scaffolding strategies introduced by the research team during co-design process, such as the bilingual vocabulary teaching, multi-modal vocabulary wall, bilingual sentence stems, and the translanguaging discourse moves. Her translingual and transmodal scaffolding seemed to be particularly useful to support Dominique, the ML with limited English proficiency. We observed several interactions between Elle and Dominique where her encouragement of MLs to use their home language and her attempts at translanguaging enhanced Dominique's participation in the whole-class discussions as well as during pair work. Her scaffolding played a critical role in supporting MLs to participate in discussions as much as their EML peers, giving them more confidence and agency to contribute to conversations as the "more knowledgeable other" (Abtahi et al., 2017). Although MLs with limited English proficiency tended to be less engaged in class discussions and group activities in English-medium classrooms (Safford et al., 2017), the translingual and transmodal scaffolding strategies provided by Elle significantly improved MLs' participation, resulting in a more balanced level of participation among all students.

Second, our findings also revealed that both MLs and EMLs were noticeably more active during the VR pair programming activity than other activities. The frequency of active participation observed during the VR pair programming session ($n = 129$) was markedly higher than the second most active session ($n = 97$) and all the other sessions, where the frequencies ranged between 13 and 95. We postulated that the disparity was due to the multimodal features of the VR and the pair programming design. Firstly, immersive VR uniquely provided transmodal meaning-making opportunities (Ding, 2024; Ding & Cha, 2024; Fusaro et al., 2025; Mills et al., 2022), prompting students to actively interpret the multimodal input and convert the information into different communicative modes for interaction with partners or task execution. This feature intrinsically enhanced students' active engagement. Secondly, the VR session deliberately incorporated the pair programming design (Fan et al., 2025; Su et al., 2024; Xu & Correia, 2024), where students

were assigned roles and alternated between them. This intentional collaborative learning design appeared to be a fundamental aspect distinguishing the VR session from other sessions that also included hands-on pair or group work. In the author's prior study, where the pair programming strategy was not employed, it was observed that MLs were less engaged when watching others' VR interactions and performed lower than their EML counterparts (Ding et al., 2025). Compared to the findings of the previous study, the participation levels revealed in this study are promising and suggest significant implications for implementing pair programming strategies in VR-based learning activities.

5.2. Active Participation Did Not Necessarily Lead to High Quality Science Talk

Although equal participation among MLs and EMLs was an exciting outcome, our findings also further cautioned and revealed the shortcomings of our current design, with the findings on the quality of the student talk. We found that some of the most active sessions, especially the VR pair programming session, in fact had the lowest percentage of specialized science talk. As indicated by our findings, although all six students were highly engaged during the VR sessions, they mainly used plain words or non-verbal actions to converse and complete the learning tasks together. There were a few opportunities that prompted them to communicate specialized terms or concepts during the VR-related sessions. On the other hand, some of the teacher-led sessions in fact afforded more equal contributions of specialized science talk among the six students. This reveals the important roles of teachers' direct instruction and guided practice. As elementary students are still developing and acquiring the disciplinary literacy practices (Moje, 2015), teachers' modeling and scaffolding become extremely important to support learners' adoption of the disciplinary discourse practices, including the use of specialized terms to explain and name a scientific concept or practice (Fackler et al., 2024; Zhu & Lin, 2024).

Additionally, our findings showed that during the investigative lab activity where all six students worked as a group, the distribution of specialized science talk was highly unequal, with one EML student dominating and producing significantly higher instances of science talk, and the one ML with limited English proficiency produced only one instance of specialized talk. This aligns with Pérez Fernández (2024), where MLs with limited English proficiency were less confident in participating in the sensemaking process due to insufficient opportunities to incorporate multilingual resources and non-verbal cues. We postulated that the limited use of specialized science talk by Dominique was due to the lack of translanguaging practice from the EML students and the lack of assigned roles during group work. Using only English creates an unbalanced power dynamic between EMLs and MLs with limited English skills, reducing their ability and confidence to contribute. Without assigned roles or tasks, MLs may be sidelined and gain little from group work.

5.3. ML and EMLs' Talk During Scientific Sensemaking Through the Translingual and Transmodal Scaffolding Design

In this study, we found that the quality of science talk differed among the three pairs, and MLs are still generally demonstrating lower percentages of specialized talk. We found that the EML-EML pair demonstrated a consistently higher percentage of specialized talk (28% and 31.4%) than the other group. The advantages of English-dominant instruction and working with peers speaking the same language still allow them to take on the academic discourse more easily.

