School of Education
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A Case Study of Emergent Bilinguals Meaning-Making during Multimodal Science Lessons in a Bilingual Primary School

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007 updated March 2014). The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number HRE2017-0112.

Contents

Abstract

The learning of science presents difficulties to bilingual and multilingual learners, mostly due to the demands of scientific language. However, when viewed through a contemporary language lens the language of science is considered multimodal and presents alternative meaning opportunities. This is because meanings are made from the use of multiple modes as evidenced in the theories of social semiotics, multi-literacies and translanguaging. Some modes, such as gestural, visual and tactile modes, are called non-linguistic modes and do not require knowledge of national language or dialect. Closer inspection of the non-linguistic modes in science shows their importance in the meaning-making process. For instance, the visual mode is necessary when constructing and interpreting visual representations and visual explanations. It is therefore reasonable to suggest that science meanings can be made and communicated with the use of non-linguistic modes.

Consequently, this study attempts to address language learners needs by reconceptualising their issue's through a contemporary theoretical lens. The premise is that non-linguistic modes provide alternative ways for language learners to make meaning. The aim is to investigate to describe how the use of non-linguistic resources plays a role in bilingual and multilingual learners' (BMLs) meaning-making in science. To do this, a literature review was conducted to reconceptualise the findings from previous research. Then a case study approach was employed to capture the meaning-making of ten Grade 5 language learners as they participated in lessons using a multimodal instructional approach. Over nine months, the two groups were filmed during the nine science lessons that encompassed concepts from biology, physics and chemistry. Data was collected from video recordings and work samples. Cross-case analysis of students, groups and science modules makes the findings in this study more trustworthy due to the triangulation of results. Video data was analysed at a coarse- and fine-grained level, and thematic analyses of both the written and visual representations were conducted. Investigations included an exploration of specific non-linguistic modes, multimodal translation and multimodal integration in the lessons.

Results show meaning-making with non-linguistic modes allowed BMLs to elicit meaning from all of their resources. In the multimodal lessons, meanings formed in each mode provided a foundation in which to build upon and translate into the next mode which produced detailed explanations. Gestural and tactile meanings were drawn upon and became influential when describing concepts with movement and ensured that meanings which BMLs could not communicate in English were included in the discourse. Likewise, the visual mode provided relevant spatial information in explanations that was not always translated into written explanations. Non-linguistic modes facilitated language development when students and teachers translated non-linguistic meanings into every day and academic language. Access to a visual metalanguage unveiled alternative visual elements that altered BMLs visual explanations and enhanced teacher questioning. This study found that consideration of non-linguistic modes was important for BMLs in science, as it ensures BMLs have access to their entire meaning-making repertoire when translanguaging, which provides others with access to their understandings while simultaneously valuing their cultural identities.

This is a thesis by publication, and the structure includes four manuscripts that each act as a chapter.

Keywords: bilingual learners, multilingual learners, multimodal meaning-making, multiliteracies, social semiotics, science teaching

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List of publications arising from this thesis

This thesis is presented with a series of publications. I am the lead author in all publications. All publications received rigorous peer review (see Appendix 1).

1. Williams, M., & Tang, K.-S. (2020). The implications of the non-linguistic modes of meaning for language learners in science: A review. *International Journal of Science Education, 42*(7), 1041–1067. https://doi.org/10.1080/09500693.2020.1748249

2. Williams, M., Tang, K.-S., & Won, M. (2019). ELL's science meaning making in multimodal inquiry: A case-study in a Hong Kong bilingual school. *Asia-Pacific Science Education*, *5*(3), 1–35. https://doi.org/10.1186/s41029-019-0031-1

3. Williams, M. (2020). Fifth graders' use of gesture and models when translanguaging during a content and language integrated science class in Hong Kong. *International Journal of Bilingual Education and Bilingualism.* Online 12 May 2020. https://doi.org/10.1080/13670050.2020.1754752.

4. Williams, M., & Tang, K.-S. (2021). The outcomes of fifth-grade emergent bi/multilinguals' introduction to a visual metalanguage to when constructing scientific explanations in Hong Kong. *Asia-Pacific Science Education, 7, 309–342.* https://doi.org/10.1163/23641177-bja10028

Unpublished manuscript listed in the appendices.

5. Williams, M. (Decision reversed). STEM: What's in it for English language learners? Extension lessons help ELLs define STEM problems. *Science and Children*.

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List of presentations arising from this thesis

I presented the early results arising from this thesis project at international conferences (two oral presentations and one poster). Each proposal was accepted following a rigorous peer review (Appendix 2).

Presentations: Refereed conference proposals

1. Williams, M., Tang, K.-S., & Won, M. (2018). Using a multimodal teaching approach to support the meaning making of English language learners in science. *Australasian Science Education Research Association (ASERA),* Gold Coast, QLD, June: Paper presentation.

2. Williams, M. (2019). Gesticulations and pantomime reduce the language gap for Chinese emergent bilinguals in science. *European Science Education Research Association (ESERA),* Bologna, Italy, August: Paper presentation.

3. Williams, M., & Tang, K.-S. (2019). Implications of non-verbal modes of representation for language learners. *European Science Education Research Association (ESERA),* Bologna, Italy, August: Poster presentation.

Statement of contribution

I attest that Research Higher Degree candidate Melanie Williams contributed to the publication for which I am a co-author. My contribution to the research output is shown below.

	Conception and Design	Acquisition of Data and Method	Data Manipulation	Analysis	Discussion	Final Approval	Giving Feedback	**Total**
	Manuscript 1							
Kok-Sing Tang	-	-	-	-	-	Yes	Yes	**5 %**
	Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Mihye Won	-	-	-	-	-	Yes	Yes	**5 %**
	Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
	Manuscript 2							
Kok-Sing Tang	-	-	-	Yes	-	Yes	Yes	**10 %**
	Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
	Manuscript 4							
Kok-Sing Tang	Yes	-	-	-	-	Yes	Yes	**10 %**
	Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Thesis structure

This thesis presents a series of four published papers. To make explicit the connections between the manuscripts, several additional sections have been written. The thesis structure is presented below.

Chapter 1: Introduction

The first section defines the issue: describes who the BMLs are, depicts why they are increasing in number and explains why they have an issue learning in science. It outlines the need for a renewed perspective including a renewed theoretical lens and describes the aims and research objectives for this study.

Chapter 2: Theoretical framework and inquiry

The second section offers details of the renewed theoretical lens employed to address the issue in this study. It outlines the methods used to fulfil the research objectives.

Chapter 3: Manuscript 1

Manuscript 1 addresses the first research objective.

Chapter 4: Manuscript 2

Manuscript 2 addresses the second research objective.

Chapter 5: Manuscript 3

Manuscript 3 addresses the third research objective.

Chapter 6: Manuscript 4

Manuscript 4 addresses the fourth research objective.

Chapter 7: Discussion and conclusion

The final section sums up the findings of the study in relation to the research objectives and discusses their implications for science teacher education and researching communities. It revisits the limitations and concludes the study.

Appendices: The appendices include the anonymous reviews for the manuscripts and conferences, the nine MIA lesson plans, manuscript 5 and the editor’s decisions.

Definitions

Mode: A semiotic system developed over time in a society (Hodge and Kress, 1988). Modes can vary in form such as writing, visuals or gestures.

Multimodal: Refers to something (e.g. an item or action) that is composed of more than one mode; for instance, a text can have visual and written meanings.

Placemats: A page of the most importance concepts, listed as words, images and diagrams, for each theoretical science model, Forces, Life, Energy, Particles. These were given to all groups of students at the beginning of each lesson (Newberry et al., 2011).

Thinking Frames Approach: A multimodal inquiry approach (MIA) that asks students to explain an unknown phenomenon they either observe in a demonstration or are asked about. Groups of students produce an explanation using multiple modes, though predominantly and consecutively through a verbal, visual and written mode (Newberry et al., 2011).

Abbreviations

APSE	*Asia-Pacific Science Education*
BML	bilingual or multilingual learner
CBLT	content-based language teaching
CLIL	content language integrated learning
CMOI	Chinese medium of instruction
EAL	English as an additional language
ELL	English language learner
EL	English learner
EMI	English medium of instruction
ESL	English as a second language
ESOL	English for speakers of other languages
IJSE	*International Journal of Science Education*
L1	first language or 'mother tongue'
LEP	limited English proficient
LL	language learner
LOI	language of instruction
MIA	multimodal inquiry approach
MOI	medium of instruction
NDLB	non-dominant linguistic backgrounds
SFL	systemic functional linguistics
SLL	second language learner
TFA	Thinking Frames Approach (Newberry & Gilbert, 2016)

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1
Introduction

A rationale for educational research on bilingual or multilingual learners (BMLs) in science, the causes of their escalation in number and the importance of meeting their needs, is provided in this section. In the first section, the contributing factors attributing to the worldwide rise in number of BMLs in science classrooms are explained and the terminology used to categorise the learner is discussed. The complexity of the phenomenon for the learner and teacher is unravelled in section two. This leads to a review of the findings of studies to ascertain what supports they suggest for the BMLs in section three. Section four presents the conceptual lens. Finally, this section concludes with an outline of the research agenda, aims and methods for this study.

1.1 Background

1.1.1 Why BMLs are growing in number

Supporting BMLs in science is an international research priority of the 21st century (Bravo & Cervetti, 2014), as was evidenced by the 2019 European Science Education Research Association (ESERA) conference. Learning science in a foreign language was the topic of a major address at the conference due to the rapidly increasing number of BMLs around the world. A BML embarks on a complicated mission when learning science, as they must simultaneously learn the language of instruction (Garza et al., 2018; Gibbons, 2003; Haneda, 2014; Lee & Luykx, 2005). As a result, learners are powerless to access science content at their ability level until they are able to decipher the language. However, in the ESERA address, the presenters raised concerns over the complexity of the issue—complexity that emerges for the researcher who is attempting to build upon the findings of prior studies. One reason is because the worldwide contexts that account for this phenomenon are diverse, therefore making comparisons between findings problematic.

The diversity in contexts emanates from the wide-ranging factors attributed to the growing number of BMLs that has increased the significance of their plight. For many countries, migration has been a predominant cause of the rise in number of BMLs and growth in their significance in science classrooms. Records from the global migration data analysis centre showed 2015 had the highest level of forced migration since the Second World War (International Organization for Migration, 2017). This is in addition to the many choosing to relocate their families worldwide for employment or other opportunity. In England, for example, migration was believed to be the cause for the doubling in number of English-learner students learning science between 1997 and 2015, reaching over a million (Afitska, 2016). Likewise, the United States recorded an increase of over a million students learning English as an additional language (EAL) between 2000 and 2016 (McFarland et al., 2019). By 2030, it is predicted that 40 per cent of all students in K–12 schools in the US will be EALs (Thomas & Collier, 1997). In Australia, 31% of the total student population in New South Wales and 26% in Victoria come from language backgrounds other than English (NSW Government Education and Communities, 2013; Victoria State Government, 2014), while in Canada, in the Greater Toronto Area, BMLs account for 85% of students in elementary schools. Despite the increase in migrants, they are not the only source of BMLs in science.

In other countries and parts of the world BMLs exist and are on the rise for different reasons. In multilingual contexts, where multiple national languages are present in schools, bilingual education programs may be present. Different descriptors are used to describe bilingual programs, for instance, content-based language teaching (CBLT), content language integrated learning (CLIL) and language immersion. In schools, the aim is to provide BMLs with a genuine social context for meaningful use and application of the additional language, which is considered to increase language proficiency as well as content learning (Lin, 2019). In postcolonialism countries, the decision to teach science in English may be considered a way to stay current in the global society, such as in South Africa (Probyn, 2006) or Malaysia (Evans, 2009). Growing globalisation may have caused English to rise in science in the 20th century. English is now considered by some anglophone nations such as the UK and US to be a fundamental requirement for conducting international business in the 21st century and achieving cross-cultural communication (Babaci-Wilhite, 2017). Similarly, Hong Kong, once part of the

British Empire, has changed its language of instruction (LOI) policies multiple times due to political, economic and societal pressures (Perez Milans, 2014). For instance, following the 1997 handover from the British, a time when 90 per cent of schools taught in English, new stipulations required all secondary schools to revert to Chinese. The move resulted in social discontent from many parents who attributed the change to falling English exam scores that limited students' university choices (Perez Milans, 2014). At present (2021), schools are able to adopt an English LOI within given parameters, but as Hong Kong has two national languages, Chinese (standard written Chinese and spoken Cantonese) and English, this leads to diverse bilingual and multilingual school models.

For some governments and schools, the choice to teach science in English may be made because English has become the international language for science (Callahan et al., 2019; Drubin & Kellogg, 2012; Rollnick, 2000). Although once a polyglot profession, science has been influenced by historical shifts, such as a move away from German during the First World War and the departure of the US school students from learning additional languages (Gordin, 2015). In other countries, national languages such as Japanese, Maltese and Turkish may not include the vocabulary necessary for precise science terminology and as a result prevent students from making meaning (Kawasaki, 2002; Mifsud & Farrugia, 2017; Ünsal et al., 2018). Thus, for students to succeed in becoming scientists and share their discoveries with the world they must use English to publish in the top-ranked science journals such as *Nature*. In journals such as *Nature* translations are rarely provided, although editorial support is offered to authors whose native language is not English. At the world-renowned science education conferences such as those of the US National Association for Research in Science Teaching (NARST) and the European Science Education Research Association (ESERA), the predominant language of presentation is English. These are just some of the factors that contribute to the global increase of BMLs in science and the unique context of each demonstrates the complexity of this as a global issue.

Each context warrants careful investigation to ensure individual BMLs are able to receive equitable learning environments in science. Given the reach of the issue, one may infer that there are countless studies in this area. However, the limited number of publications about BMLs in the main international science education journals suggests there is more work to be done (Martin & Chu, 2015). It has been suggested that the inadequacy of publications regarding BMLs in top-ranking science education journals may arrive due to reviewers who are unable to value the significance of this issue, or who are unfamiliar with the context, or who afford little latitude to non-English-speaking writers (Martin & Chu, 2015). Alternatively, editors of the top-ranking science journals may hesitate to publish manuscripts due to the spotlight on the additional research field of language. However, there is cause for concern if researchers of BMLs perceive a BML's plight to be merely a matter of language or lack thereof. That science intersects with language should not be a deterrent to those less familiar in language theory—an insight that motivated Lee to call for multidisciplinary research teams following a review of the research on BMLs (Lee et al., 2016). Likewise, the panel of researchers at the 2019 ESERA conference recommended the use of multidisciplinary research teams when researching multilingual contexts in science.

Thus, the increase in number of BMLs in science classrooms worldwide has not only heightened the significance of their plight but has also assisted in advancing the dialogue on how to best to address the issue. This is a research area in need of immediate investigation.

1.1.2 Categorising the learner

Another reason the population of BMLs may be underrepresented in science education research or high-ranking science education journals is the array of terms used to describe the learners. At present, there is little consensus on how to categorise these learners, perhaps as descriptors used by researchers must attempt to describe learners from diverse contexts and locations, for different target audiences. Yet, the choice of terminology is important. A descriptor conceals the cultural norms that reveals the epistemology, hidden values or agenda within a study (Garcia & Wei, 2014). Thus, a descriptor may embed an unnecessary bias or power disparity between different participants in a study. For instance, the mention of English in a descriptor may give the English language authority over other languages if they are not mentioned. Though students in many studies of science are learning English, we cannot overlook that in other studies they may be learning a different national language or dialect as they learn science. Should English be afforded such a predominant stature?

Until recently, the research community used the following descriptors in science research: English as a second language (ESL), limited English proficient (LEP), English language learner (ELL), English learner (EL), non-dominant linguistic backgrounds (NDLB), English for speakers of other languages (ESOL), English as an additional language (EAL) and second language learner (SLL). From these descriptors we notice an English language dominance. In addition, several of the descriptors imply that the students are inexperienced or have limitations. Subsequently, these traditional descriptors reveal an epistemology fitting with that of a monolingual perspective or former language theory that implies languages are separate entities. In contrast, a more affirmative descriptor used in bilingual language research is *emerging* (or *emergent*) *bi/multilingual*. This descriptor also has limitations, as the term *bi* identifies two separate entities and *multi* suggests more than two entities. At present, this is considered the most suitable descriptor fitting with the epistemology of a contemporary language lens, where multiple cultural semiotic resources, including languages, are considered assets.

For this thesis, I refer to the learners as bilingual or multilingual learners or BMLs in Chapters 1, 2 and 7. Due to the readership of the targeted journals the students were described differently in the manuscripts. For instance, manuscript 1 (Chapter 3) refers to the students as language learners (LLs), manuscript 2 (Chapter 4) refers to the students as English language learners (ELLs), manuscript 3 (Chapter 5) refers to the students as emergent bilinguals, and manuscript 4 (Chapter 6) refers to the students as emergent bi/multilinguals.

1.2 The issue

Finding support for BMLs in science is complex not only for researchers, but also for learners and teachers. In the following discussion, I provide a description of the issue from the perspective of the learner. I examine what a BML faces as they learn science. Next, I describe the perspective of a teacher of BMLs. Finally, I reveal any methods or strategies recommended for BMLs from science literature to identify the gap in the current literature.

1.2.1 Language is a cultural construct

To begin, I unearth and dispel the misconception that the issue is merely a language issue. After all, language is more than the words we read or the things we say; it is a cultural construct; it evolves within a culture (Halliday, 1975; Vygotsky, 1978). For instance, consider how greetings in cultures differ. Do you hug, shake hands, bow, elbow bump, or something else? Cultural differences offer reasons why national languages and dialects differ from each other. Due to this, learning science as a BML is complex because the language of instruction comes from a different culture from their own. Consider, for example, a student immigrant, who is unlikely to recognise the cultural norms of their new environment or school and may be the only student in the classroom who understands their home culture or language(s). For this student, who likely feels like an *outsider*, not only are the words foreign, but so are the contexts, associations and mannerisms. This is because learning a new language presents a BML with an insight into a new culture and its cultural norms (Halliday, 1975). As a result, a student such as this may begin to feel anxiety, fear, isolation and loneliness. For a BML who is unaware of the culture, learning science may prove challenging.

However, in different contexts a BML may have access to supports. For instance, in another context, such as the one in this study, students at a bilingual school experience science lessons in a language of instruction different from their home language(s). As a result, the BMLs are surrounded by others in the classroom of similar culture and home language(s). In this context the learners are surrounded by *insiders* or others who understand the hidden meanings and mannerisms and have shared experiences of each other and their school surroundings. Here, it may be the monolingual English teacher, of a different culture and language from the students, who is the outsider. This juxtaposition may result in discourse disconnect, particularly since English and Chinese languages do not share cognates. Thereby, it is unlikely that the everyday (basic) words a teacher uses in English to simplify abstract concepts of science are representative of those in Chinese. Moreover, translations of English science vocabulary can fail to convey culturally associated meanings. Thus, disparity between culture and language may inhibit discourse.

Despite the varying contexts described, in both situations learning science in an unknown language presents difficulties because of the entanglement between culture and language, which are unfamiliar to the BML.

1.2.2 Learning science through an unfamiliar language

One of the tensions of learning science through an unfamiliar language is the demanding academic language that science presents. Academic language differs from everyday language (Duff, 2004). It is subject- and content-specific and consequently occurs in all academic subjects (Cummins, 1979; Cummins, 1981). Academic language uses distinctive linguistic register, lexicon, grammar and vocabulary (Bauman & Graves, 2010; Snow & Uccelli, 2009; Schleppegrell, 2004). The science discipline contains a large quantity of academic language. For example, science texts include: high lexical density, a measure of information density or the amount of content words found in clauses; nominalisation, compacting a large volume of information into phrases and generalisations that require prior experience to decipher; technicality, applying the technical terms for things such as classifications; and authoritativeness, the tone of scientific information which necessitates timelessness, objectivity and authority (Bruna et al., 2007; Fang, 2005). It takes a BML between five and seven years to master academic language (Cummins, 1981). As a result, the academic language of science makes science particularly cumbersome for BMLs, who are novices of the language of instruction (LOI).

However, a learner's ability to navigate academic language is believed to be a key component necessary for success, as students form conceptual understandings and build knowledge in science through language (Cummins, 2000; Taboada & Rutherford, 2011; Huerta et al., 2016; Larsson & Jakobsson, 2020; Lemmi et al., 2019; Ryoo & Bedell, 2017). For instance, when reading or writing science texts, BMLs require academic language skills to comprehend or communicate the apparent conceptual relationships. Moreover, since thoughts are internalised through language, language is central to learning (Vygotsky, 1986). From this logic, the ability to explore science and science concepts that require abstract thinking is dependent on understanding the language of science. It is also accurate to deduce that internalised thoughts or 'thinking language' can be conveyed in an alternative language (Bloom & Keil, 2001). If access to science content is via verbal or written means in an unknown language, it is likely that a BML may still need words to be translated before they can understand what they mean or process their implications. This requirement circles back to a BML's lack of academic language in the science classroom. So, for a typical BML to understand academic language at their age level, they must advance nine years in the space of six to be on equal footing with their classroom counterparts (Roseberry-McKibbin & Brice, 2005).

1.2.3 Teaching science to BMLs

To make these gains and learn the academic language of science is a difficult feat for BMLs. With little time, what should a teacher do? The data shows BMLs are not reaching their full potential. For instance, in Hong Kong, between 1998 and 2010, approximately 300 local secondary schools reverted from English to a Chinese-only medium of instruction (MOI) in grades seven to nine. This meant students had to become BMLs in their later years of secondary school, when subjects such as science were first taught in English. This language conversion was attributed to a decline in student test scores and declining English language standards—an outcome that is highly probable, since researchers show significant correlations exist between BMLs performance in science assessments and their language proficiency in the LOI (e.g. Maerten-Rivera et al., 2010; Stoffelsma & Spooren, 2019).

While multiple reasons are possible for BMLs' low performance, one explanation might be that science teachers lack the experience or knowledge to teach BMLs. Currently, Hong Kong schools are offered a choice of MOI that includes partial use of English as the medium of instruction. The stipulations for English medium of instruction (EMI) or partial EMI include that teachers reach an English language benchmark themselves. These teachers are then required to complete a minimum of 15 hours of professional development for every three years. The question becomes how much of this limited training includes science education. Since teaching BMLs is an issue that is likely to feature in the life of a teacher and is expected to cause confusion for science teachers, they may adopt inadequate methods to support BMLs (Cummins, 2007). For instance, perceiving that the teaching of vocabulary is all that is necessary to improve academic language for BMLs will likely present a disadvantage to the learning of science concepts (Bruna et al., 2007). This is because academic language includes language skills and content concepts as well as vocabulary (Tong et al., 2014). Hoare (2010) found this to be true when investigating approaches to content-based language teaching (CBLT) in Xi'an, China. Teachers of the English immersion program focused on science facts rather than concepts or cause-and-effect relationships, which he attributed to the teachers' limited knowledge of CBLT and science. Other methods resorted to by inexperienced teachers include over-evaluating their students' progress by providing grade-level written materials once a BML's spoken language is comprehensive, and misinterpreting their students' needs as developmental learning deficiencies by mistakenly reporting them to developmental psychologists for testing (Schofield & McGeary, 2016).

Fortunately for some teachers, it appears teacher training of BMLs is taking shape. For instance, a review of in-service preparation for mainstream teachers of BMLs in the US found 12 studies in which teachers reflected on their own practice in collaboration with others with the aim of improving their skills for teaching BMLs (Brancard & Quinnwilliams, 2012; Brooks & Adams, 2015; Choi & Morrison, 2014; Deaton et al., 2014; Johnson et al., 2016; Martin-Beltrán & Peercy, 2014; Peercy et al., 2015; Russell, 2014, 2015). In this review nine of the ten studies that focused on improving the teachers' subject area knowledge for teaching BMLs were centred in science (e.g. Adamson et al., 2013; Buxton et al., 2013; Johnson et al., 2016; Lee et al., 2007; Lee et al., 2008a; Lee & Maerten-Rivera, 2012; Shanahan & Shea, 2012; Shea et al., 2012). Thus, it appears science education, at least in the US, has made steps in the right direction to prepare teachers in the field.

Nevertheless, this shift cannot come soon enough for many teachers around the world who remain unaware of how to cater for BMLs in science.

1.3 How to cater for BMLs

A question science teachers ask themselves is 'What are the best ways to support BMLs?' A simple solution does not appear to exist. At present, bilingual education models are believed to be most successful in meeting the needs of the BML over the long term (Thomas & Collier, 1997). However, criticisms have been made regarding the modernist views of bilingual education in Hong Kong, described as 'a conflation of two separate monolingualisms' (Perez Milans, 2014, p. 8). It appears languages often remained separated within bilingual schools, slowing connections and making-meaning practices within and between subject areas (Perez Milans, 2014). Furthermore, a bilingual modification does not fit all contexts; nor is it likely to be feasible in societies with rising diversity, in schools that lack resources, or in international school settings.

Therefore, to find solutions, we need to inspect the recommendations in current research. On closer inspection of the studies with programs aimed to prepare science teachers for BMLs, the evidence suggests the addition of both linguistic and non-linguistic resources into the science classroom. For instance, Adamson, Santau and Lee (2013) found teachers (Grades 3–5) indicated the most common way to support ELLs in science was by using multiple communication resources as well as fostering science vocabulary. Similarly, large-scale interventions that encourage inquiry-based methods frequently provide access to multiple communication resources via a variety of materials, such as science booklets and science supplies (e.g. August et al., 2009).

Another source for teacher recommendations is key scholars who have extensive research experience in the field. For instance, Lee et al. (2016) recommend that in content area subjects such as science, BMLs benefit from several things: firstly, hands-on purposeful activities, realia (real materials) and multiple examples of language in different contexts; secondly, participation in discourse and the use of multiple modes (gestural, oral, pictorial, graphic and textual); thirdly, the use of their home language as a supporting tool; and finally, the integration of students' cultural artefacts and community resources in meaningful ways (p. 581). The list shares similarities with another by Shaw et al. (2014), who depict six beneficial teaching practices for BMLs in science. These practices are derived from observations within their own studies and further justified by empirical research from others (e.g. Cervetti et al., 2007; Doherty & Pinal, 2004; Hilberg et al., 2000; Lee et al., 2008b; Stoddart et al., 2002). They include: (1) facilitate collaborative inquiry, (2) promote science talk, (3) use literacy in science, (4) scaffold and develop language in science, (5) contextualise the science activity, and (6) promote complex thinking (p. 625). These practices aim to integrate language and literacy learning with science.