The ML-EML pair had 17.5~18.4% of specialized talk but 39.7~43.1% of relevant verbal talk. This potentially indicated that with this type of pair, students would leverage their non-academic discourse more to communicate with each other. Specifically, instances of transmodaling were observed during the interactions between the ML and the EML, but instances of translanguaging were very limited. Future studies would need to explore

further strategies to support the ML-EML pair's engagement with academic discourse with translanguaging strategies.

Finally, in the ML-ML pair, the ML with higher English proficiency had 25.8% of specialized science talk, while the ML with low English proficiency only had 8.7%. It is clear that the translanguaging and transmodal design benefited the ML with high English proficiency significantly. Being able to converse in both English and Spanish with peers allowed him to dominate the conversations on multiple occasions. However, for the ML with limited English proficiency, while our translanguaging and transmodal design allowed him to actively participate in science, his contribution to the specialized talk was limited on multiple occasions. This is understandable as those academic discourses may not yet be part of developing MLs' linguistic repertoire. Future research should investigate more ways to encourage the developing MLs' acquisition and use of specialized academic discourse. It is important to note that while the developing ML's specialized talk was low in this study, it does not mean that translanguaging and transmodaling could not support developing MLs' quality of science talk. Translanguaging and transmodaling should be ongoing practices, not isolated events (L. Wei, 2024; Satar et al., 2024). In this study, Elle implemented these strategies for the first time, and students only had opportunities to go through translanguaging and transmodal practices in one unit. We contend that, over time, when both teachers and students are accustomed to these practices, the translanguaging and transmodal scaffolding would be able to support both EMLs and MLs' participation and talk in science. And as MLs with limited English proficiency build confidence and expand their linguistic resources for academic discourse through this approach, their quality of science talk will improve over time as well (Lemmi & Pérez, 2024).

5.4. Implications and Recommendations

This exploratory case study provides some important implications for designing science instruction and materials to support MLs. The unique context of this study also allows us to gain some initial insights on how translanguaging and transmodal scaffolding and the use of VR influence students' participation in scientific sensemaking. Based on our findings, we provide several practical recommendations. First, providing professional development for teachers to enhance their translanguaging scaffolding strategies is essential to equipping them to facilitate bilingual and multimodal learning experiences for linguistically diverse students. Second, structured roles and responsibilities during group activities can ensure equitable participation and minimize power imbalances, encouraging meaningful contributions from all students. Third, expanding the design of VR pair programming to include opportunities for specialized science talk could involve integrating targeted prompts, collaborative tasks requiring technical vocabulary, or teacher-led post-VR discussions. Additionally, future research should focus on scalable strategies to implement translanguaging practices across diverse educational settings and explore ways to foster peer translanguaging to bridge communication and participation gaps further.

5.5. Conclusions and Limitations

This study highlights the pivotal role of translanguaging and transmodal scaffolding in fostering student participation and talk during scientific sensemaking, particularly for MLs with limited English proficiency. The intentional translanguaging and transmodal designs in this unit, including the teachers' translanguaging and transmodal practices and the VR pair programming design, facilitated meaningful participation and talk among students. Students leveraged bilingual discussions, nonverbal cues, and gestural responses during their interactions, showcasing their adaptability and engagement with the scaffolded materials. Additionally, the incorporation of pair programming and VR-mediated learning

provided avenues for active and transmodal participation, ensuring equitable involvement among students. The findings also emphasize that translanguaging and transmodal scaffolding strategies supported MLs in progressing through complex scientific concepts, enabling their equal participation and collaboration alongside their EML peers.

Despite these promising outcomes, the study has notable limitations. The sample size was small, comprising only six fifth-grade students and one teacher, which constrains the generalizability of the conclusions to larger populations. Furthermore, the corrupted data for James and Nancy, who were frequently out of frame, posed challenges in analyzing their contributions accurately. This limitation required considerable effort to align audio and visual data, yet the pair's data remained less comprehensive compared to other students. Future research should aim to expand the sample size and explore scalable methods for implementing translanguaging and transmodal scaffolding across diverse educational contexts. Additionally, iterative studies could refine the use of emerging technologies, such as VR, to enhance bilingual and multimodal learning opportunities for all students.

Author Contributions: Conceptualization, A.-C.E.D.; methodology, A.-C.E.D.; formal analysis, A.-C.E.D., J.H.C., K.M. and K.Z.; investigation, A.-C.E.D., J.H.C., K.M. and K.Z.; resources, A.-C.E.D.; data curation, A.-C.E.D., J.H.C., K.M. and K.Z.; writing—original draft preparation, A.-C.E.D., J.H.C., K.M. and K.Z.; writing—review and editing, A.-C.E.D. and K.M.; visualization, A.-C.E.D., J.H.C., K.M. and K.Z.; supervision, A.-C.E.D.; project administration, A.-C.E.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was approved by the Institutional Review Board of the University of Georgia (protocol code PROJECT00010727; date of approval: 25 November 2024).

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The anonymized data presented in this study are available on request from the corresponding author due to protect participants' identity.

Acknowledgments: The research team acknowledges the collaborative efforts of the elementary school educators, administrators, and students that participated in and supported this case study.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EML	English monolingual learner
VR	Virtual reality
ML	Multilingual learner

References

- Abtahi, Y., Graven, M., & Lerman, S. (2017). Conceptualising the more knowledgeable other within a multi-directional ZPD. *Educational Studies in Mathematics*, 96(3), 275–287. [\[CrossRef\]](#)
- Achieve. (2017). *Using phenomena in NGSS-designed lessons and units*. Achieve.
- Adžgauskaitė, M., Abhari, K., & Pesavento, M. (2020). How virtual reality is changing the future of learning in K-12 and beyond: Using the needs-affordances-features perspective. In C. Stephanidis, D. Harris, W.-C. Li, D. D. Schmorow, C. M. Fidopiastis, P. Zaphiris, A. Ioannou, X. Fang, R. A. Sottilare, & J. Schwarz (Eds.), *HCI international 2020—Late breaking papers: Cognition, learning and games* (Vol. 12425, pp. 279–298). Springer International Publishing. [\[CrossRef\]](#)
- Canagarajah, S. (2018). Translingual practice as spatial repertoires: Expanding the paradigm beyond structuralist orientations. *Applied Linguistics*, 39(1), 31–54. [\[CrossRef\]](#)
- Celic, C. M., & Seltzer, K. (2013). *Translanguaging a CUNY-NYSIEB guide for educators*. CUNY-NYSIEB.