What is noteworthy in both lists of recommendations is that BMLs appear to benefit from actively participating in the language of science and using multiple and varying resources to do so. For instance, in the first, second and final point of their list, Lee et al. (2016) demonstrate the need for resources which are non-linguistic, such as tactile (realia, cultural artefacts), gestural, pictorial and graphical resources, as well as linguistic resources (oral, textual). In their third point they highlight the benefit of utilising other languages. Likewise, it can be inferred from the practices described by Shaw et al. (2014) that the collaborative inquiry problem-solving environment is likely to require the manipulation of tangible science resources, making tactile communication accessible. Furthermore, it can be anticipated that face-to-face discussion during scientific discourse includes the use of home language, gestures and/or paralinguistic communication. Thus, in both situations multiple meaning-making resources, which encompass both non-linguistic and linguistic resources, appear probable.

Thus, it appears a popular consensus among researchers that support for language learners in science should include multiple communication resources, including non-linguistic resources. As a result, the premise for this study is that multiple resources benefit BMLs in science. What is missing from the existing research is a consistent explanation for *how* multiple resources help BMLs make meaning in science. Perhaps understanding how multiple resources help BMLs will provide relevant information for the wider education research community and have further implications for the science education community.

1.4 Meaning-making in science

To better understand the influence of BMLs' use of multiple resources in science, we look to theories of language and learning. On closer examination, it becomes clear that language is conceived as a tool for meaning-making. A functional view of language is inspired by the work of Halliday (1978) and is similarly seen, though in less pronounced form, in the work of Vygotsky (1978), who considered language a sign-based tool. In more detail, Halliday's (1978) systemic functional linguistics (SFL) theory proposes that language is a seminal semiotic resource while also consisting of multiple semiotic resources. Consequently, SFL opposes the idea that language is a stagnant medium of communication and instead repositions the meaning-maker as part of a dynamic interplay between thought, meaning intention, the use of semiotic resources and interpretations of meaning. As a result, meanings evolve in a process of making meaning.

The contemporary language theories that perceive the functional role of language chosen to extend this study's description of language and conceptual lens are social semiotics (Halliday, 1993), multiliteracies (New London Group, 1996) and translanguaging (Garcia, 2009; Garcia & Wei, 2014). Social semiotics and multiliteracies offer more details of the diverse semiotic tools available in societies, known as modes. A mode is a group of similar forms of meaning; for instance, the visual mode can include pictures, images, graphics, drawings and more. Both theories reiterate the idea mentioned earlier that all modes are cultural constructs. In addition, these theories subscribe to the idea that all meanings are multimodal. This notion begins to explain why the use of multiple resources in science might be of help to BMLs. To extend this explanation, translanguaging theory is applied to this study, as it suggests that BMLs communicate in fluid practices by accessing their linguistic and semiotic (non-linguistic) resources as needed. As a result, the theories I have chosen provide implications for how multiple resources may support BMLs in science, such as ensuring BMLs have communication agency, access to modes, and a variety of modes. These implications warrant further investigation.

Despite the possibilities a contemporary lens offers BMLs, few studies have so far applied such a lens. This means the findings of most studies were unscrutinised for both the implications of multiple modes and the potentials of non-linguistic modes. It appears the researchers of the science education community remains unaware of the potential of a contemporary language lens. So, considering the probability for science to offer multiple resources, it is reasonable to suggest that science is an exemplary subject in which to study a BML's meaning-making through a contemporary language lens. I seek to fill this gap by addressing the issue from a renewed theoretical lens in an attempt to clarify current understandings and stimulate more. That the issue is complex and warrants a fresh perspective provides the motivation for this research agenda.

1.5 Research agenda

The need for a renewed perspective on a complex and increasingly pertinent issue set the agenda for this thesis. From my viewpoint the issue is bifold. In one way, the arguments in this thesis attempt to address the challenges BMLs face when learning science, and also to redefine the conception of the issue for the science educational research community. To do this, this study makes attempts to support the BMLs through a contemporary language lens. This lens provides all learners with access and equality in science. Altering the conception of the issue in this way may serve to contribute clarifications. Another way, the thesis offers a renewed perspective of the issue is from publishing the outcomes of the study. Publication aims to expand the readership of the outcomes and possibly facilitate an adjustment to the current perspective of the issue for the science education researching community.

1.5.1 Research objectives

To address the complex and multifaceted issue, this study has multiple objectives (see Figure 1.1). Each objective is addressed by a separate manuscript. Together these objectives help to achieve the reciprocal research agenda (see Figure 1.2). To fulfil objective one, this study attempts to retrospectively unravel the outcomes of non-linguistic modes for language learners by extrapolating and conjecturing the findings of others. Next, to achieve objectives two to four, this study employs a case study that investigates Grade 5 BMLs meaning-making in multimodal (gestural, written, verbal, visual) science lessons.

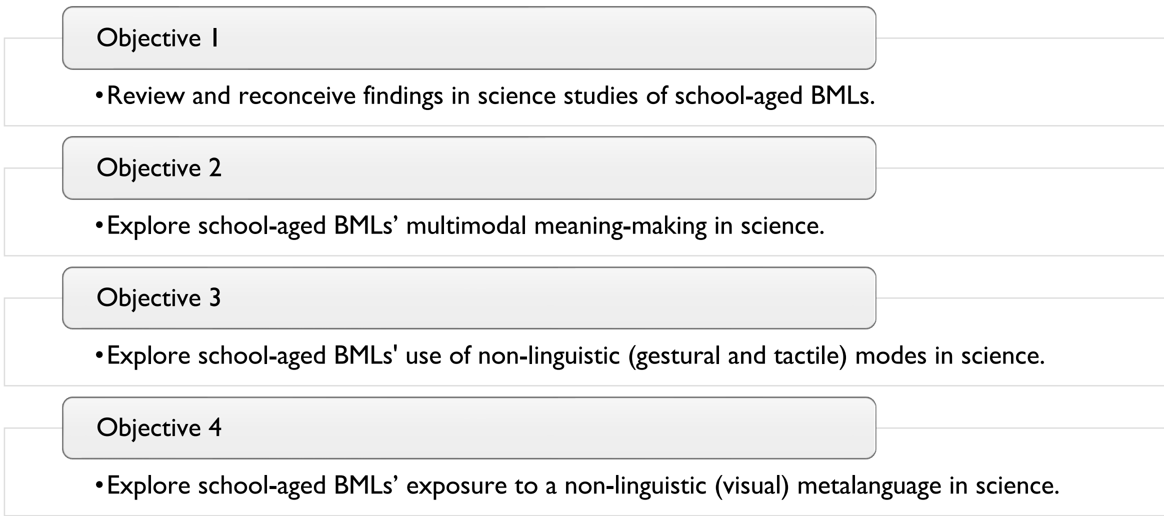

Figure 1.1 The research objectives addressed in each manuscript

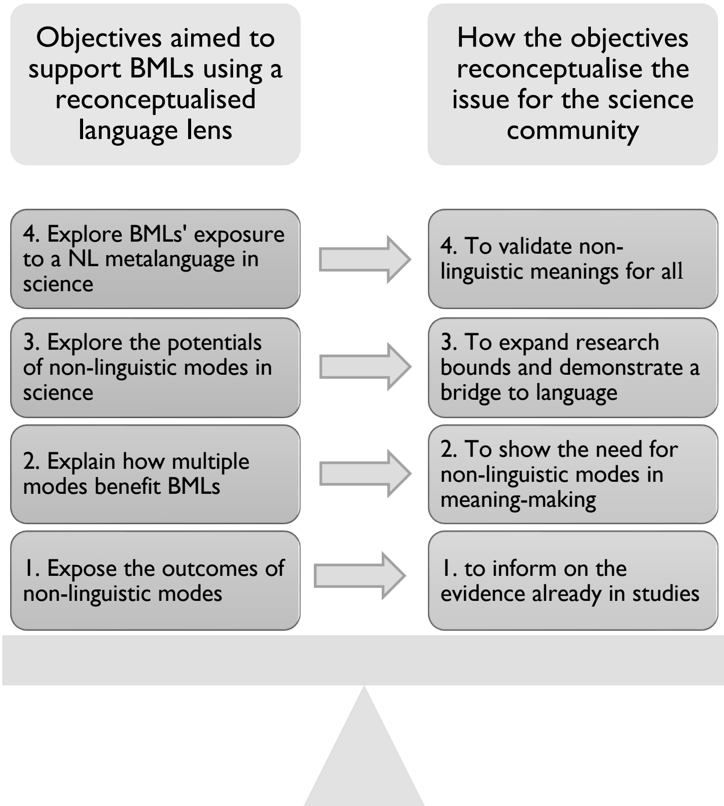

Figure 1.2 The balanced reciprocal research agenda addressed in this thesis

1.5.2 Overview of methods

In the most general sense, the research goals of this study are to illuminate new understandings on how to support BMLs in the science classroom and to change the current conception of the issue. Both goals require substantial empirical evidence from a sustained investigation in the field. Thus, multiple methods are necessary to combat the multiple aims. First, to investigate and reconceive the findings of past studies of BMLs in science a review is necessary. Next, to enable an in-depth conception of meaning-making within a qualitative realm, a case study design is employed (Denzin & Lincoln, 2005; Guba & Lincoln, 1989; Stake, 1994). A case study ensures a comprehensive holistic approach to understanding the educational phenomena, thereby remaining compassionate to the cultural influences that may be present. As discussed earlier, it is important to acknowledge that culture plays an important role in language and the learner. To fully appreciate the cultures of the participants an interpretivist epistemology is adopted.

1.5.3 Epistemology

The underpinning epistemology already described is interpretivism. Becoming an interpretive researcher allows me to construct understandings from the data collected. As such, constructivist ontology has been assumed. Social entities contained within this study are considered ‘social constructions built up from the perceptions and actions of social actors’ (Bryman, 2001, p. 18). Thereby multiple realities exist and are subjective. Harmonising my current educational philosophy that ‘knowledge is constructed’ with a complementing ontology, also cited as an interpretive paradigm by Denzin and Lincoln (2005, p. 13), aids in trustworthiness and helps maintain consistent interpretations in the study. While discussing the epistemology, it is important to critique the associated paradigms not selected in order to remain open and honest throughout this study. The critical paradigm, although naturalistic (like interpretivism), is concerned with illuminating the participant’s values and beliefs for critical inspection and later development or change (Cohen et al., 2011). In this study, it is not my intention to cause change to a participant’s culture or teaching pedagogy.

1.5.3.1 The review

A review of literature is necessary to identify the boundaries of the study by discovering the current implications of using multimodal approaches and/or non-linguistic modes. To satisfy the first objective, a systematic literature review is conducted (manuscript 1). The findings of the selected studies are reconceptualised under the contemporary language framework. This helps to provide parameters for the investigations in the field.

1.5.3.2 The case study

A case study is necessary to address the final three research objectives that are specific to meaning-making (see Figures 1.1 and 1.2 above). To address objective two, the case study explores the meaning-making of ten Grade 5 BMLs in a science classroom and aims to explain the implications of research that suggests multiple semiotic resources are beneficial for learning science (manuscript 2). To satisfy the objectives three and four, requires the observation of individual non-linguistic modes during meaning-making in science lessons, to attempt to understand the implications of non-verbal resources for BMLs in science (manuscripts 3 and 4). I was the researcher and the science teacher throughout the entirety of the case study.

The following section offers an overview of the contemporary theoretical framework used in the study and uncovers my assumptions about why the use of multiple semiotic resources could be beneficial for BMLs' meaning-making. The specific research questions are made apparent at the completion of the discussion on theoretical lens. By revealing the research questions at the end, I make attempts to illustrate the evolving theoretical direction of the study that led to the subsequent inquiries.

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2
Addressing the issue through a contemporary language lens

This chapter presents a rationale for the reconceived theoretical framework suitable to address the issue. First, the reconceptualisation of language and its implications are revealed, followed by an inspection of the language of science and the conception of the learner. The next section unveils and justifies the chosen contemporary language theories in this study, and then presents the possible beneficial applications of these theories for BMLs. The final section reveals how each manuscript applied the theoretical framework to address an objective in this study.

2.1 Reconceptualising language

A reconceptualisation of language is necessary to observe the issue in this thesis, as it will illuminate how meanings are made with the multiple resources found in science.

For a new conception we look to the pioneering linguist Michael Halliday (1978), who includes the semiotic resources people use for communication when he takes into account the social context and the function of language. His interest in how people used language in social interactions and what they used to make meaning led to the development of functional linguistics or functional grammar. As a result, he presented a linguistic theory that, for the first time, was more concerned with meaning and function than form. Systemic functional linguistics (SFL) theory proposes that language is a semiotic tool and system. 'Systemic functional linguistics enables us to see the ways that language, as a semiotic tool, interacts with social contexts in making meaning' (Schleppegrell, 2004, p. 18). From an SFL perspective, all semiotic resources used in the language of science can be accounted for. Consequently, reconceptualising language to study BMLs in science provides the implication that multiple resources are beneficial for BMLs.

2.1.1 Multimodal language of science

Since science is abundant with semiotic (meaning-making) resources, it seems fitting to apply a lens that can account for the production of these resources and the meanings they can make. To make meaning in science, scientists must use multiple and varied resources. According to Lemke (1990), meanings made in science are made by actions when doing science. In his explanation of what scientists do, he lists 'observing, describing, comparing, classifying, analysing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching' (p. ix). Similarly, recent curriculum developments such as the Next Generation Science Standards (NGSS) in the US (National Research Council, 2012) align to a vision of science as action. For instance, the NGSS is comprised of eight science and engineering practices for students to actively participate in. Each practice begins with a verb, accentuating the importance of action in science classrooms. Examples are: asking questions; developing and using models; planning and carrying out investigations; analysing and interpreting data; using mathematics and computational thinking; constructing explanations; engaging in argument from evidence; and obtaining, evaluating and communicating information (National Research Council, 2012, p. 3). From this perspective, it is reasonable to suggest that action not only embodies the nature of science but also the language of science.

That the nature and language of science are active means students who participate in science use multiple semiotic resources. For instance, non-verbal meanings are made through the use of science materials and two- or three-dimensional models. To carry out investigations and develop and use models, students must produce non-verbal meanings. Consequently, when participating in science students actively use non-verbal resources to communicate meanings such as 'diagrams, mathematical and chemical symbols and formulas, pantomimes of natural processes, physical demonstrations of scientific phenomena, slide shows and films, 3D physical models and so on' (Lemke, 2012, p. 82). Therefore, the language of science encompasses multiple semiotic resources, and meanings can arrive from more than just the reading and writing of science texts. As a result, semiotic resources that can produce non-verbal meanings are infused with the learning of science.

2.1.2 Language and learning theory

For a deeper understanding of how science resources assist in the learning of science we look to both language and learning theory. Both Vygotsky (1978) and Halliday portray a conception of language that has influenced contemporary language theory, diverting it from the previously held notion of language as merely a communication medium void of social and cultural interactions. From a developmental psychology perspective, Vygotsky's describes language as a tool for semiotic mediation (Vygotsky, 1978; Wells, 1994). An analogy of a tool can be compared to a material object with an intended use. As such, an artefact with a dual nature that requires a physical and mental action from a human can be described as a tool. Similarly, language has multiple functions. It acts as: a mediator of social discourse through external speech; a sign-based medium of representation; and a mediator of thought via inner speech (internal discourse) (Vygotsky, 1978). When students learn science, the people and resources the students communicate with influence the meanings they make. Thus, learning language is considered synchronously with learning itself (Halliday, 1993). Consequently, language is central to Vygotsky's sociocultural learning theory, which suggests students learn best by using language for a social purpose. As at first, interactions must be stimulated on a social plane and only then can they become internalised. Similarly, Halliday (1993) describes language as the 'process by which experience becomes knowledge' (pp. 93–94). Identifying the involvement of students is an active process. Thus, the notion of language as a social and cultural construct is confirmed in Vygotsky's work, which makes clear that learning, like language, is a social enterprise.

2.1.3 Reconceptualising the learner

A notion of language as a process of active meaning-making changes the role of the learner from a passive entity to a designer of semiotic tools (New London Group, 1996). From this view, a BML's language repertoire becomes an asset when learning, and more so when we consider it is important to encompass all semiotic resources when learning. However, a linear or monolingual standpoint has been applied to examine BMLs' language use and learning for decades (Garcia, 2009a; Garcia & Sylvan, 2011). Likewise, science education researchers' investigations of BMLs rarely integrate or take into consideration a BML's ability to comprehend multiple national languages or dialects. Some exceptions include circumstances where an avenue is provided for the BMLs to use their *mother tongue* or *L1* or where the BMLs are offered a list of translations of relevant science vocabulary in the language of instruction (e.g. Lee et al., 2007; Lee et al., 2016). For BMLs' complex meaning-making to be considered researchers must include BML's language resources or a theoretical framework that addresses BMLs meaning-making. Otherwise, an absence of either may prevent researchers from comprehending the scope of the issue.

The lack of consideration for BMLs' excess language resources may be connected to the categorisation of the learner. For most descriptions of BMLs, the bi- or multilingual element of the participants is unobservable (see 1.1.1). Making it conspicuous may mean it will be more likely to be construed. Rephrasing the descriptor could ensure a reconceptualisation of the issue takes place. However, without the necessary theoretical constructs in place to explain and adequately examine the meaning-making of bi- and multilingual students, the investigation and findings may remain superficial. It is clear that this issue crosses research boundaries into bilingual education that are not presently or sufficiently bridged. Since learning science would not be possible without language, it is first necessary to understand how BMLs use their linguistic resources if we are to fully comprehend how they learn science. Thus, to accurately comprehend this issue and address how BMLs communicate in science, the theory of translanguaging is included in the study (see 2.2.3).

The theory of translanguaging is among others that are included in the contemporary language lens and will be discussed in the following section.

2.2 Applying a contemporary language lens

To offer more details regarding the form and function of semiotic resources in science, this study is situated in the following contemporary language theories. Multiliteracies (New London Group, 1996) and multimodal social semiotics (Kress, 2010) have been influenced by the work of Halliday (1978). These theories extend Halliday's notion of language as a semiotic system by suggesting that multiple semiotic resources combine to form the system. In the system, groups of semiotic resources can be referred to as *modes*, *modes of meaning* (New London Group, 1996) or *modes of representation* (Kress, 2010**).** Semiotic resources are grouped together by their materiality. For instance, resources that make meanings with sound are grouped in the auditory mode. Since modes evolve through their use in societies, they have social and cultural influences. This explains why the written and spoken mode is distinctive in different societies or countries. This was evident in China, where the Chinese dialect Putonghua was predominantly used in Beijing, while another Chinese dialect, Cantonese, was predominantly used in Hong Kong. While the modes allow us to organise and provide order (social construct) to the enormity of the system, the function of language itself is to make meaning and communicate those meanings to others.

The theory of multiliteracies and multimodal social semiotics describe the communication process as active and label people as *designers* or *sign makers*, respectively. From this theoretical perspective, it is clear that language is not a static or a fixed entity; nor is the use of language a passive activity. This corresponds with the description provided earlier of the language of science as ‘active’. Furthermore, since science requires meanings to be made through action, such as by conducting investigations or producing models, it requires the use of multiple semiotic resources or modes. As a result, contemporary language theories offer an appropriate conception of language with which to research BMLs in science. Contemporary language theories not only correspond to the language of science but also validate the nature of science.

The contemporary language theories, multimodal social semiotics, multi-literacies and translanguaging that are applied in this study will now be discussed in more detail.

2.2.1 Multimodal social semiotic theory

From the assumption that actions are responsible for the meaning-making in language, the central idea of multimodal social semiotic theory is that signs are made rather than used. Signs are made in a process referred to as representation, which is dependent on the social context, the sign-maker’s motivations or interests and the semiotic resources accessible (Kress, 2010). Since the purpose of signing originates from the sign-maker, the theory exemplifies the functional role of language influenced by Halliday (1978; 1993). Multimodal social semiotic theory presupposes that as all signs are meaningful they present meaning as a combined whole with others. Sign-makers are said to use signs to ‘remake concepts and “knowledge” in a constant new shaping of the cultural resources for dealing with the social world' (Kress, 2010, p. 62). The reshaping of semiotic resources is what enables BMLs to remake concepts through non-linguistic signs and modes.

2.2.2 The theory of multiliteracies

Similar to multimodal social semiotic theory, multiliteracies theory assumes all semiotic activity to be a process of active and innovative design (Cope & Kalantzis, 2009). The addition of multiliteracies theory complements the theoretical framework of the study as it implies equality and equitability of meaning-making for language learners (Cope & Kalantzis, 2009). Multiliteracies theory values all students, their intrinsic cultural resources, their perspectives and their ways of making-meaning. Inclusivity became the foundation of multiliteracies theory as the New London Group (1996) attempted to establish a theory in response to the changing communication mannerisms. These mannerisms were shaped by two main factors, attempts to communicate by increasingly diverse populations, and the use of new technologies in societies. The New London Group's attempt to harness literacy in the shifting landscape makes multiliteracies unlike traditional language theory, as it is not restricted by governing rules (Cope & Kalantzis, 2015). Instead, the theory of multiliteracies attempts to address the variability of meaning-making in social and cultural contexts extending branches to include new cultural and contextual resources used in societies to make meaning (Cope & Kalantzis, 2015). Thereby, multiliteracies theory indirectly validates the meaning-making of language learners, and also, due to its fundamental appreciation of power, aims to establish a civil and pluralistic society. This contrasts with learners being frequently marginalised for their linguistic deficiencies (Warren et al., 2001). That BMLs have agency over meaning validates their meaning-making and provides equity in the science classroom.

That designers and sign-makers have agency over their expressions of meaning achieves beneficial outcomes for language learners. First, agency gives language learners the authority to choose modes based on their individual language preferences and strengths. Second, agency allows language learners to maintain their identity in a social and cultural context (Cope & Kalantzis, 2009). This is evidenced in two functions of multiliteracies. *Experiencing* attests to the necessity for cultural weaving, interested in bringing the learners' outside experiences in and merging the unfamiliar with the familiar (Cazden, 2001; Cope & Kalantzis, 2015). Similarly, *applying* integrates students' expression and perspectives into learning (Cope & Kalantzis, 2015). As a result, meanings made in social contexts encompass the cultural knowledge and experiences of the learner, which thereby values the learner.

The multiplicity of modes is what makes designer agency significant for BMLs. This is because they can choose how to make meanings from many different modes. Modes can be considered linguistic (e.g. written and oral) or non-linguistic, if they do not require knowledge of a national language or dialect. Non-linguistic modes include visual (image, video, graphics), spatial (architectural spaces, episodic movement), gestural (hand, arm and body movements), audio (sound effects and music), and tactile (sensory, hands-on) (Kalantzis et al., 2016). The multiplicity of modes allows meanings to be made from a combination of modes and is why all communication is said to be multimodal (Kress, 2000, 2010).

2.2.3 The theory of translanguaging

Since meanings are multimodal, it is possible that BMLs make meaning using their multiple known languages. To account for the linguistic and cultural diversity of the BMLs, I broadened the research bounds to add a final theory. The theory of translanguaging is fundamental for a reconceptualisation of language because, as well as explaining how BMLs communicate in the science classroom, it also legitimises their practices (Baker, 2001; García, 2009a, 2009b). Translanguaging theory describes both, the fluid actions or practices BMLs use to communicate, and, it describes the pedological practices that support these language practices (Garcia, 2009a, 2009b; Garcia & Wei, 2014). This study defines translanguaging as the dynamic, complex designing of new language practices by a BML.

Translanguaging theory transcends outdated perspectives of supplementary languages and furthers the dynamic meaning-making process described earlier. Originally conceived by Cen Williams in Welsh as '*trawsieithu*' in 1994, and later translated into English by Baker (2001), *translanguaging* has been expanded into a language theory by the work of Ofelia García (2009a) and others (e.g. Canagarajah, 2013; Creese & Blackledge, 2010; Wei, 2011). The theory of translanguaging portrays a concept of language similar to Halliday's proposal, seeing it as situated in social action and having a meaning-making function (Garcia & Wei, 2014). As such, translanguaging answers linguistic researchers' calls for a new paradigm that focuses on the ‘doing’ of language (Kendon, 2014). Translanguaging shifts old views of bilingualism from these equivalent monolingualisms to a complex and intertwinement of all available languages and interrelated language practices.

What makes the theory of translanguaging different from previous language theories in the fields of sociolinguistics and applied linguistics is that it rejects the notion that boundaries exist between different languages (Garcia, 2009b). Instead, it suggests all languages interconnect in a dynamic way in a linguistic repertoire (Garcia, 2009a). Linguistic meanings occur from one linguistic system, thereby extending the description of *hybrid language* (Gutierrez et al., 2001, p. 128). Previously, being bilingual has been regarded as having two different language repertoires, sometimes termed *first* and *second*, which are kept more or less apart in the linguistic community (García 2009b, García & Sylvan 2011). From a trans-languaging perspective, rather than describing BMLs as ‘code-switching’ when they move from speaking one national language or dialect to another, they are said to be suppressing a language.

Fitting with this study’s theoretical framework, translanguaging embraces all semiotic resources. Accordingly, the theory of translanguaging suggests BMLs have a communication repertoire that includes a linguistic and semiotic repertoire (Garcia & Wei, 2014). Essentially the term ‘translanguaging’ describes how learners draw upon their linguistic and semiotic repertoire as they make meaning. For instance, ‘Translanguaging … incorporates an understanding of how different modes, including our bodies, our gestures, our lives etc., add to the semiotic meaning-making repertoire that is involved in the act of communication’ (Garcia & Otheguy, 2020). This description of translanguaging indicates that the BMLs already have a sizable repertoire to draw from when making meaning. Due to the potentially diverse communicative and linguistic repertoires of the BMLs, this study extends the perspective of language to consider a linguistic mode that integrates all linguistic resources.

The addition of translanguaging theory ensures the diverse linguistic repertoires of BMLs are, firstly, considered, and, secondly, viewed as an advantage. After all, hybrid language has been found to allow BMLs to remain focused on science instead of deciphering a new language (Amaral et al., 2002). This is because bilinguals can select from their linguistic repertoire depending on the ‘contextual, topical, and interactional factors’ (Garcia & Wei, 2014, p. 15). Like multiliteracies, translanguaging has an additional community goal: to liberate sign systems and give voice to those oppressed by sociopolitical domination, by redefining the power among speakers (Garcia, 2019, Chapter 6). To do this, translanguaging addresses issues such as cultural hybridity and provides an philosophy that embraces the BMLs cultural assets.