- Cenoz, J., & Gorter, D. (2020). Pedagogical translanguaging: An introduction. *System*, 92, 102269. [CrossRef]
- Cohen, E. G., & Lotan, R. A. (2014). *Designing groupwork: Strategies for the heterogeneous classroom* (2nd ed.). Teachers College Press.
- Daniel, S. M., Jiménez, R. T., Pray, L., & Pacheco, M. B. (2019). Scaffolding to make translanguaging a classroom norm. *TESOL Journal*, 10(1), e00361. [CrossRef]
- Ding, A.-C. E. (2023). *Examining the affordances of virtual reality for supporting English learners' science learning: A multimodal perspective*. Available online: <https://www.researchgate.net/publication/370105031> (accessed on 21 May 2025).
- Ding, A.-C. E. (2024). *Empowering multilingual learners through translingual and transmodal practices in virtual learning spaces*. Available online: <https://www.proquest.com/scholarly-journals/empowering-multilingual-learners-through/docview/3115807595/se-2> (accessed on 21 May 2025).
- Ding, A.-C. E., & Cha, E. E. (2024). The integration of virtual reality-enhanced multimodal meaning-making improves knowledge acquisition and disciplinary literacy development in science classrooms. *Learning and Instruction*, 94, 101999. [CrossRef]
- Ding, A.-C. E., Shi, L., Lee, I. H., Demirata, A., Cha, E., Zhu, Z., & Yang, H. (2025). *Investigating the impact of learning modes and instructional sequences of VR-integrated station activities on science learning from the multimodal perspective* [Unpublished manuscript].
- Fackler, A. K., Adah Miller, E., & Li, T. (2024). Promoting meaningful and equitable modeling practices: Developing agency, using diverse ways of knowing, and collaborating to build knowledge through modeling practices. *Science and Children*, 61(1), 25–31. [CrossRef]
- Fan, G., Liu, D., Zhang, R., & Pan, L. (2025). The impact of AI-assisted pair programming on student motivation, programming anxiety, collaborative learning, and programming performance: A comparative study with traditional pair programming and individual approaches. *International Journal of STEM Education*, 12(1), 16. [CrossRef]
- Froehlich, F., Hovey, C., Reza, S., & Plass, J. L. (2024, March 16–21). *Beyond slideshows—Investigating the impact of immersive virtual reality on science learning*. 2024 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2024 (pp. 945–950), Orlando, FL, USA. [CrossRef]
- Fusaro, M., Lisi, M. P., Era, V., Porciello, G., Candidi, M., Aglioti, S. M., & Boukarras, S. (2025). The transformative power of virtual reality: Redefining interactions in virtual platforms, education, healthcare, and workplaces. *Topoi*, 1–16. [CrossRef]
- García, O. (2017). Translanguaging in schools: Subiendo y Bajando, Bajando y subiendo as afterword. *Journal of Language, Identity & Education*, 16(4), 256–263. [CrossRef]
- García, O., & Wei, L. (2014). *Translanguaging: Language, bilingualism and education*. Palgrave Macmillan. [CrossRef]
- Grapin, S. E., Pierson, A., González-Howard, M., Ryu, M., Fine, C., & Vogel, S. (2023). Science education with multilingual learners: Equity as access and equity as transformation. *Science Education*, 107(4), 999–1032. [CrossRef]
- He, P. E., & Lin, A. M. (2022). Translanguaging, trans-semiotizing, and trans-registering in a culturally and linguistically diverse science classroom. *Sociocultural Explorations of Science Education*, 27, 143–171. [CrossRef]
- Jensen, B., & Thompson, G. A. (2019). Equity in teaching academic language—An interdisciplinary approach. *Theory Into Practice*, 59(1), 1–7. [CrossRef]
- Jewitt, C., Kress, G., Ogborn, J., & Tsatarelis, C. (2001). Exploring learning through visual, actional, and linguistic communication: The multimodal environment of a science classroom. *Educational Review*, 53(1), 5–18. [CrossRef]
- Jiang, L., Li, Z., & Leung, J. S. C. (2024). Digital multimodal composing as translanguaging assessment in CLIL classrooms. *Learning and Instruction*, 92, 101900. [CrossRef]
- Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher*, 38(5), 365–379. [CrossRef]
- Kress, G. (2009). Multimodality: A social semiotic approach to contemporary communication. In *Multimodality: A social semiotic approach to contemporary communication*. Routledge Taylor & Francis Group. [CrossRef]
- Langeloo, A., Lara, M. M., Deunk, M. I., & Bosker, R. J. (2021). Profiles of learning opportunities of multilingual and monolingual children in kindergarten. *European Journal of Psychology of Education*, 36(2), 379–404. [CrossRef]
- Lemmi, C., & Pérez, G. (2024). Translanguaging in elementary science. *International Journal of Science Education*, 46(1), 1–27. [CrossRef]
- MacDonald, R., Cook, H. G., & Miller, E. C. (2014). *Doing and talking science: A teacher's guide to meaning-making with English learners*. Board of Regents of the University of Wisconsin System.
- Miller, E., & Reigh, E. (2020). Interactional approach to language: Supporting all students to engage in equitable sensemaking. In M. Gresalfi, & I. S. Horn (Eds.), *The interdisciplinarity of the learning sciences: 14th International Conference of the Learning Sciences (ICLS) 2020* (Vol. 2, pp. 923–924). International Society of the Learning Sciences.
- Mills, K. A., Scholes, L., & Brown, A. (2022). Virtual reality and embodiment in multimodal meaning Making. *Written Communication*, 39(3), 335–369. [CrossRef]
- Mina, L. W. (2021). A transmodal framework for teaching multimodal composing practices to multilingual students. In *Plurilingual pedagogies for multilingual writing classrooms* (pp. 45–57). Routledge. [CrossRef]
- Moje, E. B. (2015). Doing and teaching disciplinary literacy with adolescent learners: A social and cultural enterprise. *Harvard Educational Review*, 85(2), 254–278. [CrossRef]