As a result, the application of translanguaging theory in this study is pertinent and may help shift how BMLs are perceived by others in the science education researching community. As currently, instead of valuing a bi/multilingual for their complex linguistic practices, many educators have upheld the separation of national languages by offering language acquisition programs and separate language classes, possibly due to a conception of bilingual people as having two separate languages (Garcia & Otheguy, 2020). This study argues that lack of consideration for bi- and multilingual elements in research studies may be a result of the categorisation of learner as a *language learner* rather than an *emergent bilingual*. With multilingual elements kept inconspicuous in the majority of descriptors used for BMLs in education, there stands no cause to reflect on them. However, making multilingual elements conspicuous means they must be construed. Thus, rephrasing the descriptor could ensure a reconceptualisation of the issue takes place.

More assumptions will now be uncovered in the following discussion which illuminates why a contemporary language lens may be beneficial for BMLs.

2.3 The implications of a contemporary language lens for BMLs

The choice to apply a contemporary language lens in this study arrives from the assumption that non-linguistic modes present BMLs with the opportunity to design science meanings in less confronting ways. Non-linguistic modes permit meanings to be made by BMLs, who may be unfamiliar with what words to use in the LOI, since they are able to be design the meaning in other ways. For instance, if a BML cannot convey the speed and direction a car travels in science by writing, they may simultaneously use gesture, body movement and sound. In either way, the representations are meaningful. Furthermore, agency over designs ensures that the BMLs and their choice to make meaning is of value.

2.3.1 In the absence of contemporary theory

Until recently, contemporary language theories have been largely overlooked in science research. This is likely due to the dominance of linguistic outcomes by the educational community which includes standardised testing and educational reforms, such as the No Child Left Behind Act 2001 in the US (Barton & Tan, 2009). The unrelenting attention driving the need for students to become literate (read and write) in science remains focused on principles from societies of the past that came at a time when civil engagement mandated the ability to read or write national languages (New London Group, 1996). Old ways of thinking can undermine the observed potentials of non-linguistic resources especially if they are perceived as merely an accompaniment or expressive quality of linguistic modes, as has been the case with gestures in relation to speech (Kendon, 1980; McNeill, 1992).

Possibilities for supporting BMLs may go unnoticed with the absence of a contemporary language lens, as it is a theoretical framework that influences the epistemology of a study, and is responsible for how we interpret data, conceptualise findings and determine the important takeaways. For example, the sociocultural learning theory is widely accepted and has been used to research language learners in science (e.g. Shaw et al., 2014). However, the sociocultural learning theory does not discriminate between language resources or account for the value of a semiotic system with multiple linguistic or semiotic resources. It does not focus attention on the non-linguistic meanings found in language (Vygotsky, 1978). Thus a framework absent of contemporary language theory can allow non-linguistic elements to go unnoticed in research findings and subsequently provide inaccurate explanations of this issue.

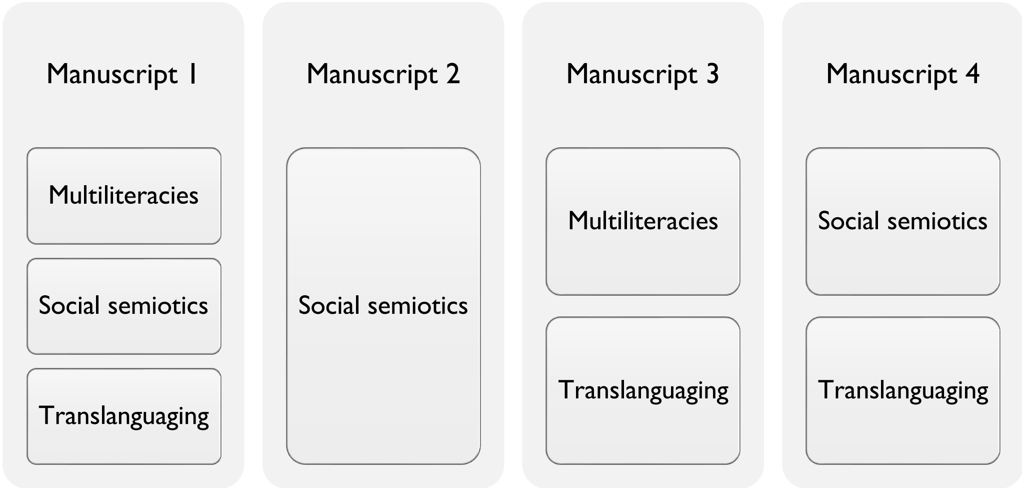

Figure 2.1 The theories present in each manuscript

Thus, because of the absence of a contemporary theoretical lens, questions remain unanswered about why the use of multiple modes is beneficial for BMLs in science and what specifically non-linguistic modes offer. These questions form the basis of the research inquiries, which are discussed in the following section.

2.4 The empirical inquiry aimed to address the BMLs' issue of learning science

An overview of the context that led to achieving each research objective including the associated research questions addressed in each manuscript is given in this section.

2.4.1 The research questions addressed in the study

Following the reconceptualisation of language, the objectives for this study became clearer and more justified. Each manuscript aimed to address one objective for the study (see Figure 2.2). Additionally, each manuscript aimed to build upon the information before it to unearth more information regarding how to best support BMLs in science. Alternatively, each manuscript intended to contribute to the corresponding objective, to inform the science education and researching communities of a new perspective and answer the question surrounding the use of multiple modes. Since multimodality in the science classroom typically includes gestural, mathematical, tactile, verbal and visual modes. The non-linguistic modes chosen to be inspected in more detail for this study of a Grade 5 science class include gesture, tactile and visual. Due to the BMLs' age and level of science, a mathematical mode was not considered to be pertinent.

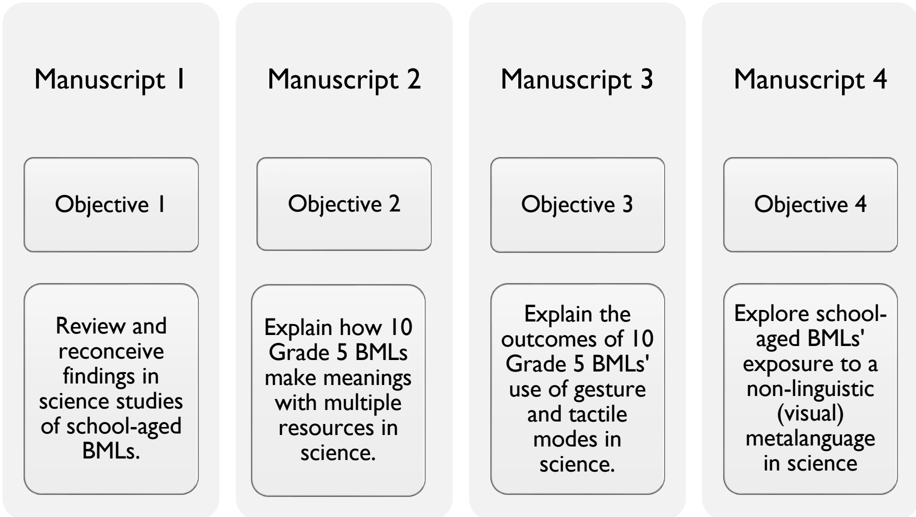

Figure 2.2 The research goals addressed by each manuscript

2.4.1.1 The research questions that addressed objective 1 in manuscript 1

Objective 1 aimed to expose the outcomes of non-linguistic modes during BMLs' multimodal meaning-making in science. To satisfy this objective and account for the lack of findings regarding what the non-linguistic modes have to offer BMLs in science, I conducted a review. In the review, the findings of studies were reconceptualised to elicit the potentials of non-linguistic modes (see Chapter 3). To reconceive the findings of studies, I employed the theory of multiliteracies with its educational foundation and pluralistic aims. Here multiliteracies theory helped to categorise the modes under investigation. In addition, the theory of translanguaging extended the theoretical lens by embracing the diverse communication practices of the BMLs. So, with an awareness of BMLs' communication practices and a spotlight cast on all modes, the implications of non-linguistic modes could be observed more acutely. Due to the scarcity of prior information which left an uncertainty regarding what would be found and to ensure this study unearthed all implications, the second question remained relatively open-ended. The first manuscript addressed the following questions:

1. What non-linguistic modes have been used with language learners in science?
2. What can we learn from studies about supporting language learners in science through non-linguistic modes?

Since the results of previous studies had little focus on the non-linguistic modes, a rationale was formed for the need to include all credible inferences made in the manuscript. This explains why the various inferences were organised into three wide-ranging categories: aid science discourse, accommodate multicultural learning spaces and ensure equitable learning for diverse science communities (see Chapter 3).

2.4.1.2 The research questions addressed objective 2 in manuscript 2

Objective 2 provided the initial inspiration for this entire research agenda. Yet following the literature review and in the science educational researching community, it continued to remain unanswered. Due to the wide-ranging potentials inferred in manuscript 1, the need to empirically explain why multiple modes are recommended for BMLs to learn science was intensified. In order to advance this study's research agenda it was necessary to take measures to fill this gap. Manuscript 3 attempts to unearth the correlation that exists between the multimodal language of science and the multiple modes found in contemporary language theory to the science researching community. Specific focus is on the social semiotic theory, used to capitalise on the perspective that language is actively created. Making this connection explicit to the educational researching community ensures that science is seen as an exemplary subject area for the discovery of how best to teach BMLs. After all, science provides access to multiple modes that are not frequently integrated into language arts instruction (Kress et al., 2001/2014). So, in an attempt to explain why the use of multiple modes benefit BMLs and address this research gap, I adopted the following questions in manuscript 2 (see Chapter 4).

3. How are meanings made in a multimodal instructional approach?
4. How does the use of modes within a multimodal instructional approach support BMLs' meaning-making?

2.4.1.3 The research questions that addressed objective 3 in manuscript 3

To accomplish objective 3 and further broaden the perspective of the issue for the science education community, the third manuscript aims to provide a bridge to language education research, specifically bilingual education (see Chapter 5). This was necessary as the context of the learner, until recently, consistently appeared to be limited in the science studies interested in BMLs. This was because few studies applied a theory to account for the use of a BML's semiotic and linguistic repertoires while learning. Interpretations of results are influenced by the theoretical lens. Despite the obvious difference between a BML in science and a monolingual student, few studies applied a theoretical framework to account for or explain the BLM's meaning-making. In response to this missing element, multiliteracies and translanguaging theories were drawn upon in this manuscript to uncover the outcomes of BMLs' use of non-linguistic modes.

One hope was that mounting evidence of the BMLs' semiotic repertoires would expose the importance of all modes when learning science, especially the non-linguistic modes. As a result, this manuscript (and the next) explore further into the gestural and tactile moves found in the BMLs' meaning-making. This manuscript also made attempts to bridge the divide between science and language disciplines through its subject matter. Gesture has long been a topic of discussion among linguists. Many embrace it as part of the language of communication, while other deny their claims. Another way to connect the two disciplines and promote contemporary language theory was to feature this research in a language journal for BMLs. The question I ask is,

5. How do emergent bilinguals use their semiotic repertoire, in particular the gestures and tactile manipulations of artefacts, in a content-based science class?

2.4.1.4 The research questions that addressed objective 4 in manuscript 4

The final inquiry aims to move the issue forward by investigating the outcomes of making a non-linguistic mode (visual) explicit to BMLs in science (see Chapter 6). The first three inquiries exposed to the researching community to the potential that non-linguistic modes have for BMLs' meaning-making in science. The final inquiry hopes to validate the non-linguistic meanings for the BMLs. The intention is to provide BMLs with more agency and consideration of their meaning-making within a non-linguistic mode. Illuminating the visual elements from the visual mode may offer BMLs further meaning-making opportunities. Validation of meanings made with predominantly non-linguistic modes, for BMLs and the science researching community, may offer further supports or implications in the science classroom.

6. What are the outcomes of introducing the visual metalanguage for
   (a) students to construct explanations, and
   (b) teachers to influence students' construction of visual representations?

The research questions focused each inquiry and together addressed the research objectives for this study. Each question necessitated methods be identified that were an appropriate way to find an answer. The first two questions demanded a method of review. While the other four questions required an investigation into the meaning-making of BMLs in a science classroom, this warranted a case study. These are the topics of the following discussion.

2.4.2 The review

In response to the first inquiry and research objective (see 2.4.1.1), a systematic review was initiated with the intent to reassess and reconceptualise the results of past studies. I chose three concepts for the search of literature: BMLs, modes (multiple modes and/or non-linguistic) and science education. After collating the data from a systematic search, the search for more research continued using the references of studies already located and through searching specific journals that were unlisted in the search parameters of the Web of Science or ProQuest. Detailed information of the search process and analysis is provided in Chapter 3.

2.4.3 The case study

At the 2019 ESERA conference, BouJaoude, Espinet, Martin, Msimanga and Rodriguez (2019) ask: what research methodologies are appropriate to capture the complexity of the identified culturally diverse classrooms? It appears, from the range of methods adopted in the studies of BMLs in science collated for the review (in inquiry one) that a plethora of vantage points exists from which to make attempts to understand the BML issue. Since this study investigates BMLs' meaning-making, it requires a vantage point from within a science classroom. From inside it is possible to view the diverse signs the BMLs make with the available semiotic resources (see earlier theoretical discussion in section two). Thus, to achieve objectives two to four, and in response to inquiry questions three to six, access to a science classroom was necessary. For this study, my Grade 5 science class presented an appropriate vantage point.

From within the Grade 5 science class, it is possible to capture an in-depth conception of the multimodal meaning-making of the BMLs using a research method that allows an investigation of the complex social interactions, such as a case study. Case studies deliver answers to explanatory questions such as ‘what?’ or ‘how?, corresponding to the research questions in this study. In doing so, they allow more than one variable of possible significance to be considered (Cohen et al., 2011). Knowledge of what is of actual importance to the research question often only becomes apparent during the case study, when the researcher ultimately decides what is necessary (Stake, 1994). This flexibility is seen as a criticism and perhaps a limitation of case study research (Yin, 2009). However, Stake (1994) explains that a case study is ‘both the process of learning about the case and the product of our learning’ (p. 237). With this study’s concern to gain a deeper conception of the BMLs’ meaning-making by answering ‘how?’ and ‘what?’ questions, the researcher must be free to move within the bounds of the case when searching for answers.

As teacher-researcher I was in a position to explore and comprehend the meaning-making of ten BMLs in a Grade 5 science class, thus an inductive case study was chosen. The case study spanned nine months. I created nine multimodal inquiry science lessons using the Thinking Frames Approach (TFA) model (Newberry & Gilbert, 2016). Three lessons were each embedded into the science disciplines biology, chemistry and physics. Thus, I, as teacher-researcher, was a participant. A participant viewpoint is considered an asset for verifying meanings in real time. Nevertheless, steps were taken to address the criticisms of participant research, criticisms that include data evaluation bias, data manipulation and ethical concerns. For instance, the data collected, including video and work samples, was analysed within a multimodal social semiotic lens, and required multimodal transcription prior to thematic analysis. As a result, the raw data could be checked by viewing the recordings. Likewise, the thematic analysis was verified by others. Comparisons between the data from multiple participants and two student groups allowed a comprehensive understanding to form. Details of the case study will be presented in the discussion below.

2.4.3.1 The case selection

The case selection describes how this research study was implemented, including where it occurred, how access was gained, and how the participants were approached.

2.4.3.1.1 Context

To ensure that the research took place in a classroom comprised of BMLs who were learning primary science in English, purposeful sampling was necessary (Creswell, 2014). My Grade 5 class seemed an appropriate fit, as I taught BML students science in English at a bilingual school.

The independent school was located in Hong Kong, China. It was large, with ten classes in each grade, and included affluent families. This school was distinct from local Hong Kong schools as it offered a bilingual and bicultural education. To accomplish its mission, the school encompassed a gradual shift in the language of instruction from kindergarten to Grade 12. In the first few years students learnt within a 70% Putonghua (Standard Mandarin) to 30% English ratio of instruction, which then increased to 60% to 40% respectively in Grade 3, and finally 50:50 by Grade 4. From Grade 6 to Grade 12 (secondary school), subjects were taught in English except for Chinese and Chinese heritage. Since language and culture are inseparable, the anticipated result of the language shift was that students would gain an understanding of both Confucian heritage and Western cultures.

The unique language policy led to a unique curriculum model complete with multiple educational philosophies. This is because the integrity and pedagogical norms associated with the dominant culture of each language were embedded in the curriculum. This meant the common teaching approaches from local Hong Kong or mainland China and the inquiry methods that dominated the Western world were all expected. Consequently, as the languages, Putonghua and English, wove in and out of the subject disciplines (including science), so too did the diverse teaching styles. This implied that by the final year of primary school (Grade 5), the students received an equal division of educational delivery in both Chinese and English, languages and educational philosophies.

The primary school curriculum was unique to the school due to its distinctive nature. Every subject discipline occurred in two languages, Putonghua and English. As a result, each curriculum was condensed to allow for its counterpart in the supplementary language. Moreover, multiple curricula were used to satisfy the bilingual and bicultural school ethos. Consequently, subject disciplines had constraints that prevented the use of one curriculum. It was therefore necessary to borrow from, or rewrite, curricula to achieve a suitable fit. As a result, English primary science reflected the local Hong Kong science curriculum (Education

Bureau of Government of HKSAR, n.d.), the Taiwan national science curriculum (Ministry of Education, 2001) and the Next Generation Science Standards or NGSS from the US (National Research Council, 2012).

The effects of the rigorous curriculum and language policy could be witnessed throughout the day, as a myriad of specialist teachers entered and exited classrooms. Numerous teachers were required at each grade level, all which consisted of at least ten classes. Apart from specialist lessons, students remained in their classroom as teachers and subject lessons changed throughout the day. Almost all subject disciplines had exclusive teachers. For example, the English department in Grade 5 included teachers for art, drama, information technology, library, mathematics and music. However, English language and English science were taught to a class by the same teacher. Within the Chinese department in Grade 5, the subjects consisted of dance, sport, Wushu (Chinese martial arts), mathematics, library, humanities together with science, and Chinese language. Most were taught by different teachers. The subjects themselves were unequally dispersed within the timetable based on their educational significance. For instance, in Grade 5, most of the time was devoted equally to Chinese and English language, followed closely by Chinese mathematics and English science. The expectation at the time of the study required the students to speak in only the LOI in each class during lessons, critics describe these policies as a conflation of two separate monolingualisms' (Perez-Milans, 2017, p.8).

This may be the reason, science spiralled between both languages within the school. Corresponding with the gradual shift in language, science was taught in Putonghua only during the early years (kindergarten to Grade 2). Science lessons in English began in Grade 3. At first, students received three 40-minute science lessons (in English) a week, which progressed to five lessons by Grade 4. However, science and humanities were grouped under the same subject area in the Chinese curriculum, so the teaching time for science was more limited than in the English curriculum where it was a single subject. Therefore, the curriculum stipulated that science in Chinese include only earth science in Grades 3 to 5, and other science disciplines, including chemistry, physics and biology, be addressed within the science curriculum in English. Presently, schools, who are awarded a preference of LOI can create unique bilingual models that segregate content areas (e.g.science disciplines) by language. This phenomenon is believed by some to be responsible for inhibiting

BMLs from making connections within and between content areas (Perez Milans, 2017).

2.4.3.1.2 Access

To gain initial access, I informed the head of the school through email and provided him an information letter and consent forms. He agreed to participate and notified the principal of primary, of the details of the study. However, the power imbalance between the teacher-researcher and her students raised ethical issues, so procedures were set up to prevent undue discomfort for the student participants. Firstly, I removed myself from the class to allow the students to be informed about the research through the Grade 5 level leader. The BMLs were notified during a morning homeroom session, when all 18 students in the class were presented with sealed envelopes. The envelopes contained information sheets, parent consent forms and student assent forms.

Next, the families were contacted via letters brought home by the students. The students were asked to read and discuss them with their families. Finally, any willing participants could then hand their forms in to the third party instead of their teacher. The letters informed the families that non-participants would receive the benefits (if any) of the MIA lessons regardless of their decision. The only difference the student-participants experienced in the classroom was being grouped with other participants and being filmed by the camera. If they chose to participate, they could return the forms to myself or the Grade 5 level leader. They had two weeks to consider their choice and were notified they could always change their minds later. Students and parents were welcome to contact the teacher-researcher to ask further information. Altogether, ten students took part and chose to bring the forms directly back to the teacher-researcher.

2.4.3.1.3 The student participants

The ten student participants in this study were BMLs who received five 40-minute science lessons a week in English. All the students were aged nine or ten and were of East Asian origin. Like the other students in the school, they came from affluent families residing in either Hong Kong or mainland China. For most their home language was listed as Chinese, which referred to either Putonghua (Beijing dialect) or Cantonese (local Hong Kong dialect), though some spoke both Chinese dialects.

The students varied in ability level in the English language, though most chose to speak English during English lessons and Chinese in break and lunch times. The dominant and preferred language within the teacher-researcher's classroom was Chinese. This was demonstrated by the language they chose to speak when they were not participating in activities, such as when they were given free time.

2.4.3.1.4 The teacher-researcher

In this case study, I, a 37-year-old female monolingual Anglo-Saxon, was the teacher. In the interpretivist research paradigm, the teacher-researcher's presence is viewed as a benefit. For one reason, my proximity to the BMLs meant I could clarify the students' meanings while I was teaching the MIA lessons. In addition, since I had worked at the school for four years as the head of English science, I was knowledgeable in the science discipline. I was considered a master teacher by the school and coached teachers in inquiry. Furthermore, I had taught Grade 5 at the school for several years and had established a rapport with the participants over three months prior to the study. My presence in the classroom was therefore normal and could be more of a comfort to the BMLs than a visiting researcher. Moreover, as the Grade 5 class teacher, I had substantial knowledge of each student. This was beneficial in two ways: first it meant I could target the lessons at the students' interests and appropriate science level, and second, it meant that inferences I made as a researcher came from a knowledgeable grounding and context about each student. Thus, my insider knowledge ensured I could explore the bounds of this case further in the given time. I planned the learning experiences for the multimodal inquiry approach lessons in consultation with my Grade 5 team and academic advisers.

2.4.3.2 The multimodal inquiry approach (MIA)

To achieve the aims of this case study, I adopted a multimodal inquiry approach from the Thinking Frames Approach (TFA) model (Newberry & Gilbert, 2016). The TFA was chosen as it fulfilled many of the recommendations for teaching BMLs discussed earlier (see section 1.3). These included using an inquiry approach, presenting a challenge, requiring collaborative group work, facilitating shared experiences, allowing opportunities for multimodal and multilinguistic discourse, affording linguistic scaffolds, such as science word mats, writing performers and sentence starters. In fact, the TFA was created from the premise that children must learn how to simultaneously visualise (through a scientific model) and communicate (in any form) to construct scientific explanations (Newberry & Gilbert, 2016). This idea exemplifies and adds to the need for multimodal lessons for BMLs.

The TFA encompassed multiple modes including linguistic and non-linguistic modes (visual and tactile). The multimodal structure helped to achieve the research objectives. The TFA includes five steps: setting the question, brainwave, see, think-sequence and paragraph (Newberry & Gilbert, 2016). Each step is described in detail below with reference made to how the step unfolded in the classroom.

2.4.3.2.1 Setting the question

The first phase required a problem be presented to the BMLs, usually in the form of a question. The intent of this phase was to spark and drive student inquiry. To set the question in a motivating way, I use a model, demonstration or experiment to explore a real-life phenomenon. This step not only presents an exciting beginning but also enables the teacher to draw from the student's prior experiences and understandings. These will be elicited through discourse surrounding their initial ideas, allowing learning in previous lessons to be revealed and investigated in greater depth.

The problem will usually be presented through a tangible experience. These include using models, demonstrations or experiments. The models will be either newly introduced, or will be built in prior lessons, such as the water bottle lungs (Human Body Lesson 1) or a balloon car (Forces In Motion Lesson 3), which requires the students to explain their workings in greater detail. New demonstrations include pulling the note from the coins on the bottle (Forces In Motion Lesson 1). These new phenomenon allow the students to use their knowledge repertoire to try to explain the events. Each method used to set the questions provides an inquiry situation which aims to enhance thinking and discussion, and the use of multiple modes. Together these methods align to researcher's beliefs of how BMLs learn best (Lee et al., 2016; Shaw et al., 2014).

2.4.3.2.2 Brainwave

The Brainwave step aims to ensure the students gather certain language resources necessary in order for them to explain the phenomenon. Four placemats will be made available to each group of BMLs each with a different scientific model: cells, forces, energy and particles (Newberry & Gilbert, 2016). Every placemat has verbal and visual stimuli and matching representations for each scientific model. The students are free to use these as necessary at any time during the lesson, and will be particularly encouraged to do so during this step. During this step, the students will also be free to locate and modify representations found in the classroom, including words on the word wall or pictures on posters. Following this, the chosen vocabulary will be written in the box above the space for the drawing. The teacher will encourage the students to refer to these words throughout the lesson, particularly when writing their final explanation paragraphs. The Brainwave step aims to provide a language scaffold for BMLs, by introducing and reminding them of key scientific terms.

2.4.3.2.3 See

In the See step, the students will collaboratively produce scientific representations within a pictorial mode. This follows the Brainwave step, in which a discourse over what concepts are involved will occur. During the discourse it is likely that initial thoughts or mental models will form in the student's minds. The See step requires the students to transcribe their mental representations into pictorial form. The collaborative act in this step means that students can actively partake in discourse that enables conceptions to be discussed, argued and justified until a final consensus is reached. This step allows the students time to conceptualise their own beliefs and modify their internal representations while using their mother tongue if necessary. According to Cheng and Gilbert (2015), students learn through both verbalising diagrams and solidifying their verbal statements through drawing.

The See step is an important meaning-making act that encourages students to choose from their previously selected list of words, concepts and images and to transfer them and their current understandings into a visual representation explaining the event.

2.4.3.2.4 Think-sequence

This step allows the students to order their ideas logically into a sequence. The Think-sequence follows on from the students' joint construction of a visual representation. Its order in the lesson is to make sure the students have been provided with an appropriate time and enough experience with the phenomenon, for their internal representations to be modified and solidified. This step adds yet another layer of scaffolding for the BMLs, before they attempt to write their explanation paragraph. This is because the Think-sequence requires students to separate their explanation of the event into the form of a written conceptual idea. The 'Why' TFA questions also require events and reason to be placed in separate boxes on the paper. This step proved to be one of the most difficult for the students as they transferred their verbal and visual explanations into written form in English. However, the prior steps provided the students with multiple access points for meaning-making, and the multiple modes—including verbal and pictorial representations along with gestures—aided their ability to construct internal representations and provide the necessary language scaffolds useful in writing exercises.

2.4.3.2.5 Paragraph

The final multimodal step in the construction of their scientific explanation is to add the grammatical elements to produce a scientific genre. Students used their think-sequence explained above as a guide to finish a grammatically complete explanation. However, many chose to use it as an opportunity to elaborate and provide more detail in their explanations, some even adding in examples or their thoughts. During this step, the teacher-researcher reminded students to check back to the vocabulary chosen during the Brainwave step as well as the pictorial representation (made during the See step), to check if they missed out any areas of the explanation necessary.

2.4.4 Planning the learning experiences

The MIA lessons were constructed with the following considerations in mind. First, the learning experiences had to build upon the BML's prior understandings. Second, the learning experiences had to align with the school curriculum and be age-appropriate for the BMLs. Third, the lessons had to fit into the BMLs' timetable. Finally, the participating BMLs' science learning goals and learning time had to be valued, so ethics protocols were necessary.

2.4.4.1 Prior understandings

With the research agenda aimed to support BMLs, it was necessary to allow them to assimilate new representations and understandings into their current ones (Mann & Treagust, 1998). Furthermore, enabling BMLs' ideas to be challenged by new experiences or conflicting information helped them to examine their existing knowledge (Mann & Treagust, 1998). To make certain the TFA lessons provided the BMLs with an appropriate challenge, the teacher-researcher targeted their zone of proximal development (Vygotsky, 1978). To do this, research was conducted into the common misconceptions of the science concepts to facilitate experiences of new phenomena to allow BMLs opportunities to solve problems (Newberry & Gilbert, 2007). This research was conducted for each of the science topics: biology (Human Body), physics (Forces in Motion) and chemistry (Matter). This research, together with discussions from other academic advisers and science educators, inspired the teacher-researcher to create TFA lessons with motivating problems that were developmentally appropriate.

2.4.4.2 School curriculum

The MIA lessons had to align with the school curriculum and be age-appropriate for the BMLs. To achieve this, the learning intentions for this grade level were contrasted with the objectives from the grade above and the grade below. Illuminating these curriculum objectives highlighted the expected level of science knowledge and skills of the BMLs. This information was combined to recent student work samples from science lessons to gauge the appropriate level of challenge for the learning experiences.

2.4.4.2.1 The 7E lesson plan

English science lessons were aimed at increasing inquiry skills in students. All Grade 3 to 5 teachers were trained in using the 7E inquiry cycle to plan and deliver lessons. With an overall aim to support BMLs learning, it was important that this study give attention to their needs. To do this successfully, it had to maintain consistency with the school goals (already in place), which support the BMLs' scientific learning. Subsequently, the 7E inquiry cycle (Eisenkraft, 2003) was used when developing the TFA lessons.

The 7E cycle was a modified version of the Biological Sciences Curriculum Study (BSCS) 5E model (Bybee & Landes, 1990). It had been chosen by the school for its pedagogical strengths in developing thinking skills (e.g. Eisenkraft, 2003). The BSCS 5E model was developed from the Science Curriculum Improvement Study (SCIS) learning cycle (Atkins & Karplus, 1962). It built upon the ideas of Herbart and Dewey and had itself been modified to include an engage-and-evaluate phase (Bybee et al., 2006). The 7E inquiry cycle added two more steps: 'elicit', to find out the learners' prior knowledge, and 'extend', to stretch the learners' thinking skills (Eisenkraft, 2003).

2.4.4.3 Timetabling MIA lessons

English science was taught five times a week in 40-minute lessons, some of which were grouped into 80-minute blocks. It was decided a double block was an appropriate time to implement this study. Other lessons within each topic included a combination of whole class and group activities to address the learning objectives required by school curriculum and for which year level teachers plan accordingly. Assessments in each topic include a variety of formative tasks, including work samples, quizzes and performances, as well as summative group projects and independent tasks.

2.4.4.4 Ethical implications

The final consideration when planning the TFA lessons was the ethical implications. It was essential that the science learning goals of the participating BMLs were met, and that this study value their learning time. Therefore, for the study to be ethically sound, links were made to the BMLs' learning goals for each unit. Thus, by integrating the TFA lessons into the Grade 5 scientific units and marrying with the school curriculum objectives was pertinent for student learning.

2.4.5 Implications of the MIA lessons

For triangulation of results, three MIA lessons were created in each of three Grade 5 science units: the Human Body, Forces in Motion, and Matter. Accordingly, the MIA lessons were thoughtfully embedded within the Grade 5 English science units. Each English science unit lasted approximately seven to nine weeks, and within this time three MIA lessons were delivered. However, the data collection phase lasted approximately nine months (October to June), as it also encompassed school holidays.

2.4.5.1 Trialling the learning experiences (one year earlier)

The MIA lessons were trialled with a Grade 5 class a year before the study. This provided time for each lesson and learning experience to be reviewed and modified. Likewise, it allowed the researcher a chance to familiarise herself with the lessons and provided time for her to improve data collection and analysis methods. Results of the trial are unable to be identified here, due to the ethics protocols. However, several changes were made, including revising several learning experiences in the Matter unit. One of the original Matter lessons required the creation of ice-cream, which was later changed due to the conceptual difficulty the students found when deciphering the explanation and the time constraints required to produce ice cream.

2.4.5.2 Introducing the MIA lessons to the participants

Before the study began, two introductory lessons were provided to the participants for several reasons. Most importantly, the aim of the intervention was to support the BMLs. Student comfort was a priority during this study. If the students did not feel comfortable, it was presumed that they would not be able to make meaning in a natural way. Therefore, time and practice of the MIA lesson was warranted to ensure the students felt comfortable with the new MIA lesson format and the presence of cameras.

With respect to the research integrity, in any new situation data collection strategies require testing and checking. Providing trial TFA lessons supported this requirement. In fact, it helped to eliminate unnecessary elements, such as the iPad which was expected to record audio. After the investigation, it was found the sound captured on the video camera alone was good enough for transcription purposes. Since the iPads were causing distractions for the students during the MIA lessons, they were eliminated.

Another area worthy of mention was the modification of the MIA lessons. The trial provided time for the lesson plan structure and timings to be modified. During the trial, changes were made to the delivery method and the allotted time expectations for each step. It was noted that once the students became accustomed to the lesson format, they required less explicit explanation of what to do and less time to complete each step.

2.4.6 Data collection for the case study

Data collection was synchronised with the research objectives' interest in discovering how meaning-making occurred in a science lesson. Therefore, data collection strategies were chosen that captured the entire meaning-making event or scientific discourse. Scientific discourse includes but is not limited to verbal language, gestures, model manipulation, drawing, writing, mathematical calculations and graphs (Lemke, 1990). As the BML's meaning-making could include signs from any mode, multiple data collection strategies were needed.

Accordingly, observation was a necessary method of capturing the verbal, gestural and model-manipulation signs. Due to the fact the researcher was teaching the lessons, video cameras were required to capture these signs. In addition, the work samples created by the BMLs were considered artefacts. Thus the signs created through drawing or writing, or by mathematical or graphic representation, were part of the meaning-making process and were subsequently collected.

2.4.6.1 Video recordings

Use of a video camera is now considered standard practice in qualitative research (Bezemer & Jewitt, 2010). Two cameras were used to record the meaning-making of participating BMLs in each lesson. One camera was focused on each group. Video cameras were necessary to encapsulate the entire meaning-making experience of the BMLs, rather than audio recordings, which have limitations when capturing and transcribing the findings of multimodal experiences (Norris, 2002). This is because signs such as gestural and tactile meanings require vision. Not recording these signs would have meant the transcription made of the meaning-making would be inaccurate as it would leave out an entire mode of meaning.

While all students in the classroom participated in the MIA lessons, only the consenting participants were filmed. The participants sat in the two tables closest to the back wall and near each corner. The cameras were positioned on either side of the classroom, pointing towards each of the back corners of the class. This was to safeguard against non-participating students accidentally being filmed by walking through. Students not participating in the research were also grouped and sat at neighbouring tables towards the front of the room.

2.4.6.2 Work samples

Work samples captured the meaning-making signs that a camera could not. These include visual, writing and graphic representations. The work samples collected for this study included the two pages of TFA scaffolds and also any other paper the students had chosen to make representations on. In occasional circumstances other work samples were collected, for example, the graphs created during the MIA FIM Lesson 2. All work samples were collected by the teacher-researcher at the completion of each lesson. Following this, they were immediately scanned. Each scan was identified using the chosen code.

2.4.7 Data analysis in the case study

The tools for analysis aimed to satisfy the research questions. The tools chosen for each inquiry are described in detail in the corresponding manuscript (see Chapters 3 to 6). This section provides an overview and discussion of the forms of analysis.

2.4.7.1 Multimodal analysis of scientific discourse

Multimodal analysis is the analysis of more than one form of communication. Within this study and contemporary language lens, meanings from all modes are of value. As a result, the meanings were collected from: speech, gesture, drawing, model manipulation and writing. Each mode was analysed with respect to its specific meaning-making affordances and limitations. The students' visual representations for instance were analysed through a visual semiotic context. In addition, the meanings made at a similar time were analysed as a meaning-making unit. For example, the drawing was analysed with respect to the speech, gesture and other meaning-making signs that occurred simultaneously. Interpreting signs within the multimodal context in which they were created ensured the social semiotic underpinnings of the study were sound.

The multimodal analysis of scientific discourse presented challenges. There are three parts to qualitative data analysis, data reduction, data display and conclusion drawing (Miles & Huberman, 1994). The multimodal discourse from the video presented challenges in 'data sampling, reduction, re-representation' (Hackling et al., 2014, p. 2). Another concern emerged from the circumstances surrounding the analysis. Critics comment that multimodal analysis stems from the interaction with the transcript instead of directly with the source (O'Halloran & Smith, 2011). How these challenges were overcome with respect to this study will be outlined in the following section.

2.4.7.1.1 Multimodal transcription

Creating a multimodal transcript from video is 'a prerequisite to any adequate multimodal analysis' (Norris, 2002, p. 105). Termed 'multimodal discourse analysis' (Norris, 2002) or 'multimodal transcription' (Bezemer & Mavers, 2011), the transcription of multiple meanings presents new methods of data analysis that, at present, have no shared commonalities within the researching community (Hackling et al., 2014). Yet the act of analysing the transcription is seen as a crucial part of social research (Cowan, 2014). In fact, the multimodal social-semiotic theory presupposes that transcripts are artefacts and their construction is a meaning-making act (Bezemer & Mavers, 2011). This raises concerns that the transcripts themselves are subjective, as they can be deciphered in multiple ways. On the other hand, the fact that a video segment can be transcribed in multiple ways through multiple lenses is considered to be essential (Coates & Thornborrow, 1999).

Consequently, multimodal transcription is necessary for the process of analysing the meaning-making captured in the video recordings. Due to the issues raised earlier, it is imperative that a researcher determine what a transcript's affordances are and critically review their interpretations in order to increase reflexivity (Cowan, 2014). Although agreement as to how to best transcribe multimodal scenes is not yet apparent, there appears to be a shared understanding that transcribing merely audio is inadequate, as is the case for interactive exchanges that include a computer or television (Norris, 2002). In this study I decided to use screen shots of actions from the video instead of written descriptions when creating transcripts, and this proved successful (see Table 5.2 below). However, as the collection of screen shots was extremely time-consuming, written information ensued. When the interpretations were checked by multiple researchers, with either screen shots or written descriptions, the researchers had access to the corresponding video recordings of these actions. This ensured that the interpretations of the written information were detailed appropriately and that interpretations were corroborated and verified by multiple researchers.

Table 5.2 Example of the multimodal transcription of a forces and motion lesson

Time	**Verbal Mode**	**Gestural & Tactile Modes**	**Description**
1:13	Nick: *air comes in*	 	moves hand along tube in one direction
1:14	Nick: *and*		

1:15	Nick: *if this is there*		assembles model correctly

2.4.7.1.2 Multimodal analysis

After the multimodal transcription came the analysis. However, due to the novelty of multimodal analysis, no external software was found that heightened the aims of the analysis or reduced the time of the process. As a result, the analysis was carried out by the researcher digitally. First, a structuration table (Kelly & Chen, 1999) or content log (Jordan & Henderson, 1995) was used to sequence the events from each video recording in a timeline format that enabled frames needing further analysis to be highlighted. Next, semiotic units—also referred to as idea units (McNeill, 2005) or semiotic bundles (Radford & Sabena, 2015)—were located within these frames. Semiotic units are combinations of signs that together make a whole meaning. Boundaries were added between semiotic units as the ideas changed, such as when new meaning evolved and differed from the previous one. For instance, the posing of a question may divert the discourse to begin a new semiotic unit. Other boundaries include a new participant joining the discourse (e.g. the teacher arrives) or the sharing of personal anecdotes.

The semiotic units provided the means to inspect meaning-making at a fine-grained level of analysis over a shorter time period (Tang et al., 2014). Thus, the semiotic units related to the learning experience were highlighted and separated from the unrelated discourse that occurred naturally within the science class. At this level thematic analysis (Lemke, 1990) could be used to examine the semantic relationships among the words that were spoken (see Figure 4.4) or the visual elements used in the drawings (see Chapter 6). In another investigation, the participants' mode shifts were identified within appropriate semiotic units to draw comparisons between the BMLs over several lessons (see Chapter 5). Similarly, visual analysis of the drawings was conducted at a fine-grained level using Kress & van Leeuwen's (2006) visual framework (see Chapter 4) and Tang et al.'s (2019) visual framework (see Chapter 6).

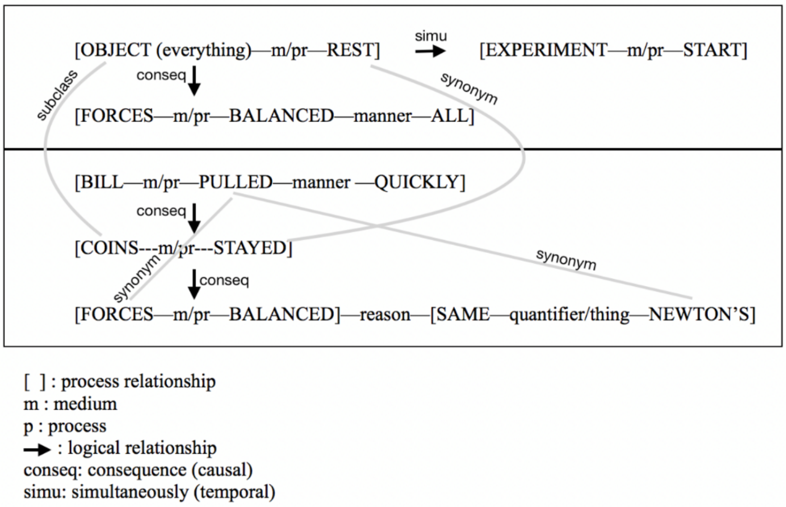

Figure 4.4 Student K's written explanation

However, this study also drew upon other forms of analysis that were necessary to address each of the research questions. For instance, to examine and compare the language used in the final written artefact with the language used by BMLs in each phase, a mode continuum (Gibbons, 1998) was used (see Chapter 4). Another coarse-level analysis, symptomatic of a larger compositional grain size (Tang et al., 2014) explored how the BMLs' representations (e.g. written paragraphs) were constructed and re-represented through each phase of the MIA (see Chapter 4). As with all of the described investigations, interpretations were reviewed by multiple researchers. Furthermore, the data gathered was analysed with respect to the research objectives to provide me with the necessary evidence to allow trustworthy conclusions to be drawn.

2.4.8 Trustworthiness of the case study

Since this study is situated in the interpretivist paradigm, alternative quality standards are included, as 'objective reality can never be captured' (Denzin & Lincoln, 2005, p. 5). Trustworthiness*,* according to Guba and Lincoln (1989), includes credibility, transferability, dependability and confirmability.

a. Credibility: research is carried out in a rigorous and suitable way, including persistent observation and prolonged engagement.
b. Transferability: accurate and detailed descriptions of the case including time, site, context and culture are provided. Accurate descriptions of the context and participants are presented along with the findings of each inquiry.

c. Dependability: record keeping is complete and comprehensive, including any changes. A data collection plan ensures the multiple records are collected and maintained.
d. Confirmability: discoveries and findings can be tracked through the data to the source. Multimodal transcripts with links to the video recordings and multiple researchers ensure interpretations and findings are confirmable.

Furthermore, the research approach allowed for triangulation to occur. This added to the credibility of the findings as it ensured that the discoveries had depth and accuracy. Multiple cases provided more insights into meaning-making as they were analysed and compared. The multiple lessons, participants, student groups, and units allowed for comparisons of how meanings were made, thereby solidifying the trustworthiness and credibility of results (Guba & Lincoln, 1989). Together trustworthiness and triangulation provided the quality measures necessary for the case study.

Finally, I was a participant in this study, I added a unique perspective to the research, as I could immediately check the interpretations of the meanings made (Guba & Lincoln, 1989). This encouraged reflexivity which allowed a complete process of inquiry (Bryman, 2012)**.** Reflexivity ensured I reflected on my interpretations made of the data throughout the research journey, considering my position as the teacher, my prior knowledge of the students and my cultural background (Creswell, 2014; Taylor & Madina, 2013).

Adhering to these quality standards has maintained the integrity of the research. The following section discusses the perceived limitations of the research approach, data collection tools used and the data analysis.

2.4.9 Limitations

The case study approach was chosen to provide a complete and in-depth understanding of how multiple signs are used in different modes to make meaning. Therefore, the aims of this study constrained the sample size to achieve an in-depth analysis. As a result, findings cannot be generalised. Though the ability to generalise relates more to a positivist research paradigm, in the interpretive paradigm the concern relates to the *comparability* of research (Lincoln & Guba, 1985). Thus, the descriptions of the context provided with the data and results make it possible for the readers to interpret the *transferability* of the study (Lincoln & Guba, 1985). For this reason, the context and the nature of the participants were made explicit in the thesis and manuscripts to provide the reader with an accurate and detailed account of the case.

The purpose of this study was not to generalise but to explore the meaning-making and surmise possible answers to how it occurs. This study is not attempting to imply that the results will occur in any other school. Since language is directly connected to culture, it suggests that the school and classroom culture, as well as the culture of the participants, will influence the results. Nevertheless, the more data researchers collect from the different contexts surrounding how meanings are made, the more comprehensive a picture the education researching community can build in which to look for solutions for the BMLs' issue in science. Thus, by making the context, the methods, the analysis and the interpretations visible to readers, it allows researchers to accurately interpret and appropriate methods in their contexts.

A final limitation of the case study relates to the number of recording devices. I filmed each small group of participating BMLs with one fixed camera. I considered using a second camera to capture a different angle of each group. However, due to the limited time and the time necessary to analyse an additional camera's data, it was not a viable option. In the testing phase an iPad was added to the centre of each group's table to maximise the sound captured. However, due to the students' tendency to play with it during the lesson in addition to the poor quality of the camera's sound output, I deemed it unnecessary. Instead, I maximised the potential of the single camera per group by ensuring the greatest visibility and sound. To do this, I positioned the students' chairs around one desk and pointed the chairs towards the camera. This allowed all the students' faces to be observed in the recording as well as their body language.

When viewing and interpreting this data, one could question the researcher's observation abilities and training (Merriam, 1998). Prior to this research I had completed multiple degrees that ensured I was well-trained in interpretive research methods. Likewise, I had successfully completed research where observation was a main data collection strategy. In addition, the analysis strategies of the meanings had specific guidelines which were followed and discussed in detail in each of the following chapters. For example, the methods for what constituted a semiotic unit (Chapter 4) or the types of hand movements that negate a gesture (Chapter 5). These guidelines ensure transparency for the reader and consistency for the analysis.

This section provided a description of the empirical investigation that aimed to address the BMLs issue from a new theoretical lens. The next section explains how this study addressed the issue for the science researching community.

2.5 Reconceptualising the issue for the science community

Decisions regarding what to include in an investigation and how to disseminate findings were made in consideration of the science researching community. This was necessary to achieve the corresponding research goal: to inform and communicate a new perspective for addressing the BMLs' issues in learning science.

2.5.1 Multimodality in science

When deciding what modes to focus on in the investigation, the prevalent modes used in a science classroom were considered, which are gestural, mathematical, tactile, verbal, visual and written. To provide a trustworthy investigation into multimodal meaning-making in science, a representative context was necessary. Thus, a lesson approach was chosen that included opportunities for most of the modes listed. Yet, due to age of the students and their corresponding science level, the mathematical mode was not considered to be as pertinent and was not a focus for this study. Next, to investigate the use of non-linguistic modes by the participants in this research, an in-depth inspection of gestural, tactile and visual modes was conducted. Manuscripts were created to present the findings of the investigations into different non-linguistic modes.

2.5.2 The publications

The choice of academic journal the manuscripts were submitted to aligned with the research agenda. To maximise the impact of this research I attempted to disseminate the renewed perspective in a wide-ranging manner. To achieve this, I targeted a broad selection of journals that would encompass the research community, local and international readers, and the academic fields of science education and language education. The *Asia-Pacific Science Education* (*APSE*) journal, while relatively new, was a journal created to accommodate scholars from Asian nations whose subject matter was frequently passed over by top-ranking science education journals (Martin & Chu, 2015). This journal was also chosen to contribute to the local community where the research was conducted. Since providing context in a small case study was vital, it seemed fitting to communicate this study to educators in a community with a similar context. For the international academic community of science education, the *International Journal of Science Education* (*IJSE*) and for language education, the *International Journal of Bilingual Education and Bilingualism* (*IJBEB*). Finally, another way to maximise the impact of each journal paper was to make them open access. This provided a wider research and education audience with access. Open access makes research accessible for no cost to the reader, allowing members of the public and scholars from poorly funded institutions to read the full text.

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3

The implications of the non-linguistic modes of meaning for language learners in science: a review

Preface

To begin to reconceive the issue for BMLs, the first chapter addresses the first objective and reviews the findings in science studies of school-aged BMLs. The contemporary theoretical lens applied in this review both considers the communication practices of BMLs and takes the approach that language is multimodal. As a result, the meaning-making potentials of all modes are exposed. This lens is necessary to reinspect the findings of studies for the science education community. In doing so, the outcomes of the review show the needs for BMLs' meaning-making in science. From these findings, new research paths can be developed and investigated (see Chapters 4 to 6). This chapter presents the results of the empirical review using theoretical thematic analysis.

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3.1 Abstract

In response to the globally escalating number of language learners tasked with learning science through a foreign language, this review seeks to bring new perspectives by reframing research findings, still dominated by historical language assumptions, through a contemporary language lens. We aim to unearth, amalgamate and expose the potentials of non-linguistic modes described by the theory of multiliteracies that appear sporadic and fragmentary within studies due to their linguistic focus, as we surmise they offer language learners alternative avenues for meaning-making. 40 peer-reviewed empirical studies published between 1995 and 2019 were systematically found and examined using theoretical thematic analysis to expand our understandings. We conjectured findings that appeared contingent upon non-linguistic modes but did not prominently feature in the reported results. In doing so, we used a multimodal and translanguaging lens from which three themes and educational implications emerged. The integration of non-linguistic modes in science: (1) aided language learners' science discourse, provided they had access to multiple modes and agency over expression; (2) facilitated multicultural learning communities validating each learner as a sense maker; and (3) promoted authentic and equitable learning experiences. Other noteworthy findings, such as the influence of the tactile mode, are discussed. Recommendations to future researchers include adopting epistemologies of language fitting to our century and developing transdisciplinary approaches to research.

Keywords: science; multiliteracies; translanguaging; nonlinguistic modes; language learner

3.2 Introduction

Widespread global migration has caused an influx in student diversity that has seen a rise in the number of language learners in science classrooms (Gibbons, 2015). International migrants now account for 3.3% of the global population and over a third of the population in cities such as Sydney, Auckland, Singapore and London (International Organization for Migration, 2015). This has renewed efforts to address language learners' problematic expectation to simultaneously learn the language of instruction (LOI) as well as the content area language (Haneda, 2014). Yet research has remained guided by outdated theories of language with a linguistic focus (Wu et al., 2019). If we are to tackle the long-standing interests of language learners in contemporary societies, who are more culturally and linguistically diverse and globally connected via technology, then we must apply theories of language that correspond to the communication of today.

Being literate in the twenty-first century includes much more than an ability to speak a national language or interpret written text (Cope & Kalantzis, 2009). Contemporary theories of language suggest language transcends discrete systems of national languages (e.g. Garcia &Wei, 2014) and includes non-linguistic semiotic resources that do not rely on knowledge of a national language, such as tactile, gestural and visual resources (Kress & Van Leeuwen, 2001; New London Group, 1996). Since it is the specialised nature of scientific language that causes science to pose a greater challenge for language learners than other subject areas, we believe non-linguistic modes may offer language learners alternative ways to make meaning in science and surmise that contemporary language theories will illustrate this, since they include non-linguistic communication modes (Echevarria et al., 2011).

However, due to the linguistic focus in studies, many of the findings of non-linguistic modes remain unknown. For instance, research focus has included: reading, writing and speaking (e.g. Tong et al., 2014); scientific vocabulary (e.g. Rupley & Slough, 2010); written science constructs (e.g. Lo et al., 2018; Purcell-Gates et al., 2007); and science achievement tests measuring knowledge, vocabulary and reading (e.g. Bravo & Cervetti, 2014; Cervetti et al., 2015; Santau et al., 2011). Subsequently, despite the plethora of research surrounding language learners, numerous studies are driven by antiquated assumptions of language that no longer align with the language of our time.

This review aimed to unearth, clarify and expose the potentials of nonlinguistic resources to establish a more comprehensive understanding, as well as bring a different perspective to the reviews in this area and suggest a focus for future research. With a growing diversity in science classrooms this review is timely and germane.

3.3 Theoretical framework

We chose a twenty-first century theoretical lens to reconceptualise the findings of studies in this review. As we assumed a relationship between language and learning existed, we situated our framework within the sociocultural learning theory which suggests language is necessary to internalise thought (Vygotsky, 1978). In this context learning is an active process that is mediated through social interactions with artefacts and/or people (Vygotsky, 1978). Meanings made are therefore situated and influenced by the knowledge, culture and background of the language learner in addition to the immediate social and cultural context. From this perspective, we included eclectic theories of language that incorporated multiple semiotic resources because multilingual interactions include multimodalities such as gestures, objects, visual cues, touch, tone and sounds (Garcia & Wei, 2014). We assumed language was a semiotic system and so we applied the concept of multimodality in this review (Kress & Van Leeuwen, 2001).

Contemporary language theories, such as social semiotics, embrace the semiotic resources found in societies today, which can be actions or artefacts (Halliday, 1978; Van Leeuwen, 2005). Resources that have representational elements can develop over time into distinctive semiotic systems termed modes (Hodge & Kress, 1988). While linguistic modes such as speech and writing have been the predominant meaning-making resources in the past, each mode has the potential to make complex meanings, including non-linguistic modes such as action, image, gesture and sound (Kress & Van Leeuwen, 1996; Martinec, 1998; McNeill, 1992; O'Toole, 1994; Van Leeuwen, 1999). The multiplicity of modes implies language learners have diverse ways to communicate in science. For the scope of this review we limited our focus to the modes described by the theory of multiliteracies, as they pertained to a classroom setting. These included visual (e.g. images and graphics), spatial (e.g. episodic movement), gestural (e.g. hand, arm, and body movements), auditory (e.g. sound effects and music), tactile (e.g. sensory and hands-on), oral (e.g. speech) and written (Kalantzis et al., 2016).