- Monteiro, A. K., Cheyne, M., & Kline, L. (2024). Fostering inclusive collaboration: Strategies to disrupt inequities in student groupwork. *The Science Teacher*, 91(3), 68–75. [CrossRef]
- National Science Teaching Association. (2025). *Sensemaking*. National Science Teaching Association. Available online: <https://www.nsta.org/sensemaking> (accessed on 21 May 2025).
- Newfield, D. (2017). Transformation, transduction and the transmodal moment. In C. Jewitt (Ed.), *The Routledge handbook of multimodal analysis* (2nd ed., pp. 100–113). Routledge.
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press. Available online: <https://nap.nationalacademies.org/catalog/18290/next-generation-science-standards-for-states-by-states> (accessed on 21 May 2025).
- Parong, J., & Mayer, R. E. (2021). Cognitive and affective processes for learning science in immersive virtual reality. *Journal of Computer Assisted Learning*, 37(1), 226–241. [CrossRef]
- Pérez Fernández, L. M. (2024). Translanguaging in multilingual classrooms. In *Translanguaging in multicultural societies* (pp. 93–107). Palgrave Macmillan. [CrossRef]
- Prain, V., & Tytler, R. (2022). Theorising learning in science through integrating multimodal representations. *Research in Science Education*, 52(3), 805–817. [CrossRef]
- Safford, K., Tugli, F. M., Shah, S., Mukherjee, S. J., Ashour, S., Mukorera, M., & Buckler, A. (2017). *Multilingual classrooms: Opportunities and challenges for English medium instruction in low and middle income contexts*. Available online: www.educationdevelopmenttrust.com (accessed on 21 May 2025).
- Satar, M., Aranha, S., Cavalari, S. M. S., & Almijiw, W. (2024). Low proficiency level learners’ translingual and transmodal practices in telelendum: Challenging the separation of languages principle. *System*, 120, 103187. [CrossRef]
- Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development*, 50(3), 77–96. [CrossRef]
- Schwarz, C., Passmore, C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. National Science Teachers Association.
- Seedhouse, E. (2022). Presence within the virtual reality environment of the international space station. *Virtual Reality*, 26(3), 1145–1153. [CrossRef]
- Stoeckel, M. R. (2024). Using group roles to promote collaboration. *The Science Teacher*, 91(6), 73–77. [CrossRef]
- Su, Y. S., Wang, S., & Liu, X. (2024). Using epistemic network analysis to explore primary school students’ computational thinking in pair programming learning. *Journal of Educational Computing Research*, 62(2), 339–373. [CrossRef]
- Tang, K. S., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education*, 98(2), 305–326. [CrossRef]
- Tardy, C. (2004). The role of English in scientific communication: “Lingua franca” or “tyrannosaurus rex”? *Journal of English for Academic Purposes*, 3(3), 247–269. [CrossRef]
- Turner, E., Dominguez, H., Maldonado, L., & Empson, S. (2013). English learners’ participation in mathematical discussion: Shifting positionings and dynamic identities. *Journal for Research in Mathematics Education*, 44(1), 199–234. [CrossRef]
- Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, 15(3), 398–405. [CrossRef]
- Wei, L. (2024). Transformative pedagogy for inclusion and social justice through translanguaging, co-learning, and transpositioning. *Language Teaching*, 57(2), 203–214. [CrossRef]
- Wei, X., Lin, L., Meng, N., Tan, W., Kong, S. C., & Kinshuk. (2021). The effectiveness of partial pair programming on elementary school students’ computational thinking skills and self-efficacy. *Computers & Education*, 160, 104023. [CrossRef]
- Williams, L., Wiebe, E., Yang, K., Ferzli, M., & Miller, C. (2002). In support of pair programming in the introductory computer science course. *Computer Science Education*, 21(1), 197–212. [CrossRef]
- Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17(2), 89–100. [CrossRef] [PubMed]
- Xu, F., & Correia, A. P. (2024). Adopting distributed pair programming as an effective team learning activity: A systematic review. *Journal of Computing in Higher Education*, 36(2), 320–349. [CrossRef] [PubMed]
- Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). SAGE Publications.
- Zangori, L., & Forbes, C. T. (2016). Development of an empirically based learning performances framework for third-grade students’ model-based explanations about plant processes. *Wiley Online Library*, 100(6), 961–982. [CrossRef]
- Zangori, L., Peel, A., Kinslow, A., Friedrichsen, P., & Sadler, T. D. (2017). Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit. *Journal of Research in Science Teaching*, 54(10), 1249–1273. [CrossRef]

- Zheng, H., Pacheco, M. B., & Brown, J. C. (2025). Enhancing multilingual participation in science practices through language scaffolding. *Language and Education*, 39(2), 512–530. [[CrossRef](#)]
- Zhu, G., & Lin, F. (2024). Teachers scaffold student discourse and emotions in knowledge building classrooms. *Interactive Learning Environments*, 32(7), 3279–3296. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.