Investigating modes in multiple contexts, such as in the studies in this review, is complex because modes are unique to the context and culture they evolve in (Kress et al., 2001). This is because modes cultivate and accrue within communities to satisfy a societal purpose (Kress et al., 2001). As a result, the meanings of modes are influenced: socially, by the social norms that provide a context for the meaning-making; culturally, by their historical use in society; and materially, by the ways individuals can manipulate a material to construe meaning (Kress et al., 2001). These influences determine the way meanings are made but they also illustrate how meanings continually evolve within societies (Kress & Van Leeuwen, 2001). For instance, individuals design meanings during social discourse (New London Group, 1996). They do this by renegotiating available designs or modes until they result in the redesign of meaning which causes the designer and world around them to inadvertently transform (Cope & Kalantzis, 2009). Since designed meanings result from a learner's motivations and interests, the design process, together with the multiplicity of modes, provides language learners with agency over meaning (Cope & Kalantzis, 2009).

The freedom to express meanings presents further implications for language learners as the same design, or meaning, can manifest differently in different modes. This is because the influences of each mode define the semiotic potentials and constraints (Kress, 2011). For example, gestural meanings exhibit materially through spatial movements, whereas linguistic meanings require grammar, information structures, metaphor and vocabulary (New London Group, 1996). In addition, scientific language demands the use of high lexical density, nominalisation, generalisations, technicality and authoritativeness (Fang, 2005). Knowledge of these features entails an in-depth comprehension of the LOI. As a result, language learners who are learning the LOI are restricted in access to the science curriculum and achievement in science assessments (Turkan & Liu, 2012). We hypothesised that non-linguistic modes that did not require the LOI offered language learners other potentials for meaning-making.

We extended our perspective of language by adding a final theory that considered the integration of multiple national languages, or dialects, spoken by the language learners in this review that other multimodal theories had not yet accounted for (Kusters et al., 2017). We purposefully deviated from a monolingual epistemology and notions of plurilingualism that suggest the addition of separate national languages (Garcia & Otheguy, 2020). Instead we drew from the theory of translanguaging, which shifts views of bi/multilingualism from equivalent monolingualisms, where code-switching is implied, to complex and interrelated language practices that occur in one trans-semiotic system using one linguistic repertoire (Garcia & Wei, 2014). Translanguaging, a term originally coined in Welsh, can be defined as the act performed by bilinguals of accessing different linguistic features or various modes of what are described as autonomous languages, in order to maximise communicative potentials (Baker, 2001; Garcia, 2009). Therefore it embraces all semiotic modes and suggests language is interconnected in a dynamic way to form linguistic and communication repertoires (Garcia, 2009).

3.3.1 Learning science through language

In a similar way science concepts, which are depicted through a repertoire of multiple modes (e.g. verbal, visual, mathematical symbolism and active experimental operations), multiply, rather than add, meaning when they combine (Lemke, 1998b). Studies have demonstrated that multiple aspects of a science concept are illuminated through different modes (e.g. Williams et al., 2019). For example, the meaning of force is made by combining verbal demonstrations, diagrams or images, written texts and mathematical formulas. Thus, scientists work within a multimodal environment when doing science (Lemke, 1998a). Consequently, the integration of modes enables learners to make sense and reason as they move between multiple representations in science classrooms (Prain & Tytler, 2012). From this we can deduce two things: first, that all modes and their meanings are meaningful, and, second, that non-linguistic modes are likely to be accessible to language learners in science classrooms due to the multimodal nature of science (Kress, 2010; Oh & Kim, 2013). However, the use of multiple modes to make meaning is not exclusive to science, and it applies to all learning areas as all meanings are multimodal (Kress, 2010).

Empirical research that applied multiple modes in science revealed beneficial outcomes for language learners (Adamson et al., 2013). As a result, researchers made provisions for their addition, including non-linguistic modes. Researchers added visual representations (i.e. pictures, diagrams and transparencies) to both the curriculum and to teacher development (e.g. Adamson et al., 2011), recommended the use of multiple modes in the teacher guides (e.g. Bravo & Cervetti, 2014), incorporated science models into language instruction (e.g. Lo et al., 2018), and utilised non-linguistic tools (i.e. drawings, charts, tables, graphs and computer-developed simulations) as pedagogical scaffolds and ways to display learning (Cervetti et al., 2015; Santau et al., 2011). Yet despite their noted potentials, few studies shifted the focus to the outcomes of non-linguistic modes. Thus, findings regarding their potentials are intermittent and varied.

3.4 Review methods

The objective of this review was to uncover the outcomes of non-linguistic modes for language learners in science. Our aim was to provide the next steps for researchers, who continue attempts to close the achievement gap between language learners and their student counterparts in science (Bravo & Cervetti, 2014; Lee et al., 2016). Additionally, we hoped to inform science teachers, who receive little support and may be unaware of how best to teach language learners (Lee et al., 2009).

3.4.1 Methodological approach

As the outcomes of non-linguistic modes were piecemeal and dispersed in studies, we required an methodological approach comparable to empirical research that allowed the findings of studies to be re-conceptualised. Randolph (2009) provided a fitting review protocol that included problem formulation, data collection, data evaluation, analysis and interpretation, and public presentation. In the following, we share how we engaged in each of the review stages.

3.4.2 Problem formation

The research focus for this review was the use of non-linguistic modes by either language learners or their teachers in science. We created questions to guide this literature review. The first question directed our search of the literature, while the second broadened the scope of our findings and allowed us to form interpretations.
(1) What non-linguistic modes have been used with language learners in science?
(2) What can we learn from studies about supporting language learners in science through non-linguistic modes?

Since, the issue spanned all grade levels and all science topics we collected peer-reviewed empirical studies that related to (1) science classrooms or science experiences, such as museums or afterschool care, and (2) included the use of non-linguistic modes by either the teacher or language learners. We also included studies from diverse communities that had other foci as well as language learners. We collected studies investigating any grade-level but to narrow our focus to school-age participants and school teachers, we excluded research regarding universities.

3.4.3 Data collection

Since the topic of the review was vast and wide-ranging we conducted an expansive search of international peer-reviewed journals from 1995 to 2019 using three methods: (1) a database search of ProQuest, Web of Science and Scopus; (2) a manual search, as the findings we sought were frequently hidden within the text; and (3) a search of the reference lists of noteworthy studies. (See Figure 3.1.)

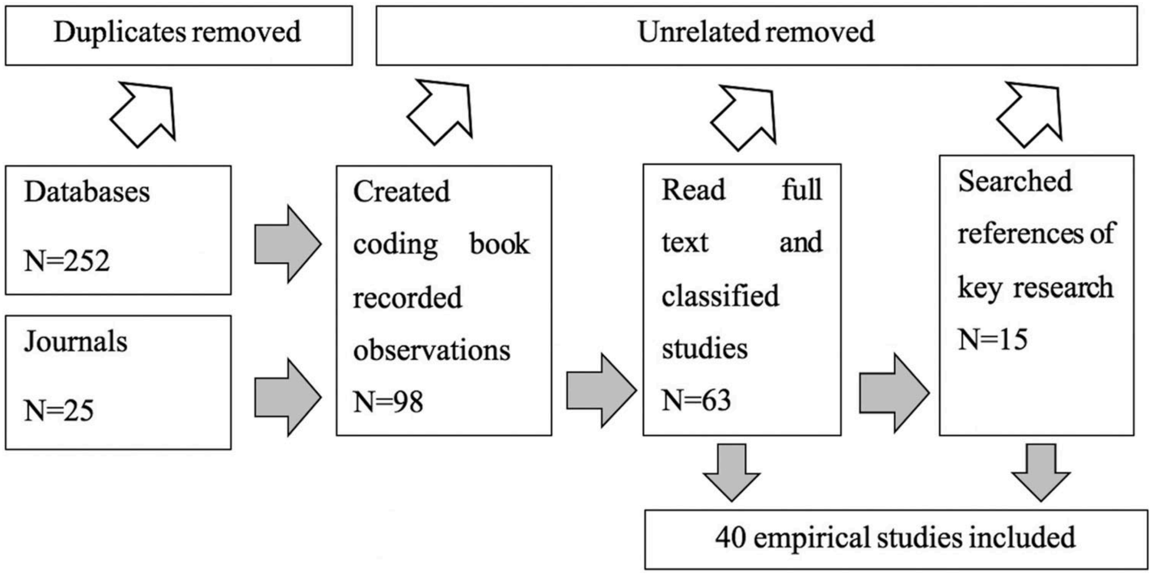

Figure 3.1 The data collection method used

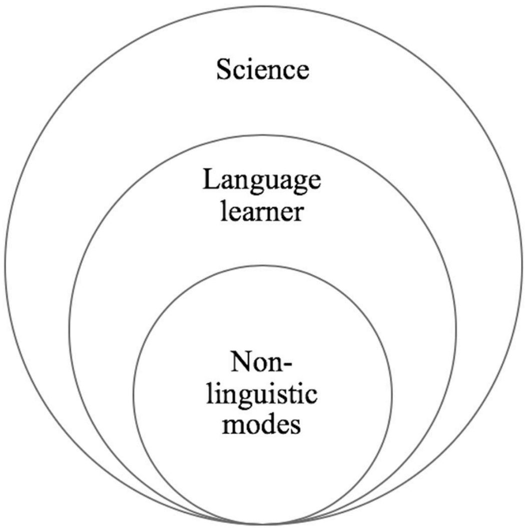

Figure 3.2 The three concepts used in the search

We chose search terms related to three concepts (see Figure A1 and Figure 3.2) and refined these during the initial searches by tailoring terms to specific databases.

Diverse terms describing language learners were also included. We excluded the search terms ‘inquiry’/ ‘enquiry’ and ‘experiment’ due to their frequency and broad definitions, respectively.

3.4.4 Data evaluation

Initially, we located 252 studies with these search terms and added a further 25 studies. Once the duplicates and unrelated studies were removed, 98 studies were each entered into the coding book for comprehensive analysis. This coding included title, authors, journal of publication, publication date, age range, grade levels, country, science context, and information regarding the modes. Each study was examined for information regarding the three identified concepts and discarded for one of three reasons: (1) if we were unable to validate the non-linguistic modes due to a lack of description; (2) if information regarding the use of non-linguistic modes was not included in the results or findings; or (3) if a connection between language learners and non-linguistic modes could not be established. After this action, 40 empirical studies remained (See Appendix C).

3.4.5 Analysis procedure

As the findings of non-linguistic modes needed to be interpreted, we adopted a theoretical thematic analysis that provided a recursive process and allowed inferences to be conceptualised over time (Braun & Clarke, 2006). However, since the studies were located worldwide and included multiple inherent social and cultural influences, we could only infer implications from the material influences. We relied heavily on the descriptions of the results to inform us of three things: first, the way modes were used by students and teachers to design a meaning; second, the way a mode was used in relation to other modes; and, third, to provide a context for the meanings made. The analysis occurred in three phases (see Figure 3.3). Phase one addressed the first research question and ensured we made valid interpretations. Phase two was an evolving process that addressed question two. Inferences solidified as evidence accumulated. During the final phase, we substantiated the value of our suppositions for language learners in science by returning to our theoretical framework and literature.

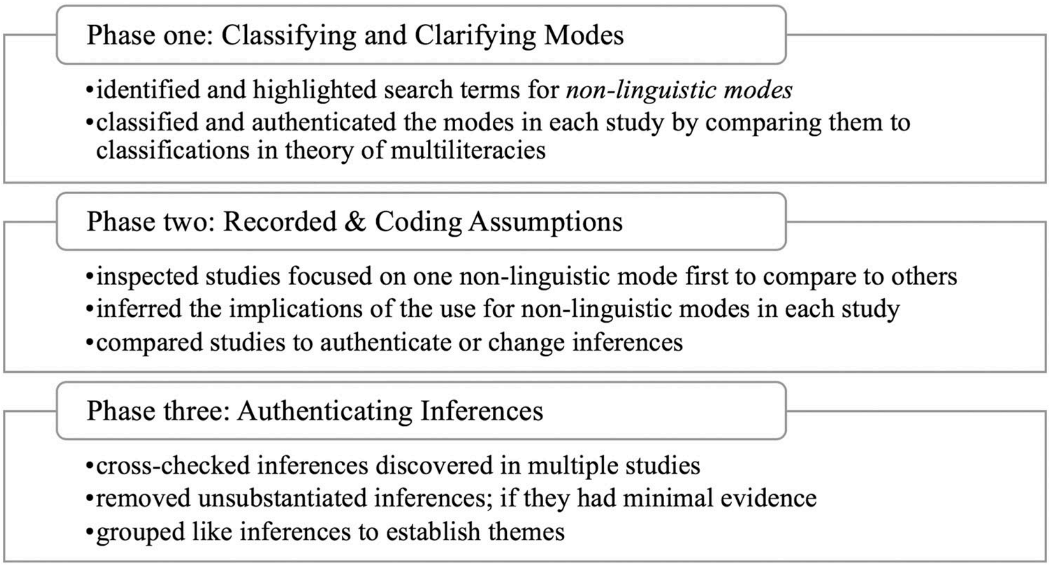

Figure 3.3 The phases of analysis

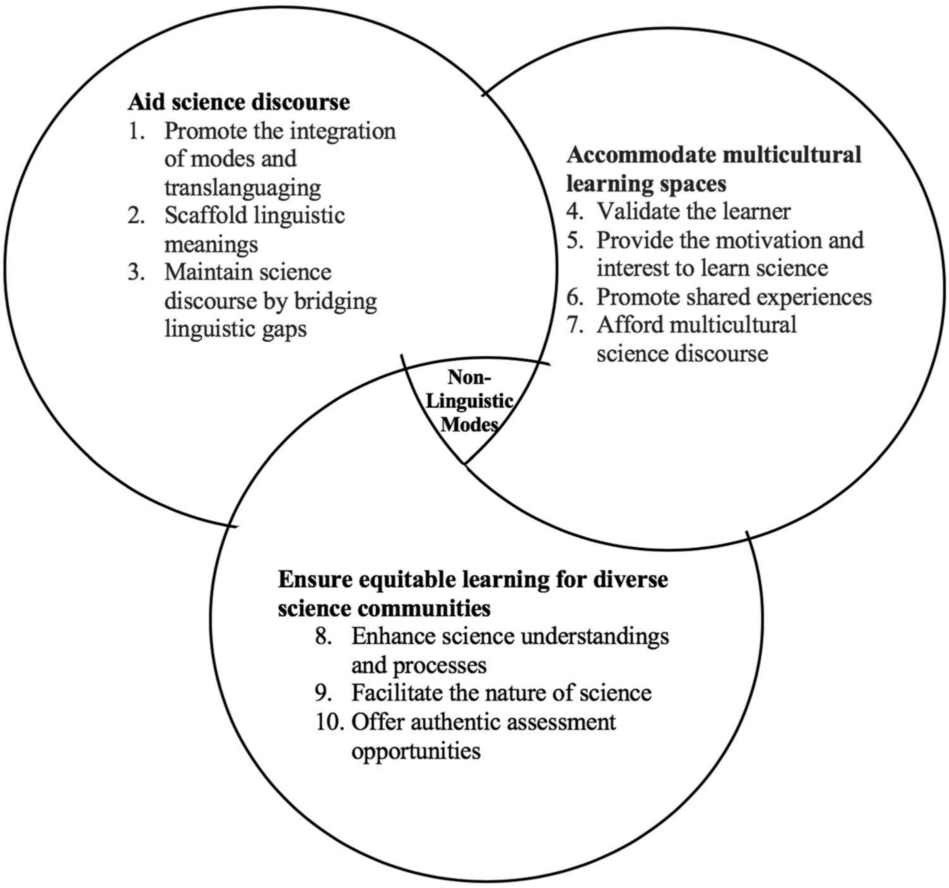

Figure 3.4 The ten inferences depicting how non-linguistic modes support language learners

3.5 Analysis and interpretations

From our analysis we deduced 10 inferences (see Figure 3.4) for how non-linguistic modes support language learners. These have been conceptualised within three themes (see Figure 3.2) and the studies harbouring evidence for each assertion are located in Table 3.1. Since a discussion of an entire data set used to surmise each inference was not possible due to space constraints, the following discussion includes noteworthy findings from studies of significance or controversy. First, a general overview of the data is provided.

3.5.1 General characteristics of the research

Studies came from an eclectic mix of journals (see Figures 3.5 and 3.6). The majority of studies included language learners between grades 3 and 7 (Figure 3.7).

Since most studies (n = 31) were conducted in the United States, the language learners were mostly Hispanics and spoke Spanish, although five studies included students from Haiti who spoke Creole, and one included students from Mexico (see Figure 3.8). Other studies came from Sweden (n = 3) and one each came from Australia, Hong Kong, Mauritius, Peru and Canada. The majority of research sites across studies were schools that required an English LOI in science (see Figure 3.9).

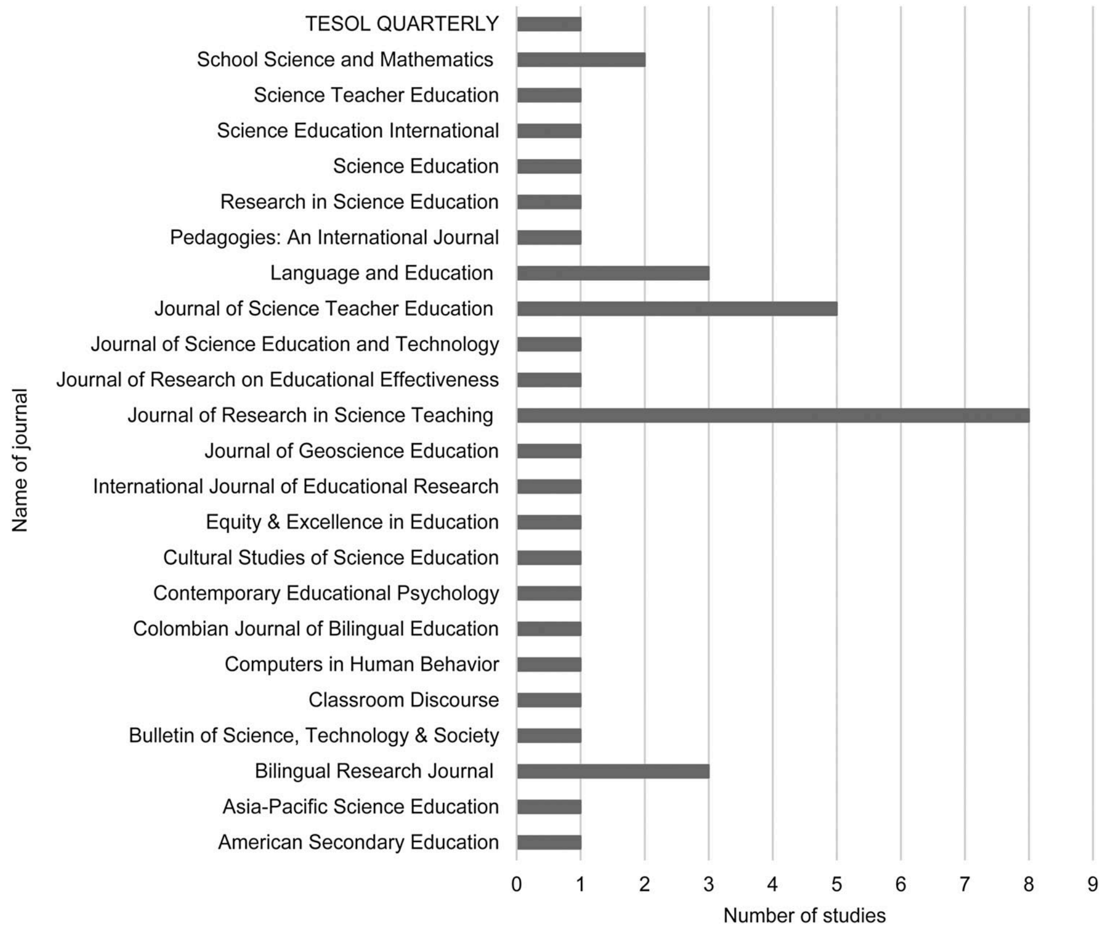

Figure 3.5 The journals that included the empirical studies found

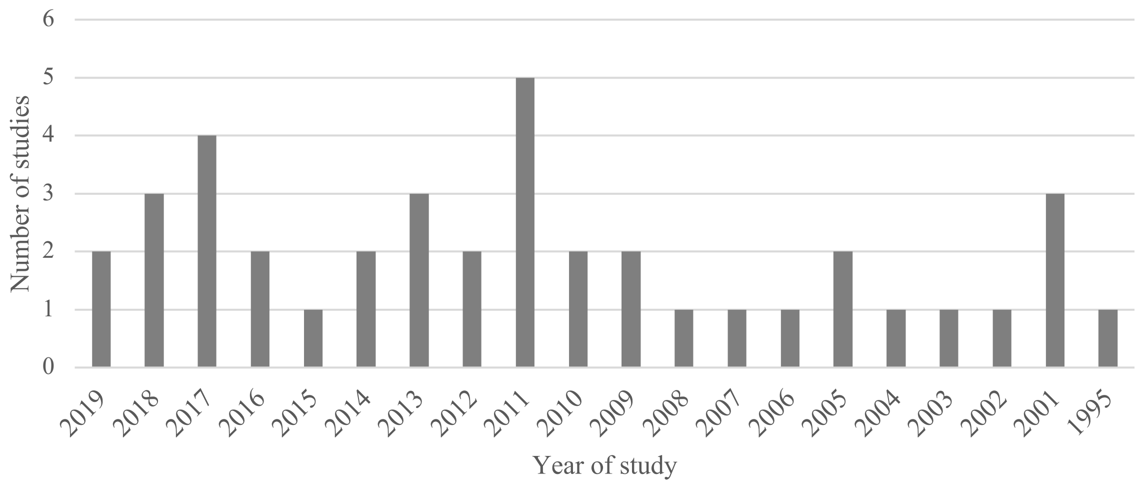

Figure 3.6 The publication dates of the studies in this review

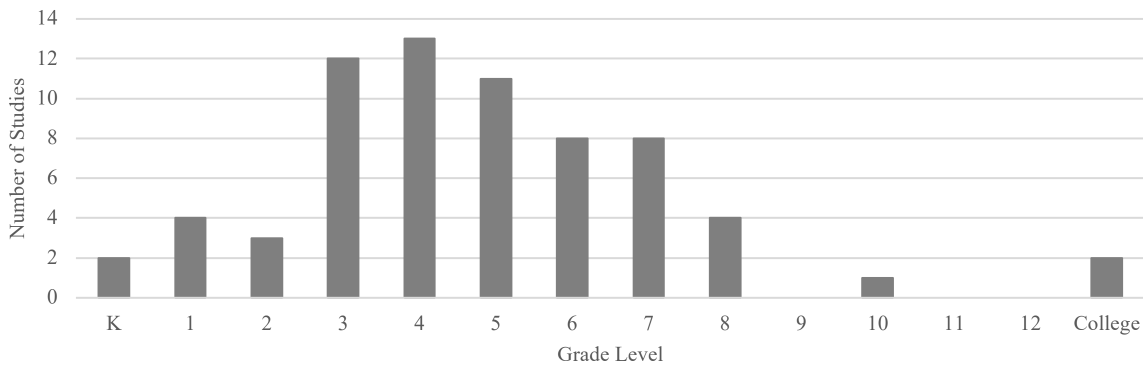

Figure 3.7 The distribution of grades included in the empirical studies

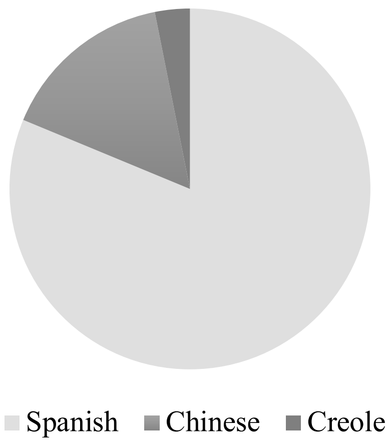

Figure 3.8 The implied home languages of the language learners in the studies in this review

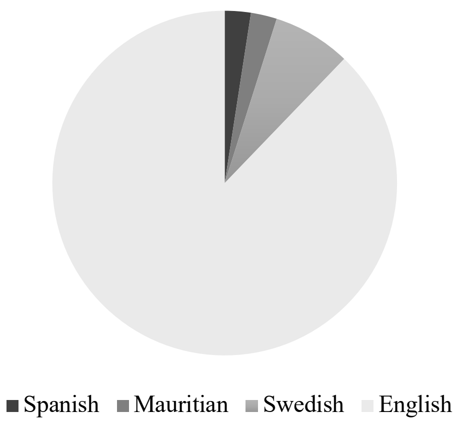

Figure 3.9 The languages of instruction in the schools within the studies in this review

Science topics varied from life and earth science to physical science. Some studies (n = 12) were indicative of a longer time span, such as interventions, and included multiple science topics. Research designs varied considerably from ethnographic to quasi-experimental studies. Overall, 19 studies included quantitative measures; eight studies used mixed methods, and while 19 studies used a qualitative design, 28 studies included qualitative elements.

3.5.2 Limitations

In reinterpretation of findings, we relied upon, and were limited to, the descriptions of findings presented by the researchers. We were unable to draw conclusions about the implication of a spatial or auditory mode because few studies reported complete data collection or results.

3.5.3 Terminology

There are multiple descriptors for language learners, such as students who learn English as a second language (ESL). Therefore, we reverted to each study's description of language learners, as seen in Figure 3.10.

Terms for Language Learner	English as a Second Language (ESL), Limited English Proficient (LEP), English Language Learner (ELL), English Learner (EL), Bilingual, L2, Multilingual, Non-dominant Lingusitic Backgrounds (NDLB), Emergent Bilingual, English for the Speakers of Other Languages (ESOL), English as an Additional Language (EAL), Second Language Learner (SLL)

Figure 3.10 The different descriptions given to language learners from the studies in this review

3.6 Interpretations

3.6.1 Aid science discourse

The first theme focused specifically on the implications of non-linguistic modes for language learners' use of linguistic modes while learning science. Findings showed there are three distinct patterns (see Figure 3.11).

3.6.1.1 Promote the integration of modes and translanguaging

In several studies we inferred that the students' use of communication modes was connected to the type of science experience or space provided. This was probably because in these studies the science experiences and spaces usually included non-linguistic modes, sometimes referred to as 'hands-on activities' (Unsal et al., 2018a). Hands-on experiences enabled participants to make meanings using a tactile mode, by manipulating equipment, and a gestural mode, by pointing out the parts of a model while describing its movement (e.g. Williams et al., 2019). In addition, we found that tactile experiences allowed for translanguaging since students were found

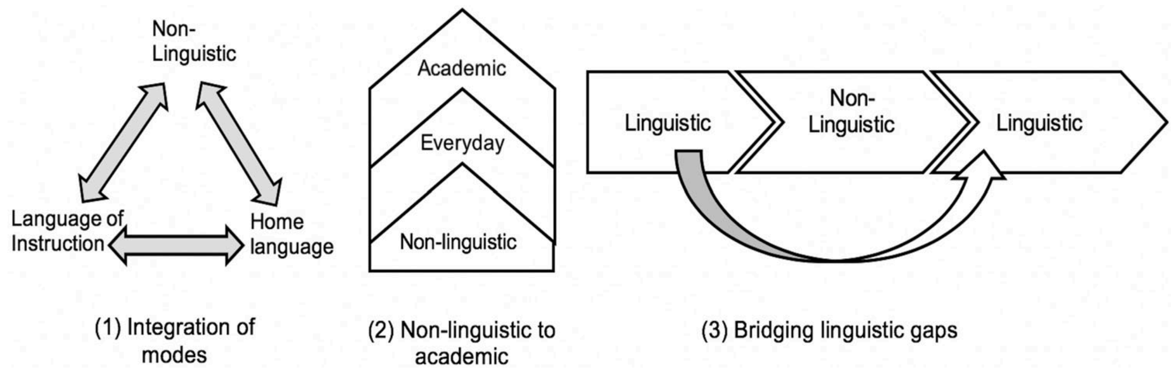

Figure 3.11 Models showing the processes the language learners used to overcome linguistic restrictions of the language of instruction when learning science with non-linguistic modes

Table 3.1 The studies providing evidence for the implications of non-linguistic modes

	Theme 1			Theme 2				Theme 3		
Studies in the Review	Promote the integration of modes (and translanguaging)	Scaffold linguistic meanings from everyday to academic language	Maintain science discourse by bridging linguistic gaps	Validate all learners knowledge, skills and life-experiences	Provide the motivation and interest to mean for all	Promote shared experiences that foster classroom culture	Afford multicultural science discourse	Enhance science understandings and processes	Facilitate the nature of science	Provide authentic assessment opportunities
1								X		
2								X		
3	X					X	X	X		
4	X				X		X	X		
5	X				X			X		
6	X	X			X	X	X	X		
7	X					X	X	X		X
8	X				X	X	X	X		
9								X		
10									X	
11								X		
12	X	X			X	X			X	
13								X		
14		X	X							
15	X	X	X		X			X		X
16				X		X		X	X	
17								X		
18					X			X		
19		X	X			X		X		
20		X			X			X	X	
21									X	
22			X			X				
23				X		X		X		
24								X	X	
25	X		X	X	X					X
26							X			
27		X					X	X		X
28		X			X		X	X	X	
29								X		
30					X					
31								X		
32		X			X					
33	X	X	X							
34		X	X				X			
35	X			X	X	X			X	
36					X	X		X		
37		X	X	X	X	X	X	X		X
38	X								X	
39	X	X	X	X		X				
40					X					

In the second step, participants translated the everyday words into science language. For instance, Jakobson and Axelsson (2017) found multilinguals in Sweden made visual meanings from a connected two-dimensional and thee-dimensional representation of the Earth's rotation around the sun, during which their linguistic meanings evolved from 'move' to 'movement' to 'goes round' (p. 486). Later, the teacher translated the everyday words to the academic word 'rotate'. In other studies, students, as well as teachers, were responsible for translating the everyday words and gestures into academic language (Gibbons, 2003; Unsal et al., 2018b; Williams et al., 2019). This frequently occurred during multimodal discourse in which linguistic gaps were bridged, as is described in the following inference.

3.6.1.3 Maintain science discourse by bridging linguistic gaps

In many studies, participants used non-linguistic modes (e.g. gestural and tactile) to aid their meanings. The evidence for this came either from concrete examples found in transcripts or from suppositions created from participants' and researchers' descriptions. Several studies revealed that participants drew upon non-linguistic modes to bridge linguistic gaps. A participant could shift from a linguistic to a non-linguistic mode to complete a meaning, or a group of students could shift between modes to co-produce meaning. We considered a bridge had occurred during meaning-making when a non-linguistic mode filled a linguistic (usually verbal) gap, for instance, if a gesture was situated within a meaning-making discourse or between spoken words (Unsal et al., 2018b). For studies where examples were not observable, descriptions of the mediation of science language were scrutinised instead (e.g. Hampton & Rodriguez, 2001; Jakobson, 2017). Studies had to show that the participant use of materials or gestures was responsible for the continuation of science discourse and linguistic modes. Interestingly, studies that depicted an absence or removal of equipment (e.g. an electrical circuit) also demonstrated this relationship, as the students' access to their communication repertoire became restricted (e.g. Unsal et al., 2018a). Altogether, nine studies were included in this inference. In one example, Unsal et al. (2018b) found emergent bilinguals in grade 3 (n = 4) and grade 7 (n = 16) Swedish classrooms substituted gestural meanings for linguistic ones when communicating science meanings (Unsal et al., 2018b). This study revealed that emerging bilinguals gesticulated in place of unknown words.

3.6.2 Accommodate multicultural learning spaces

The second theme shows that the addition of non-linguistic modes helped facilitate spaces that enabled multicultural participation from the diverse inhabitants of the science classroom. These interrelated inferences provide more information about how and why a translanguaging space could be beneficial for language learners (Garcia & Wei, 2014).

3.6.2.1 Validate the learner

We found studies that showed specific learning experiences provided learners with an opportunity to share ideas and life experiences by drawing upon their communicative repertoire, which validated learners' backgrounds and language differences. To identify these, we defined the pedagogy of each learning experience (i.e. student-centred, hands-on, enquiry) by examining the descriptions of each. The nature of the learning experience helped to justify our claims. For example, student-centred enquiry experiences require active participation from students and usually include resources that encourage multiple forms of communication, including home languages. This was seen by Martinez-Alvarez (2017) who found that digital cameras presented students with opportunities to be agents of learning via tactile meaning-making. In addition, settings with non-linguistic modes validated a learner by stimulating discourse (see inference 2) which facilitated the sharing of their ideas and experiences. For instance, photographic images taken by students provided the stimulus for discussions (verbal and online) where connections could be made and shared (Martinez-Alvarez, 2017). Student sharing was also seen in Haneda and Wells (2010) where an ELL connected a personal experience, the V formation of birds in flight, with the concept of air-resistance during multimodal science discourse. Altogether, we located six studies that showed non-linguistic modes helped to validate a learner. For example, in a four-year study, Haneda and Wells (2010) found that students (including ELLs) drew on their prior experiences to make sense of the abstract concepts. They did so while participating in tactile scientific practices (e.g. testing variables) to observe the effect of adding weight to cars. In another study, Warren et al. (2001) illustrated how a grade 5 Latino student, Emilio, applied his sense-making resources both conceptually and materially when designing an experiment to discover if ants preferred light or darkness. His conception of the material elements (e.g. dirt) transformed in the process. Enquiry settings such as those described appear to provide student interest, which is the subject of our next inference.

3.6.2.2 Provide the motivation and interest to learn science

For this inference we based our suppositions on findings in studies that made reference to an improvement in student attitude, enjoyment or oral meaning-making. An increase in speech during or following a science experience was interpreted as an increase in student interest. Studies with one or more of these outcomes were included if they attributed the outcomes to the use of non-linguistic modes. For example, if the addition of tactile resources improved learner attitude and increased oral meanings (e.g. Hampton & Rodriguez, 2001) or if the reported lessons, experiments or hands-on tasks increased student enjoyment in science (e.g. Jackson & Ash, 2012). Such outcomes were reported in 16 studies. This relationship was observable in end-of-year teacher questionnaires (e.g. Jackson & Ash, 2012), interview responses (e.g. Zwiep et al., 2011) or statistical results of student engagement (Billings & Mathison, 2012). In other studies, we made inferences from researchers' observations of student behaviour during learning experiences.

The evidence includes a study by Zwiep et al. (2011), who delivered a blended science and English language development programme, including contextual hands-on learning experiences, to three Californian elementary schools with large numbers of ELLs. Following the programme launch, the principals and teachers reported an increase in student talk and improvements in attitude. In another study by Jackson and Ash (2012), teacher (n = 24) perspectives from two ethnically diverse Texas public schools were captured during a three-year school-wide intervention. Themes revealed that 22 teachers noted an increase in student enjoyment due to hands-on tasks, while 11 reported that the multi-sensory word-wall (with realia, or real objects, available for exploration) promoted speech in English. Both outcomes were believed to show evidence of student motivation and interest (consecutively) for learning science. It is possible the style of experience promoted student interest. Shared experiences are discussed in the next inference.

3.6.2.3 Provide shared experiences

This inference suggests that shared science experiences provide common everyday experiences for language learners. We surmise that shared common experiences could bridge the cultural divide found in science classrooms with students of different backgrounds (Amaral et al., 2002). This review located findings in multiple studies that suggested the addition of materials and/or new technologies produced a common ground and a shared experience for all students. For instance, in some studies there were new initiatives, such as the use of Lego robots in an Evobots unit (Whittier & Robinson, 2007). In other studies teachers were found utilising internationally recognisable objects such as balls (Jakobson & Axelsson, 2017). Altogether, 13 studies showed indications that non-linguistic modes were used in shared experiences to develop students' understandings of unfamiliar or puzzling concepts, such as the movement of microscopic organisms (Evnitskaya & Morton, 2011). For example, a teacher used a paper pulp ball on a stick to depict the Earth's rotation in one study (Jakobson & Axelsson, 2017). The model allowed an unfamiliar process to be visualised by all students and subsequently prompted science discourse. In another study, Evobots enabled the observation of a science process too slow and difficult to observe in nature (Whittier & Robinson, 2007). A further study showed cosmology visualisations connected a familiar movement with an unfamiliar concept (Bracey, 2017). From these findings, we deduce that shared experiences with tactile materials that help students to reconcile the abstract unobservable or unfamiliar phenomena and science concepts could potentially bridge the cultural divide for language learners.

3.6.2.4 Afford multicultural science discourse

We found studies that showed collaborative experiences with non-linguistic modes (e.g. visualisations, experiments, realia and demonstrations) allowed students to participate in multimodal science discourse. Several studies also revealed that multiparticipant discourse scaffolded science learning. This occurred in different ways. For instance, multiparticipant multimodal discourse allowed language learners' linguistic meanings to advance (see inference 2) and be bridged (see inference 3) but it also enabled the co-construction of science ideas via translanguaging (e.g. Robinson, 2005). In certain studies, the non-linguistic modes were directly attributed to the discourse produced and the subsequent increase in understanding. For instance, in Bracey (2017) visualisations were found to scaffold group activity that led to comprehensive understandings of cosmology. Likewise, in Robinson (2005) the manipulation of robots and subsequent discourse led to student improvement in science and English learning. In other studies we made suppositions when non-linguistic modes in multimodal discourse scaffolded science learning. For example, Amaral et al. (2002) believed the skills of observation and exploration were responsible for students sharing with each other and learning from each other. Following our inspection of the enquiry task, we deduced these skills may have related to non-linguistic modes included in the task. Evidence for this inference was found in 10 studies.A final example provides an explanation for why scaffolding was beneficial to meaning making. Williams et al. (2019) found grade 5 ELLs used multimodal discourse to co-construct meanings. Analysis showed the combinations of modes used and the various expressions of meaning made by the students caused the science meanings to multiply due to the increase in affordances used. Further discussion of science learning will follow in inference 8.

3.6.3 Ensure equitable learning for diverse science communities

The final theme shows how non-linguistic modes enhanced the learning of science for language learners, as they helped to deepen understandings and enabled teachers the transparency to view student understandings.

3.6.3.1 Enhance science understandings and processes

Many studies in this review attributed learning gains to the use of multiple modes. Evidence for these gains varied, yet the majority were noticeable. For this inference, we included studies that credited the use of non-linguistic modes with student advances in science learning. For instance, Fradd et al. (2001) suggested that drawings, charts, tables, graphs and computer-developed simulations enhanced learning by reducing the language (i.e. linguistic) load for ELLs, thus making it easier for them to participate. In another example, Billings and Mathison (2012), who found a significant interaction effect between group assignment, language status and total score, revealed that ELLs performed better with hand-held mobile devices. In addition, Ryoo and Bedell (2017) found that dynamic visualisations enabled ELLs to make more frequent connections between visual and textual science information. Altogether 24 studies recorded learning gains which related in part to the use of non-linguistic modes. Several studies also offered suggestions as to why non-linguistic modes used in combination with other modes benefited language learners. Bravo and Cervetti (2014) suggested that multimodal experiences gave ELLs multiple entry points into understanding and processing science. Haneda and Wells (2010) suspected the movement between multiple modes allowed ELLs to process information in smaller chunks and reflect on results and explanations. A final study (Williams et al., 2019) suggested the re-representation of meanings in different modes deepened ELLs' understandings because modes harboured diverse affordances. These affordances ensured details of science concepts accumulated.

3.6.3.2 Facilitate the nature of science

For this inference, it was first necessary to consider the nature of the learning experience in each study, as with inference 4. This was because multiple studies in this review revealed that an increase in the use of materials during science experiences had beneficial outcomes. Thus, focus for this inference was specific to manual-technical operations. This outcome was mainly conveyed in teacher and researcher responses, but we inferred evidence from the descriptions and transcripts found within the studies. Nine studies showed the nature of the learning experience related to the use of the materials. For instance, an experiment required students to observe the effect of a changing variable (adding weight) on a car (Haneda & Wells, 2010). From this tangible learning experience, we concluded that an association was apparent between the students' meanings made from tactile experiences and the science processes. Another study displayed a more apparent indication, as a teacher revealed the ELLs asked better questions, learned to reason, and became more knowledgeable about the scientific process after the addition of hands-on materials and experiments in science (Lee et al., 2008). A final study, that included tactile materials implemented enquiry-based, open-ended and student-centred activities during an intervention (Cuevas et al., 2005). Cuevas found significant differences between both English- and Spanish-speaking students increased significantly in the following areas: procedures for solving the problem, recording results and formulating conclusions. Although these results cannot be directly attributed to the tactile mode, they do indicate that the addition of materials into the learning space resulted in beneficial outcomes for science students. Materials also enable student understandings to be demonstrated and is discussed in the next inference.

3.6.3.3 Offer authentic assessment opportunities

Our final inference recognised the potential of non-linguistic modes for teachers of language learners. In the studies in this review, we discovered multiple indicators that showed nonlinguistic modes supported the assessment of language learners. This appeared beneficial at overcoming limitations caused if the teacher and students did not share a language. For example, in Zwiep et al. (2011) non-linguistic forms (e.g. graphic organisers, pictures and the manipulation of materials) were added to obtain more details of language learners' understandings after the sentence frames used provided insufficient information. Indicators in other studies revealed that images had been used by teachers to gain a better understanding of what language learners were describing and thinking (e.g. Martinez-Alvarez, 2017). In five studies we deduced connections between the teaching pedagogy, science experience and assessment. For example, in a study conducted by Hampton and Rodriguez (2001), bilingual practicing teachers delivered a hands-on enquiry curriculum in both English and Spanish. Results suggested that the enquiry-based, hands-on learning allowed the teachers opportunities to observe (or assess) the students during the science investigations throughout the lesson. In contrast, one culminating English discussion appeared to prevent ELLs from communicating. Similar findings emerged in a study by Robinson (2005) that compared three different student groups from grade 8 physics, including ESL, majority ELLs and an afterschool mathematics, engineering and science group. Results showed that the use of a tactile resource, Robolab, enabled assessment transparency for all groups. This was because students consistently measured their knowledge during tasks, revealing their understandings without requiring linguistic modes. The following section will address the research questions.

3.6.3 Summary

We reviewed 40 studies that investigated language learners in science in order to discover the influence of the non-linguistic modes outlined by the theory of multiliteracies, including, auditory, gestural, spatial, tactile and visual modes (Kalantzis et al., 2016).

In regard to question 1, we found 30 studies that indicated a tactile mode was used during science experiences, 21 studies that included a visual mode, 14 studies that mentioned the use of the gestural mode, and seven studies that potentially harboured an audio mode (from video, computer or web-based programmes), although this could not be substantiated. The spatial mode was found lacking in this review, as it was observed in only two studies (Adamson et al., 2011; Cyparsade et al., 2013).

In regard to question 2, the addition of non-linguistic modes supported language learners by offering them access to semiotic resources from their communicative and linguistic repertoires. This afforded all students an opportunity to communicate their ideas and experiences by translanguaging. Thus, equitable learning spaces evolved. We found that language and science meanings were co-constructed during multiparticipant discourse which also gave language learners opportunities to fill linguistic gaps. In addition, shared experiences with non-lingusitic modes (e.g. new technologies or familiar constructs) had the capacity to ignite student discourse, lead to better understandings, and provide a common ground for all students, potentially harmonising the multicultural classrooms. The following discussion will highlight notable findings, present educational implications, and recommend future research directions.

3.7 Discussion

A large amount of research to support language learners in science education have used linguistic initiatives (e.g. Bravo & Cervetti, 2014; Cervetti et al., 2015; Lo et al., 2018; Rupley & Slough, 2010; Santau et al., 2011; Tong et al., 2014). Following the reconceptualization of findings from studies through a twenty-first century lens, we demonstrated the diversity of outcomes non-linguistic modes offered to language learners in science. While several outcomes confirmed our hypothesis, others were unanticipated. We attributed the broad range of outcomes to the inclusion of multiple theories which served to illuminate new perspectives, validate language learners and ensured that the outcomes of numerous non-linguistic modes were contemplated.

The new understandings from this review present educational possibilities and may help to overcome limitations with current models for language learners in science. For instance, a teaching model designed to support language learners recommends that science content and science language be taught simultaneously (Lo et al., 2018). However, students who have not reached the required threshold in the LOI can fail to realise the benefits of this approach (Lo, 2015). The first theme in this review showed that non-linguistic modes afforded language learners the ability to participate in science discourse and as a result learn science language. Students were not obstructed by differing levels of the LOI because in science experiences, for example, language learners frequently drew upon alternative semiotic and linguistic resources (e.g. home languages) during discourse.

Another understanding we formed was the important role the tactile mode had for language learners in science. The tactile mode was found to support language learners' to learn the target language, facilitate and instigate their participation and science meaning-making, and provide equitable learning and assessment experiences. The prevalence of the tactile mode in studies is likely due to the multimodal nature of science, which necessitates the use of materials during science literacy (Lemke, 1998a). Nevertheless, tactile experiences made it possible for all students, regardless of their background an opportunity to participate in science. Similarly, findings also showed that limited access to a tactile mode could deter a language learner from communicating (e.g. Unsal et al., 2018a). This may be a contributing factor in studies reporting assessment data that consistently shows language learners lag behind their student counterparts in science (August et al., 2009; Billings & Mathison, 2012; Braden et al., 2016). We argue that non-linguistic modes offer language learners multiple meaning-making opportunities, as they provide access to alternative semiotic resources, enable shared experiences where meanings can be co-constructed and promote equitable learning spaces.

The findings of this review offer suggestions for science teachers tasked with catering for students from different cultures. Findings suggest that enquiry tasks are more beneficial for language learners if they promote shared experiences, encompass multiple modes and give emphasis to science and language learning (Bravo & Cervetti, 2014). When studies present contrasting findings, this appeared to be a result of either the students limited access to materials, design limitations of a task, or choice of instructional method (Liu, 2004; Unsal et al., 2018a; Zhang, 2016). Nonetheless, non-linguistic resources appear most valuable when integrated with other modes (e.g. Williams et al., 2019).

For such an interrelated issue, we recommend a more integrated approach to further research. Researchers in science teaching have already begun to integrate language fields, adding multimodal elements to their designs and integrating multimodal theories into their frameworks, including social semiotics (e.g. Unsal et al., 2018b; Zhang, 2016) and, more recently, incorporating the theory of translanguaging (Unsal et al., 2018a). Instead of shifting from a linguistic centric focus to a multimodal one, we suggest that research designs be expanded to embrace the multiple linguistic resources of language learners to address the bi/multilingual world. Transdisciplinary research is necessary to expand our understandings further.

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3.9 Appendices

3.9.1 Appendix A

The Concepts Used in the Database Searches

Table A1 The concepts used in the database searches

Concept 1: Language learner	"English Second Language" ESL "English Language Learners" ELL "English as a Foreign Learner" EFL "second language learning" L2 "bilingual education" bilingual "second language instruction" "Content and Language Integrated Learning" CLIL "English Foreign Language" "Language of Instruction" LOI "second language"
Concept 2: Science	"science education" "elementary school science" "science instruction" "secondary school science" "high school science" "secondary science" "primary science" "science teaching" "science practices" "science learning" "science lessons" "learning science" "primary teaching science" "science primary"
Concept 3: Non-linguistic modes	multimodal "multimodal approach*" modal "multiple representations" representation* "modes(s)" multimodality "multimodal learning environment" image* math* graph* "science draw*" "scientific draw*" picture* symbol* "hands-on learning" "hands on" "hands on demonstration*" realia drama* gestur* "role play" role-play "model manipulation" "non-linguistic" "non linguistic" “hands on experiment*” "hands on learning" embodiment
Terms not requested	"tertiary science" "university science"

3.9.2 Appendix B

Reference List of Reviewed Studies

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4

ELL's science meaning making in multimodal inquiry: a case-study in a Hong Kong bilingual school

Preface

Following on from the first research objective and in response to the lack of information regarding 'how' BMLs make meaning with multiple modes, this chapter addresses the second research objective and attempts to explain how ten Grade 5 BMLs made meanings with multiple resources in science. To achieve this, it presents the results of a coarse- and fined-grained thematic analysis of ten BMLs' multimodal meaning-making. The content in this chapter is the version of the submitted article accepted by the journal. The table and figure numbers have been formatted for the chapter. It is published in the journal, Asia-Pacific Science Education by Springer Open, under an open-access Creative Commons Attribution 4.0 International (CC BY 4.0).

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4.1 Abstract

This paper reports on a multimodal teaching approach delivered to grade 5 elementary students in a bilingual school in Hong Kong, as part of a larger research study aimed at supporting English Language Learners (ELLs) in science class. As language demands of reading, writing and talking science place additional challenges on ELLs, there is much research interest in exploring the use of multiple modes of communication beyond the dominant use of verbal and written language. Research has shown that students develop a better scientific understanding of natural phenomena by using and alternating between a variety of representations. Yet, questions remain as to what meanings ELLs make during a multimodal discourse and, in turn, how such discourse provides support to ELLs in learning science. Drawing on social semiotics, which theorizes language as a meaning making resource comprising a range of modes (e.g. gestures and diagrams), we used a case study approach to examine how a multimodal instructional approach provided 10 students with multiple avenues to make sense of science learning. Video recordings (capturing gestures, speech and model manipulation) and student works (drawing and writing) were collected during nine inquiry science lessons, which encompassed biology, physics and chemistry science units. Multimodal transcription allowed discourse to be analysed at a fine-grain level which, together with analysis of student works, indicated that the multimodal instructional approach provided the necessary inquiry opportunities and variety of language experiences for ELLs to build science understandings. Analysis also revealed how the affordances of modes attributed to the meaning making potentials for the ELLs and how they provided alternate communication avenues in which new meanings could be made. The findings from this study have implications for ELLs learning science within the growing multilingual Asia-Pacific region.

Keywords: English language learners, social semiotics, multimodal discourse, science teaching, elementary science, multimodal analysis, multimodal instructional approach

4.2 Introduction

Communicating scientific concepts is often challenging due to the unique structure of scientific language. Scientific language has certain quirks which makes it harder for the general population to acquire and use. The unique structure of scientific language poses a great challenge to its learners (Fang, 2005; Norris & Phillips, 2003). For English Language Learners (ELLs) who are "in the process of actively acquiring English, and whose primary language is one other than English" (Bardack, 2010. p.7), this poses an additional challenge. This is because in order to understand science, ELLs must learn the language of instruction (LOI) while simultaneously learning language of the subject area, along with vocabulary and content (Gibbons, 2003; Haneda, 2014; Lee & Luykx, 2005; Poza, 2013). To make matters worse, many ELLs in Hong Kong studying in a bilingual school are presented with further challenges as the LOI in science may alternate between grades or within grades from one science topic to another. For example, Earth science (climate, landforms, water-cycle) may be taught in Chinese while Life science, a topic with considerable links to Earth science (for instance ecosystems), is taught in English. Thus, inconsistencies in the LOI cause the segregation of science topics. Currently there is a need for research on bilingual education in curriculum, including science curriculum, (Goldenberg, 2013) in the context of Hong Kong because some studies have shown concerns for ELLs in science learning (Marsh, Hau & Kong, 2000; Yip, Tsang & Cheung, 2003). These studies further affirmed low proficiency in English had negative impacts on students' achievement scores in science.

Despite the challenges of learning science for ELLs, English immersion is set to continue as a result of its popularity, particularly in non-English speaking countries (Lo & Lin, 2015). In Hong Kong for example, political, economic and societal factors influence the decision of LOI (Lin & Man, 2009; Perez-Milans, 2014). In fact, parental and socio-economic pressure resulted in a change of LOI, following a decline in achievement scores in subjects that were taught in English, including science. The decline was linked to the LOI reverting to Chinese, following the 1997 handover (transfer of sovereignty) of Hong Kong from the United Kingdom. This action not only caused a decrease in test scores, but also limited students' university choices (Perez-Milans, 2014) and future aspirations. Consequently, parental and social-economic support for English immersion in Hong Kong has strengthened

(Hoare, 2010; Lin & Man, 2009), but problems for ELLs in science are likely to persist.

As English immersion increases, so too does the need to resolve ELLs' problems in science. For ELLs, the majority of problems in science result from the extensive repertoire of scientific language (Echevarria, Richards-Tutor, Canges, & Francis, 2011; Poza, 2016). This is due to the abundance of content and skill specific vocabulary in science. It is also an outcome of several grammatical aspects such as high lexical density, nominalisation, generalisations, technicality, and authoritativeness (Bruna, Vann, Perales, & Moisés, 2007; Fang, 2005). To further accentuate this problem, elementary science teachers are offered little support and remain unaware of how best to teach science to ELLs (Lee & Luykx, 2005; Lee, Maerten-Rivera, Buxton, Penfield, & Secada, 2009). This includes a lack of professional development for elementary science teachers that would ensure they understood the complexity of language repertoire and register for their subject area (Poza, 2016). This limitation leads many teachers to teach scientific vocabulary only (Bruna, Vann, & Perales Escudero, 2007; Halliday & Martin, 1993) and disregard the scientific grammatical aspects mentioned earlier. Teaching only scientific vocabulary or isolated content means there is a possibility that taxonomic relationships will not be established, which are significant to building scientific knowledge (Bruna, Vann, & Perales Escudero, 2007). Subsequently, ELLs require more support (Goldenberg, 2013) to use and apply scientific academic language, as it remains a key component necessary for their future success in science (Taboada & Rutherford, 2011).

Given the complexity of the issue, more research is warranted, specifically, research that explores the teaching and learning of science in bilingual settings in classrooms where English is the LOI. In in this study a case study approach was used to explore ELLs' meaning making in science at a bilingual Hong Kong school. A multimodal instructional approach (MIA) was adopted and used to teach nine inquiry science lessons where English was the LOI. During each lesson, video recordings captured the meaning making of ten grade 5 students, the majority of whom were ELLs.

The goal of this study was to gain a deeper understanding of ELLs' meaning making in science. This is necessary before attempts could be made to improve their science learning using English as the LOI. Only by understanding how something works will facilitate educators and researchers to enhance, improve and extend ELLs' meaning making process. It will also generate new insights that could direct further research with the potential to result in beneficial teaching and learning implications for ELLs. So, given that the majority of studies of ELLs in science have not examined in what ways meanings are made, this study sought to contribute more information on ELL meaning making.

4.3 Theoretical Implications for the study

4.3.1 Language-Based Theory of Learning

This study uses a sociocultural lens to explore the nature of the relationship between science learning and language in an ELL science classroom. According to Vygotsky (1978), there is a strong relationship between learning science content and language. Thus, without good language skills, students struggle to learn science or any other content. This is because language is used to internalize thoughts which allows learning to occur (Vygotsky, 1986). The relationship between learning and language presents a new dimension to the challenge faced by ELLs in science. Since their problem stems from difficulties with the language of science (Bruna, Vann, Perales, & Moisés, 2007; Echevarria, Richards-Tutor, Canges, & Francis, 2011; Fang, 2005, Lee et al, 2009; Taboada & Rutherford, 2011), it suggests that there is an imperative need to support ELLs language abilities when they learn science.

4.3.2 The Function of Language

Therefore, a closer examination of language is necessary to support ELLs in science, specifically, an examination of the function of language, which has been questioned by theorists. For instance, Halliday’s (1978) Systemic Functional Linguistics (SFL) rejects the conventional view that language functions as simply a medium to communicate thoughts. Instead, SFL proposes language as a meaning making function. It states that individuals use language resources accessible to them to make meanings. This suggests that language can synchronously be a resource and an ensemble of resources resembling a system (Wells, 1994). This position is consistent with Vygotsky’s (1978) depiction of language as a sign-based tool. Therefore, language is composed of multiple resources and functions as a source of meaning making. This implies ELLs can make meaning in science in multiple ways using a variety of language resources.

With regard to the implications of language for learning, SFL makes similar inferences to Vygotsky's learning theory described earlier. While Vygotsky outlines the important role language plays, Halliday (1993) positions language as the "process by which experience becomes knowledge" (pp.93-94). Thereby offering language as the necessary system for the acquisition of knowledge. Furthermore, the fact that language includes multiple resources implies two things. First, language resources differ from each other, and second, the choice to use a language resource is dependent on the participants' selection. The first point implies that if language resources are different they will have different potentials for meaning making. The second implication suggests that language is constructed by those who use it. With regards to science, these implications indicate that scientific language is formed by the scientists who use it while at the same time influenced by the language of science (Fang, 2005; Fang & Schleppegrell, 2010; Halliday & Martin, 1993; Tippett, 2016) including the meaning making potentials (affordances) of each language resource (Lemke, 1990). For ELLs, this insinuates their involvement in the construction of scientific language by way of language resources.

4.3.3 Systemic Functional Linguistics Influences Social Semiotics

Social semiotics contributes more details regarding the language resources (meaning making tools) available to ELLs in science. Social semiotic theory was formed on the basis of SFL (Halliday, 1993), and offered a perspective of language as a semiotic (meaning making) system, inclusive of a collection of meaning making tools. For this study it is important to differentiate between an isolated meaning making tool, referred to as a mode (of communication), and something that harbors multiple meaning making tools, referred to as *multimodal*. For instance, the nature of science is multimodal because the act of doing science involves using a variety of modes such as: speech, gesture, diagrams, models, graphical representations, simulations, and mathematical expressions (Lemke, 1998; Kress, Jewitt, Ogborn, & Tsatsarelis, 2014).

The examples listed are considered modes of communication because all have the potential to make meaning. Furthermore, meanings made using modes are made through the creation of signs. This is a process which is dependent upon a person (producer) constructing the sign, and a person (reproducer) receiving and interpreting the sign (Kress & van Leeuwan, 2006; Kress, 2010). Since signs are created and interpreted by people they are considered to be social and cultural constructions. All signs include three systems of meaning making or metafunctions. These include: *ideational,* which represents ideas about the world, *interpersonal,* which refers to relationships and interactions and *textual,* which refers to the organisation of signs and connections made to other signs in a text (Halliday & Matthiessen, 2014). These metafunctions can be used to infer the meanings of signs that are created. For example, Kress, and van Leeuwen (2006) draw on metafunctions to support their examination of images. In their book *Reading Images*, they illuminate the meanings behind the way image elements (visual signs) are used. In other words they discuss the grammar of visual design. To achieve this aim, they used the three functions to present information on; visual patterns of representation, patterns of interaction and texts. Similarly, we use metafunctions to support the analysis of the meanings made in this study.

Social semiotics, like sociocultural theories, credits all communication to human experiences and considers interactions to be fundamental to meaning making. Thus, for meaning making to occur collaborative experiences that include multiple modes of communication (such as speech, diagrams, models and writing) are pertinent. Although science classrooms have been adept with multiple communication modes for years, social semiotics has highlighted their value and inspired further educational research. Researchers have been interested in multi-representations (Ainsworth, 2008; Gilbert & Treagust, 2009) and multimodal representations (Kress, 2010; O'Toole, 1994; Márquez, Izquierdo, & Espinet, 2006). For example, Ainsworth (2008), explored the roles multiple representations played in science education and provided recommendations when using them with students. While Gilbert & Treagust (2009), focused on representations related to the learning of Chemistry, specifically regarding the relationship between the three types: macro, sub-micro and the symbolic. Kress (2010), presented a view of communication and meaning making through the lens of multimodality, examining the 21st century modes of communication. Whereas, Marquez, Izquierdo, & Espinet (2006), developed a theoretical framework to study the teachers' use of communicative modes in a science classroom. Despite the variety of research, many researchers have not yet investigated the use of multiple modes with ELLs in science.

4.3.4 Implications for Meaning Making in Science for ELLs

4.3.4.1 Multimodal Learning instigated

The theories described provide insight to how meanings are made in science, suggesting ELLs learn through the social construction of scientific language, considered to be multimodal. On closer inspection though, it is actually during the assembly of modes that meanings are made (Bezemer, Diamantopoulou, Jewitt, Kress and Mavers, 2012), as a whole science concept exists only within the integration of modes (Lemke, 2000). This is because in science one mode is unable to make meaning alone (Lemke, 1998). For instance, focusing solely on writing provides an incomplete depiction of a concept (Jewitt, Kress, Ogborn, Tsatsarelis, 2000) such as force. Whereas, adding mathematical formulas, diagrams and simulations provides much needed information to achieve an in-depth understanding. Thus, meaning making in science is purely contingent on the ability to recognize and represent science concepts in multiple modes (Waldrip, Prain, and Carolan, 2010; Prain and Tytler, 2012), it is also dependent upon the ability to translate one science representation from one mode into another mode (Ainsworth 1999; Russell & McGuigan, 2001), such as writing into a model, or gesture into diagrams. An ability to do so can be considered to be part of a student's "representational competence" (Tippett, 2016, p.727). This term also encompasses an ability to understand a mode's form and function as well as create representations in multiple modes (Tippett, 2016). In this study ELLs used and expanded their representational competence during the inquiry lessons.

4.3.4.2 Scientific Inquiry

Since the provision of inquiry learning allows social and collaborative opportunities and is an expectation of science teaching, the lessons within this study aimed to provide inquiry experiences for ELLs. Inquiry learning can be seen when "the learner is challenged to gather and analyze information, review it against existing knowledge, seek connection, notice patterns and gradually build an understanding of a concept" (Murdoch & Claxton, 2015 p.14). Intriguingly, inquiry learning also utilizes multiple communication modes including; verbal, visual, oral, pictorial, graphic and textual (Lee & Buxton, 2013; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). What is more, studies show inquiry approaches to be particularly effective with ELLs (Lee & Buxton, 2013; Moore & Smith, 2015). This is because they provide an authentic context for language use (practice) in science as they incorporate: hands-on experiences, student-centered meaning making, investigation of scientific phenomena, observation and experiments (Stoddart, Pinal, Latzke, & Canaday, 2002). In these contexts, ELLs have the ability to use and practice the language of science due to the availability of alternate literacy modes such as, gesture, model manipulation, drawing, and experimenting. Many of them are less dependent on traditional English literacy forms (e.g. reading and writing) and incidentally offer more opportunities for ELLs to partake in discourse regarding scientific knowledge and process with others (Lee & Buxton, 2013). Furthermore, relationships between language and science concepts are better established during inquiry learning. This is because, firstly, language is being used within the context to which it relates, and secondly, scientific inquiry approaches can be paralleled to the use of language functions including; predicting, hypothesizing, describing, reasoning and explaining (Stoddart, Bravo, Solís, Mosqueda, & Rodriguez, 2011). In this study, contexts that provide ELLs with experiences to authentically construct, connect and use language (including those just presented) will be referred to as language experiences.

Additionally, interventions utilizing inquiry learning with ELLs have had positive outcomes (Amaral, Garrison, and Klentschy, 2002; Lee, Llosa, Jiang, Haas, O'Connor, and Van Booven, 2016). In fact, Lee and Buxton (2013), compiled intervention research used to support ELLs in English proficiency as well as science. They revealed that effective teachers communicated ideas through multiple modes, and used a variety of methods to explain concepts, such as: hands on experiences, models, realia (the use of real objects or events), and demonstrations. Furthermore, they found effective teachers employed nonlinguistic modes, such as: data, tables, graphs, diagrams, and pictures, to allow opportunities for language construction and communication. Moreover, effective teachers used activities such as those listed above as contexts in which to model language and encourage communication of ideas and high order thinking (Lee & Buxton, 2013). Since inquiry learning has similar attributes to multimodal methods and promotes beneficial outcomes for ELLs, an assumption can be made that multimodal methods will also likely have positive outcomes for ELLs.

4.3.4.3 Studies with ELLs

In fact, the few studies focused on using multimodal methods with ELLs, concurred with our assumption and found them to be useful in the learning of science (Adamson, Santau & Lee, 2013; Choi & Yi, 2016). Bravo and Cervetti (2014) concluded that multimodal methods are successful for ELL learners because they "allow multiple entry points into understanding and processing" (p.242) while other researchers found ELLs to have benefited from the use of multimodal methods; including reading, writing, talking and participating in science processes (Adamson, Santau, & Lee, 2013). Other beneficial outcomes for ELL learners include: improving ELL's self-esteem and sense of accomplishment, strengthening their understanding of texts, making meaning relevant, and giving all students a voice (Choi & Yi, 2016). Despite the advantages that multiple modes of communication offer ELLs in learning science, there appears little research making use of these approaches to support ELLs in science. Currently more research is needed which examines how multimodal approaches actually offer support to ELLs. This study seeks to add new understandings as to how ELLs make meaning in science lessons when teachers use multimodal approaches to teaching and learning.

4.3.5 Research Questions

Therefore, to address the gap identified in the research, an investigation into how meanings are made by ELLs within multimodal science lessons was warranted. Informed by our objective to explore how meanings were made within an adopted MIA, the specific research questions were: *How are meanings made in a multimodal instructional approach? And; how does the use of modes within a multimodal instructional approach support ELLs' meaning making?*

4.4 Methods

For our methodology, we used a case study as it was appropriate in answering an explanatory *how* question through an in-depth holistic investigation (Merriam, 1998). Furthermore, a case study allowed for exploration and understanding of a phenomenon (Denzin & Lincoln, 2005; Guba & Lincoln, 1989; Stake, 1994) because it yielded a comprehensive holistic approach to understanding educational phenomena (Merriam, 1998). In this case the phenomenon was the meaning making of ELLs during a MIA. The case study methodology enhanced understanding of the phenomenon by enabling an inquiry into this complex social situation that contained more than one variable of possible significance (Merriam, 1998). Given the variety of ways meanings could be made, multiple variables existed. This meant multiple data collection and analysis methods were necessary to capture the different meaning making tools utilized by the ELLs. Moreover, a case study ensured investigation of the complex social interactions (Merriam, 1998) among ELLs during multimodal discourse. Finally, the case study methodology allowed this study to be comprised of multiple cases. For instance, the meaning making of ELLs in science was investigated by adopting a MIA and integrated it into three grade five science units: biology, physics and chemistry. Each science unit (inclusive of three inquiry lessons) was treated as a separate case and analyzed separately. This enabled the researchers' credibility of results and allowed triangulation to occur. However, this paper will focus on only one lesson from one representative case to illustrate the common patterns found in other cases.

4.4.1 Research Site

The research occurred at an independent kindergarten-to-grade-twelve bilingual school in Hong Kong which prides itself on entertaining a bilingual and bicultural ethos with commitment to integrating Confucian philosophies and Chinese heritage. As a result, the ratio of the LOI shifts from Putonghua (Mandarin) to English, beginning in kindergarten with a percentage of seventy-thirty respectively and progressing to fifty-fifty by grade five. In Hong Kong, Chinese and English are the official languages spoken, although Chinese refers to standard written Chinese and spoken Cantonese (from Canton Province) or Putonghua from mainland China. Cantonese is the dominant Chinese dialect spoken in Hong Kong, but increased migration from mainland China is beginning to change this demographic, and the percentage of Putonghua speakers is increasing. As the school site honours China's heritage, a dialect from mainland China was considered more appropriate. Thus, Putonghua was taught to students complete with traditional Chinese characters.

In science, the LOI not only changes between grade levels but also between subject matter. Additionally, the time allotted to teaching science in English shifts. Science is taught in Putonghua from kindergarten to grade three. In grade three however, three additional forty-minute lessons are provided for science and these lessons are delivered through an English LOI. Instructional time increases once again in grade four, with two additional forty-minute lessons a week, which remain consistent in grade five. With respect to the teaching of science, the responsibility falls on the language teachers of Putonghua and English.

4.4.2 Participants

The teacher-researcher was of European descent and English was her first (and only) language. She had over fourteen years of international experience teaching primary students of diverse ages and backgrounds including ELLs in England, Germany, Singapore and Thailand. She had achieved a Master's of Science Education from Australia and was currently Head of (English) Science at the site. This position was shared with a Chinese colleague who managed the science units taught in Putonghua. The teacher-researcher also taught English Science to a fifth-grade class comprised of twenty students. Purposeful sampling (Creswell, 2007) was necessary to ensure the research took place inside the teacher-researcher's classroom which was predominantly comprised of ELLs.

Thus, ten students from the teacher-researcher's class participated. Each was bilingual and spoke varying degrees of Chinese and English. Since the school was an independent bilingual school steeped in Chinese heritage, it attracted mostly affluent Chinese families from a high socio-economic background who could afford to pay for their child's education. All of the student participants had Chinese heritage and currently lived in Hong Kong. Most had been born in Hong Kong except three; two had been born in mainland China and one had been born in the United States of America. The vast majority of students did not speak English as their first language, although in bilingual households it can be difficult to distinguish a first language. However, in addition to speaking Putonghua and English, five of the participants also spoke Cantonese fluently. Nevertheless, regardless of their language or science abilities, the students were split into two equal groups of five and remained so for the duration of science lessons within the study.

4.4.3 Multimodal Instructional Approach

As part of the study, a multimodal approach was adopted to design a series of lessons for the grade 5 students. The MIA (Figure 4.1) chosen for the study was adapted from the Thinking Frames Approach (Newberry & Gilbert, 2016). Through this approach, students learned science through an inquiry of a puzzling phenomenon and by using multiple modes of representation to explain the phenomenon. The modes of representation included verbal, drawing and writing.

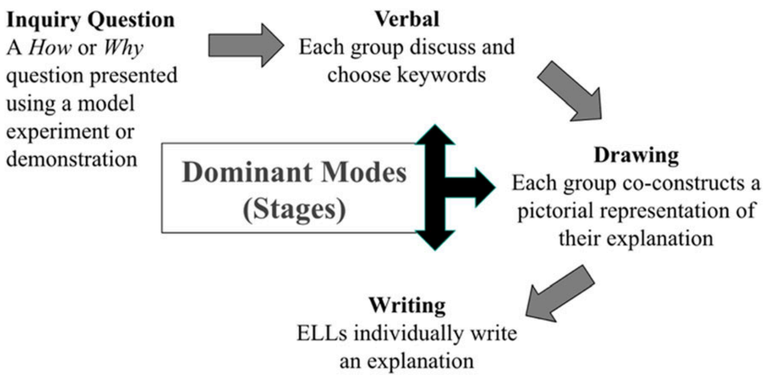

Figure 4.1 The MIA adapted from the Thinking Frames Approach (Newberry & Gilbert, 2016)

To address the research questions, we identified a *dominant* mode of representation at various stages of the lesson. It is important to acknowledge that multiple representations are always juxtaposed and used concurrently at any moment (e.g. talking while pointing at a diagram, drawing with some annotated words). However, it is possible to identify a dominant mode in which the participants oriented themselves towards most of the time (Tang, 2016). As the dominant mode of representation framed and organized the actions of the participants at any moment, each dominant mode was considered to be an indicator of a separate stage, shown in Figure 4.1. The multimodal meaning making was observed from within each stage; Stage 1 with a dominant verbal mode, Stage 2 with drawing and Stage 3 through writing. Meanings were also investigated between the successive stages, between Stage 1 and 2 and Stage 2 and 3.

The commencement of the inquiry mandated a 'how' or 'why' question be presented to the students. The question was presented with the scientific phenomenon to excite the students and stimulate curiosity. Consequently, the teacher employed either an experiment or demonstration using a model to launch the question. For example, the lesson described within this paper required a demonstration be performed by pulling a dollar bill quickly from under a stack of coins that was resting on top of a glass bottle. The force applied to the bill caused it to detach, while the other objects remained motionless. Before showing a demonstration, students predicted the result which probed their initial thinking. The inquiry question was posed following the demonstration, for instance; Why did the coins stay on the bottle? Immediately after revealing the phenomena, student groups began to co-construct their explanation and progress through the three stages of the inquiry lesson to answer the inquiry question.

The first collaborative task (Stage 1), required the students to choose science concepts that were relevant to the phenomenon observed in the demonstration. To aid the ELLs in this pursuit, catalogues were provided with key science representations (words, images, mathematical formulas) from each science topic: Life and survival, forces, energy changes and particles (Newberry & Gilbert, 2016) and remained with each group for the entirety of the lesson. The requirement of a group consensus promoted the sharing of ideas and prior experiences, and caused debates over relevant science concepts. The second collaborative task (Stage 2), necessitated the translation of a (predominantly verbal) explanation into a pictorial mode through drawing. The final task (Stage 3), required translation of an ELLs existing explanation into a written mode. In particular, each ELL was expected to create an explanation paragraph. Writing templates promoted the planning and organisation of ideas. Accomplishment of each task in the MIA necessitated that ELLs revisit the inquiry question to provide an appropriate explanation, represented in each dominant mode. A final support offered was teacher support, in the form of probing and questioning to incite ELLs to think more critically. By the end of each lesson, one group drawing and five written paragraphs were produced on paper.

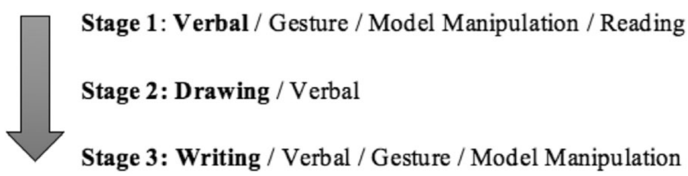

Figure 4.2 Dominant modes and expected alternate modes within the MIA

4.4.4 Inquiry Lesson: Why did the coins stay on the bottle?

To ensure accurate evaluations of ELLs' meaning making an explanation of the science concepts within this lesson is required. As this lesson occurred several weeks into an eight-week Forces in Motion unit, the ELLs had already had several lessons on concepts, such as: motion; direction; force; mass; acceleration; friction and gravity, as well as the difference between balanced and unbalanced forces. The purpose of the inquiry lesson described in this paper was to provide ELLs with an opportunity to enhance their understanding of these concepts by having them apply their current knowledge to explain a real-life phenomenon. An example of an accurate explanation is as follows:

The coins stayed on the water bottle because of Newton's first law of motion known as inertia. Since the objects were not moving, they were at rest or balanced. Objects at rest will remain at rest unless provoked by a force. Therefore, when the bill was pulled in one direction, it caused an unbalanced force allowing it to move in the given direction, but since the strong force was exerted only on the bill all other objects remained stationary. Friction was overcome by the strong pulling force on the bill and was helped by smooth surfaces of the objects touching it.

4.4.5 Data Collection

If meaning making occurs within the social and collaborative construction of signs, data collection strategies were necessary that captured each entire inquiry lesson. As the stages and discourses in the MIA equally had the potential (and were most likely) to be multimodal, video was necessary. Video could capture modes such as verbal, gestural, and model manipulation. Of the two cameras used, each was responsible for capturing a participant group. Video recordings of participant groups on average lasted approximately 40 minutes, although at the beginning of each lesson, one camera was also used to record any initial teacher demonstrations or experiments. These usually only lasted several minutes. Overall, a total of nine inquiry lessons with two cameras equated to the collection of approximately 750 minutes of recordings.

In addition to the recordings, artefacts made by the ELLs through other modes, such as the drawings and writings were collected. These were just as important as the recordings since meanings had the potential of being made by ELLs in any mode and through multiple modes. This meant each written paragraph, drawing or even doodle was of importance and needed to be analyzed separately as well as concurrently with the recordings. Therefore, the artefacts that were collected included A3 size sheets used for group drawings as well as individual A4 sheets used for the written paragraphs. All artefacts were collected from all participants at the completion of each lesson.

4.4.6 Analysis of Meaning Making

We adopt the notion of semiotic units in our analysis, to investigate meanings made within the inquiry lesson. Semiotic units are combinations of signs that are used to express a complete meaning (Wright, 2011). In this study semiotic units were considered the integrated signs that combined to represent one concept or idea. They were created through the multimodal discourse by one or more participants. When a concept or idea changed during a multimodal discourse, a new semiotic unit evolved and a new discourse began. Semiotic units and discourses could vary considerably in length. To distinguish discourses from one another we applied a construct similar to textual organisation, where one paragraph presents one idea. Likewise, individual discourses were considered to present an idea. Since discourse evolved through social interactions, boundaries were often blurred or intertwined from one into another, thus researcher checks were used to validate the analysis.

The signs constructed using modes in discourses were predicted to be the means through which ELLs made meanings. Since a variety of modes were available within the MIA, meanings were also predicted to be found within a multimodal discourse. Therefore, we chose to analyse the (signs used to create) meanings within discourses using two of the three metafunctions (described earlier), ideational and textual. Ideational has been referred to as presentation meanings (Lemke, 1998) and is closely aligned to the content matter of the science curriculum, requiring a coarse level analysis. Whereas textual, referred to as organizational meanings (Lemke, 1998) includes the intimate joining of words in a grammatical pattern and thus required a fine-grained level of analysis.

To do this, we examined discourse within semiotic units. This was made possible by discovering the meaning making potentials offered by modes, referred to as affordances (Prain & Tytler, 2012; Kress et al., 2014). Meanings made are dependent upon the modal affordance (Kress, 2010) of each mode which describe its constraints and potentials. For example, in writing, meanings are made through the use of words and grammar; likewise, in drawing, meanings are made through the affordances including line, colour and space. Gestures include types of movement, and speech has the capacity for tone and volume changes. Inspecting the meaning potentials of modes allows a more in-depth conception of the semiotic units found in the multimodal discourses.

Video was used to capture the affordances of several modes, including the expression within an ELL's speech as well as the detailed movements of a gesture. A two-part transcription was necessary to analyse multimodal discourses. First, a content log (Jordan & Henderson, 1995) helped to sequence events, enabling key frames inclusive of semiotic units warranting further investigation to be highlight. Next, these key frames were transcribed using a multimodal transcript, which provided a fine-grained analysis focused on a shorter timescale (Tang, Delgado, & Moje, 2014). Other fine-grained methods employed by the researchers were: thematic analysis (Lemke, 1990), used to examine the semantic relationships among the words that were spoken or written by the ELLs during the inquiry lessons; mode continuum (Gibbons, 1998), which examined the language used in the final written artefact and compared it to language used by ELLs as they moved through each phase; and pictorial analysis of the drawings using Kress & van Leeuwan's, (2006) visual framework.

In addition to the fine-grained analysis methods described, coarse-level analysis was also employed. This was indicative of a larger compositional grain size (Tang et al., 2014) and examined how representations as a whole (e.g. written paragraphs) were produced and re-represented. This included how science concepts were explained (accurately or inaccurately) when verbal explanations were re-represented into drawings, and vice versa. The collection of communication modes used by students during each of the stages of the MIA (Table 4.3) was also analysed. During all analysis, trustworthiness resided in the researchers critically reviewing each other's interpretations (Guba & Lincoln, 1989).

In-depth conceptions were achieved through the multi-level analysis as it allowed comparisons to be made. Furthermore, the analysis and patterns found within each lesson were compared to others within and between the three different science units. This provided enough necessary evidence to allow trustworthy conclusions to be drawn. Finally, we used narrative description encompassing "thick descriptions" to ensure findings were presented clearly and comprehensively.

Findings from the analysis are discussed in the next section. To do this, examples of multimodal discourse from the inquiry lesson are presented. The discussion includes examples from both a fine-grain (thematic analysis) and coarse-grain (writing) analysis.

4.5 Findings

The findings will now be discussed in three episodes below. The episodes were elicited from one inquiry lesson and show how the use of modes within the MIA provided both inquiry and language opportunities. Moreover, they illustrate how meanings were made by ELLs as they progressed through the lesson and how the science knowledge constructed accumulated through the stages. Each episode describes findings by including either excerpts of highlighted frames from the multimodal analysis or ELL's co-constructed representations.

In the following transcripts, which aim to illuminate assertions, individual students are denoted by letters, "K" refers to Student K. Other columns record signs found within modes. Speech is represented within one column and due to the limitation of space, gesture and model manipulation were grouped in another. During the participants' speech, considerable pauses (more than two seconds) are shown by three dots "…" together. If a student gazed at another student it is identified by ">" where the first student (letter) is looking at the second, a mutual gaze between two students is identified by "><", all other gestures and model manipulation evidence has been recorded in visual form.

4.5.1 Episode 1: Multiple Modes and Meaning Making

The first and second episodes were taken during Stage 1 directly following the demonstration (described earlier) and delivery of the inquiry question: Why did the coins stay on the bottle? At this point, students were attempting to decide what science concepts and representations related to their explanation for what happened (See Table 4.1).

Table 4.1 Identification of Science Concepts in Group 2

No	*Student*	*Speech*	*Gesture / Model Manipulation*
1	P	Forces, it's forces	
2	P	It's force	
3	A	It's force	
4	Y	It's force	
5	P	It's here, like there's pull	Points to representation for pull

			
6	A	It's force and it's so strong it can make it can withstand friction	
7	P	And Newtons	Points to key word 
8	K	And balance?	Points to key word 
9	P	Yeah, balance	
10	Y	balance or speed? Maybe?	Points to key word 
11	P	Speed!	
12	S	Speed	
13	P	Yeah Speed	
14	Y	Speed	
15	K	If you were moving very slowly… it will	Pretends to grip a note 
16	Y		Copies Student K

			
17	K	like,	Pretends to pull the note by horizontally moving her arm towards her at a constant speed
			
18	K	crash	Pretends note is now released from the coins and bottle and waves hand back as she says "crash"
			
19	Y	Maybe	
20	Y/A	It will fall	
21	Y	Yeah but if you're quick it... it will stay there	
22	P	Like quick	Grips and pulls pretend note,

by accelerating her arm towards her quickly

Episode 1, illustrates that combinations of modes included in the MIA provided inquiry opportunities for ELLs that allowed meaning making to occur. Specifically, it shows how students participated in multimodal discourses regarding science knowledge and processes, representative of inquiry learning (Lee & Buxton, 2013). This was revealed in the following patterns, first, discourses promoted the connection of prior knowledge to new ideas and concepts, second, the affordances of modes ensured discourses were meaningful to the ELLs who constructed them, third, meaningful discourses disseminated from others, and finally, discourses either ended or evolved following the introduction of new concepts or ideas by ELLs or their teacher. The first three patterns will be discussed in more detail in this episode.

The early (predominantly verbal) discourse was initiated directly following the demonstration designed to challenge students to scientifically explain the phenomenon. Initially, ELLs connected their prior knowledge to the demonstration they just witnessed. To do this they considered the relevance of each concept through the calling out of keywords (Table 4.1, lines 1-14) while often pointing to the word or matching representations (lines 5, 7, 8 and 10) found on the catalogues provided (described earlier). Initially, the ELLs accurately recognised the concepts linked to the phenomenon, such as force (lines 1-6). Student P related force to “pull” (line 5) and Student A believed the force was so strong it could “make it (the bill) can withstand friction” (line 6). Other accurate concepts linked to the phenomenon that were called out were, “Newtons” by student P (line 7) and “balance” by Student K (line 8). The act of calling out concepts prompted each ELL to consider their current understandings. As the ELLs analysed information by relating it to prior knowledge they participated in inquiry learning (Murdoch & Claxton, 2015).

So, as the concepts were stated (or pointed at), ELLs either agreed if they believed it related to a scientific explanation of the phenomenon, or disagreed if they did not. Agreement was usually shown by verbal restatement. For example, in Group 2 (Table 4.1) Students A and Y (lines 3 and 4) parroted Student P’s statement “It’s forces” (line 2). Later Student P restated the concept “balance” (line 9) together with an affirming exclamation “yeah” and in line 11, she restated a concept with enthusiasm as indicated by the tone and volume (verbal affordances) in her voice, which were re-represented as an exclamation mark. Agreement did not always require additional discourses.

However, when ELLs disagreed or needed clarification of their friend’s assertions they began seeking more connections, this consequently meant that additional discourses were needed. The connections sought during these discourses were between ELL’s current understandings and either the understandings of others, or the concepts being discussed. The ELLs’ attempts to make connections was another aspect of inquiry learning (Murdoch & Claxton, 2015) that caused meaning making to be deepened. This was because the additional discourses allowed for more in-depth discussion of ELL’s ideas and concepts in question. Thus, further language construction and meaning making experiences occurred.

Furthermore, discourses where students disagreed or clarified their thoughts usually embraced alternate literacy modes (e.g. gesture), and differed from the dominant (verbal) mode. This is illustrated in Group 2 (Table 4.1) where we see that the suggestion of the concept “speed”, sparked a discourse that inspected how speed related to the phenomenon. For instance, when Student Y queried “balance or speed?” in line 3, she did so using the affordances of tone and speech within her chosen mode of communication: verbal. These actions (within this context) signified a question was being raised, directing others to make a choice. Following this, several students confirmed “speed” was more appropriate by (assertively and/or affirmatively) repeating it in lines 4-7. Actually, the majority of students (from both groups) described the movement of the bill using a familiar everyday word: speed. However, it was the rate of speed (acceleration) and not speed (velocity) that related to this phenomenon. Although the ELLs had previously completed science tasks related to acceleration they were unable to verbally explain and apply the concept to this phenomenon.

However, the affordances of alternate literacy modes allowed ELLs the ability to demonstrate their understandings in other ways. For example, Student P proceeded to use the affordance of movement within gesture, together with a verbal mode of communication (line 22) to rationalise her thoughts. As she did, she gestured an action in which her hand (pretending to pull a bill) accelerated horizontally toward her while she simultaneously described the movement “like quick” (line 22). Thus, even though Student P was unable to verbalise acceleration, she demonstrated an accurate representation of the concept through the affordances of gesture.

Likewise, when Student K (with an original suggestion of balance in line 1) deliberated between the concepts, balance and speed, she used the same modes (as Student P), gesture and verbal to communicate (line 15-18) her ideas on how speed altered the outcome of the phenomenon. She demonstrated using both modes “If you were moving very slowly… it will” (line 15) said Student K as she pretended to grip the note and pull it towards her at a constant speed. Consequently, Student K was able to communicate her ideas because she had the capacity to choose modes that achieved her objective and combine modes to support her sharing of ideas. In turn, this allowed ELLs to receive information in multiple forms and join in the discourse from multiple access points. As a result, one ELL in the group participated through gesture and speech (line 22) while others joined in verbally (line 19-21). Multiplying the different affordances of modes permitted Student P and K the ability to make-meaning by enacting while commentating the original demonstration to communicate ideas. This example showed the affordances of modes ensured discourses were meaningful to the ELLs who constructed them and made information accessible to others.

This fragment of the inquiry lesson depicts ELLs identifying, sharing and confirming the initial concepts they believed were necessary to explain the phenomenon scientifically. When the ELLs connected science concepts and key words with the phenomenon they observed, it was considered to be both a meaning making and language experience. This identification and sharing was necessary in Stage 1 of the MIA, because the students needed to agree on the relevant concepts before using them to co-construct an explanation. Achieving this step promoted the discussion of prior understandings and the ELLs were seen reflecting on past lessons, sharing personal experiences or using phrases such as "I think" to justify their choices. This excerpt has shown that the necessary shared consensus of concepts promoted supplementary discourses where understandings could be explored more acutely.

Table 4.2 Using Alternative Modes to Test an Idea in Group 1

No	*Student*	*Speech*	*Gesture / Model Manipulation*
1	N	And pull fast	
2	H	Wait! Let me hold the…	Cups hands around bottle to catch coins
3	T	Well, we know what happens when you pull it fast so what are you trying?	
4	N		N > model, Pulls note by accelerating quickly. The coins move slightly but stay on the bottle. T2Picture1 
5	T	Put the note on again	Puts coins on table
6	H	Now slow, Oh god	Puts fingers in her ears

7	N		Pulls slowly
8	J		Squints and grits her teeth, and cups her hands around base
9	H		Fingers in ears
10	N		T2Picture2,  T2Picture3,  T2Picture4: Pulls note extremely slowly at a constant speed 
11	N		
12	J	Ow	Coins land on her hand
13	Others		Laugh
14	N	Ok so when its	

			slow	
15	T		(Now you can sit down)	T > N
16	N		it (COINS) moves, it moves with the note, but when its fast, the coins don’t have time to react	

Additionally, supplementary discourses that enabled concepts to be explored in more depth usually warranted one of two things: either evidence be examined (as was the case explored in Group 2 earlier), or ideas be tested. In both cases ELLs were interested in finding patterns to support their understandings, which was yet another aspect of inquiry learning (Murdoch & Claxton, 2015). If ideas were to be tested they were usually done so through the use of alternate literacy modes, including gesture (shown in Group 2 earlier) or model manipulation. For example, in Group 1 the testing of an idea can be witnessed (Table 4.2) as student N employed model manipulation as a representational mode to test his own idea. Similar to Student K in Group 2, he was interested in the effects speed had on the phenomenon and claimed a fast movement was necessary to perform the trick. He asked the teacher, “I want to know why when, when the note is fast they (the coins) don’t drop and why the note, when, when the note its slow…” she cut him off to invite him to test his theory (Table 4.2). During the testing of this idea other ELL’s beliefs within Group 2 surface. In fact, Student H asks Student N to “Wait! Let me hold” (line 2) while she cups her hands around the base of the bottle ready for the coins to fall when the bill is pulled “fast” (Student N, line 1). Thereby, uncovering her expectation that the coins would fall and thus highlighting a misconception. Additionally, although Student N proved his idea, “Ok so when its slow… it (coins) moves, it (coins) moves with the note, but” (line 14 and 16), he proceeded to offer a new idea, “when its fast, the coins don’t have time to react” (line 16), consequently uncovering a new misconception, instead of relating the stillness of the coins to inertia or to overcoming friction he related it to time. Nevertheless, corresponding to Group 2, Group 1 focused on the degree of speed in which to pull the note without reference to the degree of force. This was regardless of the difference in accessible communication modes, since (similarly to the gestures used by Group 2) model manipulation afforded Group 1 the necessary movements in which to demonstrate, communicate and test theories on how to pull the note. In most cases ELLs in Group 1 used more force when they pulled the note quickly and accelerated as they did, however they were unable to verbalise the action using accurate scientific vocabulary. Regardless, model manipulation (and gesture in Group 2) allowed ELLs to re-enact the phenomenon to further explore concepts in more detail.

These additional discourses ensured information was examined at a greater level in an attempt by ELLs to build understandings of the concepts. This is representative of inquiry learning (Murdoch & Claxton, 2015) and subsequently allowed further misconceptions to be uncovered. This is important when meaning making because misconceptions must be first uncovered before they can be amended by another student or teacher. Thereby more accurate and in-depth meanings could be formed. Meanings become more in-depth because not only do students understand why something is the way it is, but they also find out why something is incorrect. In essence, having the right answer is one piece of knowledge, but knowing why something is incorrect is another.

In sum, the accessible modes in Stage 1 (notably speech, gesture and model manipulation) allowed ELLs to experience inquiry learning. They provided an opportunity for ELLs share and connect their prior knowledge (as shown in Tables 4.1–4.3) to the concepts identified. Furthermore, the use of alternate literacy modes that afforded movement such as, gesture or model manipulation allowed the re-enactment of the phenomenon. This supported ELLs communication and meaning making by allowing them to explore concepts more in-depth. Furthermore, the multimodal nature of the supplementary discourses provided ELLs with the necessary affordances in which to access, communicate and discuss information. Moreover, the multimodal discourse allowed the ELLs to participate and make meaning in science regardless of their English level.

4.5.2 Episode 2: Interactions of Modes for ELL Science Learning

The second episode illustrates that interactions of modes provide ELLs with the opportunity to participate in a variety of language experiences. Language experiences, defined earlier, refer to contexts where ELLs can construct, connect and use language in science. Language experiences are pertinent if ELLs are to develop science understandings in English science lessons.

In this episode, ELLs are seen integrating alternate literacy modes (e.g. gesture) with traditional literacy modes (e.g. verbal) when constructing multimodal discourse and by doing so, practice the language of science. Furthermore, it shows how the MIA afforded ELLs the necessary language construction opportunities in science because the modes employed (during each stage) were selected by the participants of each multimodal discourse. They were not determined by the teacher's instructions or dictated by the dominant mode as previously anticipated. For instance, Tables 4.1–4.3 shows ELLs self-selecting modes (from those available) during multimodal discourses, such as in Table 4.1, where Student K (line 15) was seen choosing to add additional mode to the current discourse. Student K decided to gesture when words did not communicate the information she wanted to share. Thus, while speaking "If you were moving very slowly… it will" she simultaneously gestured an action, pretending to grip and pull the paper (horizontally) slowly toward her. The choice to represent movement through gesture illustrated to the group the measure of speed, indicating exactly how slow, slow is. Thus, multiple modes ensured a variety of details of a concept were communicated, revealed and discussed.

Table 4.3 Modes Used by Participant's during Inquiry Lesson 1

		Model Manipulation	Reading (catalogue)	Speech	Gesture	Drawing	Writing
	Participants	Stage 1- Dominant Verbal Mode					
	Student J	X		X			X
	Student H	X		X			X
	Student M						
	Student N	X	X	X			
Group 1	Student D						
	Teacher	X		X			
	Student A		X	X			
	Student P		X	X	X		
Group 2	Student K		X	X	X		
	Student S			X	X		

	Student Y		X	X	X		
	Teacher	X		X			
		Stage 2- Dominant Drawing Mode					
	Student J			X		X	X
	Student H			X		X	X
	Student M	X				X	
	Student N		X	X	X	X	
Group 1	Student D						
	Teacher			X			
	Student A			X	X	X	
	Student P			X		X	
	Student K			X		X	
	Student S			X		X	
Group 2	Student Y			X	X	X	
	Teacher		X	X	X		
		Stage 3- Dominant Writing Mode					
	Student J			X			X
	Student H	X		X	X		X
	Student M	X		X			X
	Student N			X	X		X
Group 1	Student D						
	Teacher	X		X	X		
	Student A			X			X
	Student P			X			X
	Student K			X	X		X
	Student S			X			X
Group 2	Student Y			X	X		X
	Teacher			X			

Another example in Table 4.3, outlines the modes utilized by each individual ELL in each stage during the lesson. It shows that all (Student D was absent) participants (including the teacher) made personal choices regarding how to communicate scientific information. For example, Student J and H from Group 1 employed writing in Stage 1 (the dominant verbal mode) and Stage 2 (the dominant drawing mode). Similarly, Student K and Y in Group 2, employed gestures during Stage 3 which was considered the dominant mode of writing. In actuality, the modes were determined by the communication needs of the individual ELLs themselves. In essence, students constructed language by creating signs using modes that best communicated the scientific information they wanted to share. Therefore, the collective ability to choose from and have access to multiple modes, increased language communication opportunities for ELLs during science. This was important as science meanings are made through the construction of modes (Bezemer, Diamantopoulou, Jewitt, Kress and Mavers, 2012).

Moreover, the ability to convey language ensured ELLs had the capacity to participate in multimodal discourse. Since multiple modes are necessary to achieve an understanding of a science concept (Lemke, 1990), multimodal discourse (as seen in this episode) exposed multiple details about the science concepts, thereby enabling more comprehensive meanings to be made.

Participating in multimodal discourses also presented ELLs with a circumstance in which to practice the language of science. This was a consequence of the multiple access points offered to ELLs in multimodal discourse. More specifically, some modes (gesture, drawing, model manipulation) provide affordances that do not require knowledge of English (reading, writing, speaking) allowing discourses to continue regardless of ELLs English ability levels. For example, gesture allowed Student K to make meanings she may have been otherwise unable to do using only a verbal mode. In fact, the gesture (line 15) completed an idea regarding the relationship between speed and friction. So, when she chose an inaccurate vocabulary "like crash" (lines 17-18), her fellow ELLs comprehended what she meant (from her hand gesturing a horizontal motion; see line 18) and corrected her. Consequently, the misused vocabulary "crash" (line 18), referring to what happened to the coins after the note was pulled slowly, was corrected with "fall" (line 20) by Student A and Student Y. Thus, English words were able to be connected to the gestural movements of Student K. Therefore, multimodal discourse allowed ELLs to participate by using alternate literacy modes while simultaneously learning more English vocabulary.

Additionally, Table 4.3 shows ELLs communicating through modes other than the dominant mode of a respective stage. As discussed, ELLs were seen adopting alternate modes for several reasons; explaining perspectives (see Table 4.1, lines 15-18), defending choices of science concepts and representations, and testing ideas (see Table 4.2). Nevertheless, regardless of ELLs choice of mode, multimodal discourses permitted the appropriate opportunity for the practice of the language of science.

The aptitude to self-select an appropriate mode (from multiple) ensured all ELLs had a capacity to convey meanings and communicate ideas, by choosing modes that offered alternate literacies. Furthermore, it provided ELLs with opportunities to practice the language of science. Overall, the discussion of science concepts through multiple modes insured more comprehensive meanings were made of science concepts.

4.5.3 Episode 3: Adding Modes to ELLs Science Discourse

Episode three illustrates how certain science information can only be communicated through a combination of integrated modes (e.g. drawing and speech) because the exclusive affordances found in each illuminate precise features of a science concept. Therefore, ELLs' understandings of science concepts have the potential to be expanded by introducing modes. In this episode, we explore the effect that the translation of modes has on meaning making. In particular, we inspect how meanings were translated into the modes of drawing and writing, successively. The initial excepts from Stage 2, depict the collaborative translation of Group 2's verbal explanation into a drawing. To gain a better understanding of the impact drawing had, a comparison between meanings made in the first and second stages of the MIA is presented. In addition, the final excerpts from Stage 3 show Student K's meaning making after the translation of her ideas into the mode of writing, following the construction of an explanatory paragraph.

4.5.3.1 The Drawing Mode Promotes More Detailed Science Meanings

Firstly, drawing is an alternate literacy mode and offers ELLs equal access to new information. As a result, ELLs can benefit from science concepts uncovered by the specific affordances that drawing provides, such as sequence. To illustrate this, Group 2's final pictorial representation (Figure 4.3), and excerpts from the multimodal transcription, taken before (Table 4.4) and during (Table 4.5) the construction the construction of the drawing have been included.

This first excerpt shows how the act of constructing a collaborative drawing stimulated further questions from the ELLs. These questions had to be answered before drawing could begin because like Stage 1 (Table 4.1, lines 1-6), where there was a need for everyone to agree on the related science concepts, Stage 2 of the MIA also required a consensus regarding the subject matter of the drawing. This prompted the use of verbal and gestural modes to discuss presentational and organizational meanings needed to create the drawing. For instance, Table 4 shows Student Y portraying how the action of the phenomena should be depicted (line 3-4) using verbal and gestural modes, "make it slow", then Student P intervened (line 5) to present her ideas, indicating how objects should be organised in the space provided. After which, Student P continued to suggest multiple drawings be created, “first” (line 7), and “then this one is when” (line 11) to show contrast. Finally, Student P decided that the sequence should include three drawings, “1, 2, 3” (lines 12-14). In this excerpt the affordances of drawing enabled the ELLs to view the phenomenon as a sequence and break the action into three parts. Separating the action encouraged the ELLs to consider what was happening in each picture in the sequence. This promoted a closer inspection of the science concepts at each step and in doing so allowed a more comprehensive explanation to grow, which will be illustrated in the next excerpts.

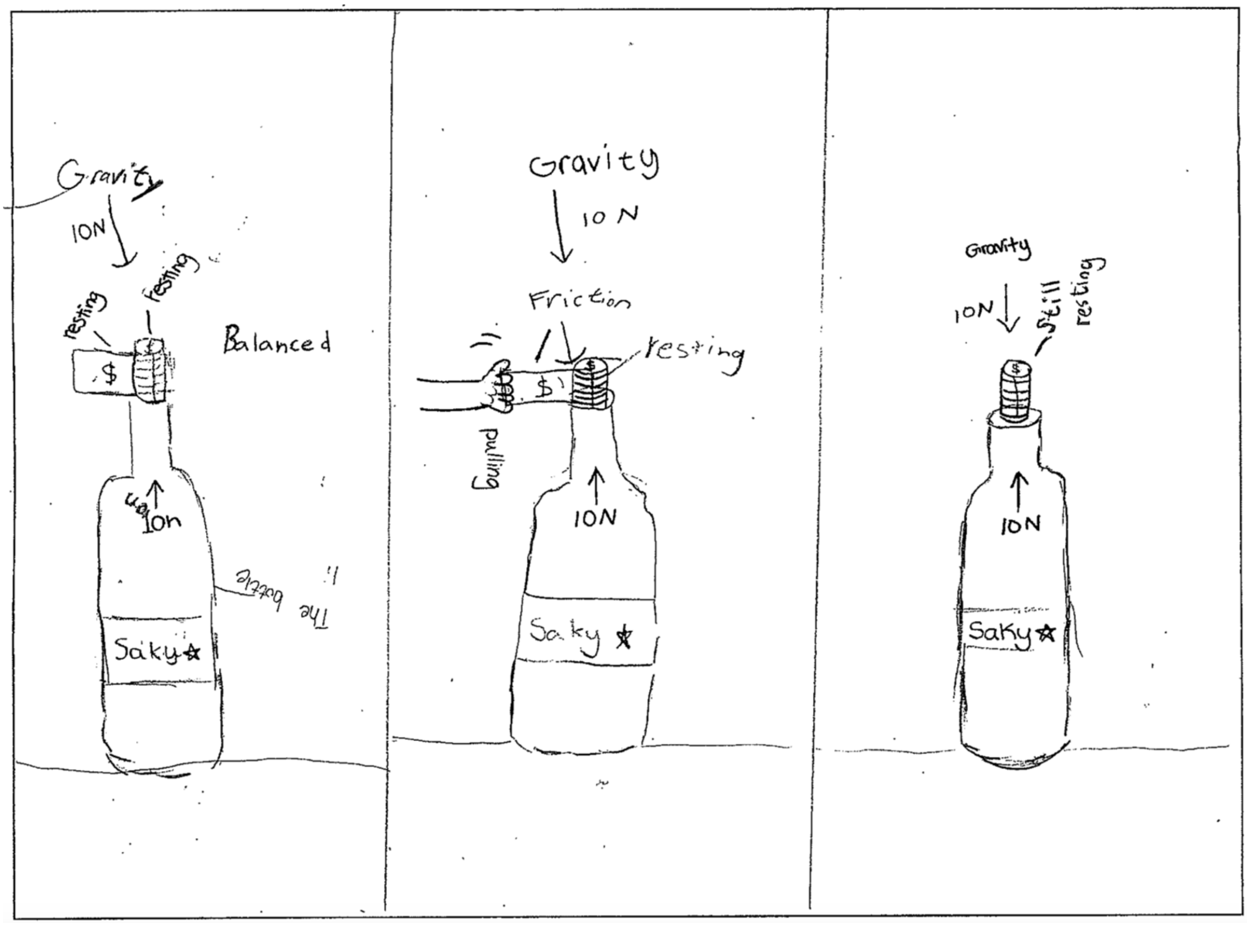

Figure 4.3 The Drawing Co-Constructed by Group 2

For instance, Figure 4.3 together with (Table 4.5) the multimodal transcript (taken during construction of the drawing) illustrates how the affordances of movement, direction and sequence, allowed science concepts to be explored and represented in more detail. For example, the depicted objects (coins, money, bottle) were able to be juxtaposed next to one another to allow comparisons to be made and illustrate the passing of time.

Furthermore, sequencing permitted Group 2 to depict objects from before, during and after the bill was pulled. In fact, the objects *at rest* in the first image became more apparent when compared to other images in the sequence. This was because movement was depicted in the second drawing, using two small curved lines directly above the hand. For the ELLs, the chance to compare images illuminated similarities and differences in each, making it easy to ‘spot the difference’ or in this case draw the difference. Since the side-by-side drawings (Figure 4.3) were mirror images (of the table. bottle and coins), it highlighted their understanding that the *pulling* force was directed at the note only, despite the image of the coins and bottle depicting no change, the ELLs wrote “still resting” on the coins to demonstrate their knowledge of this.

Table 4.5 also shows how drawing led to the application and connection of more specific and detailed information surrounding science concepts. At this point in time, the drawing contained only objects, some of which had been identified using labels, as yet, no representation of force existed. The teacher began to probe using questions seen in lines 1, 5, and 6. As students began to justify their understandings verbally, the teacher directed their focus back to the drawing, “have you shown that in the picture” (line 12). Student P asked if they would write the information, in line 15 and again in line 19, where she demonstrated a small section of paper that could be used for a written description. When the teacher denied the request, she asked the students directly, “What did we use to show force?” (line 21), Student S responded “arrows” (line 22) repeated by Student P (line 23). Following this excerpt, the ELLs were required to identify the type of force, determine the size (strength) of the arrow and direction it travelled, all of which promoted a deeper level of thinking about the concept of force. For example, the identification of forces allowed Student A to add a quantitative amount for each force (as measured in Newtons). Additionally, the sideways movement of the hand pulling the bill was seen to be countering the perpendicular direction of gravity. Therefore, not only did the affordances of drawings support ELL’s awareness and understanding of force within their explanation, but they also gave ELLs a means to make visible their ideas in order to clarify their thinking. Moreover, the drawings supported the integration of modes including the necessary speaking and gesturing before and during the drawing, to the final matching of written scientific vocabulary to the images as the students were prompted to provide labels to show what was occurring in each.

Table 4.4 Group 2 Co-Constructing the Drawing

No	Student	Speech	Gesture / Model Manipulation
1	S	What do we do here?	T4Picture1: points to blank paper
2	Y	Draw the bottle and	
3	Y	make it	T4Picture2: grips pretend note
4	Y	slow	T4Picture3: pulls pretend note towards herself
5	S	Yeah make it like…	T4Picture4: points to model
6	P	no draw	
7	P	like first	T4Picture5, T4Picture6: hand moves vertically up one side
8	P	you put the paper,	T4Picture7: drags finger horizontally
9	P	the money	T4Picture8: drags finger horizontally
10	P	and then like the coins	T4Picture9: taps the paper 3 times
11	P	and then this one is when you pull it and it stays.	T4Picture10: places hand on space P>< Y and smiles
12	P	No, one	T4Picture11: places hand in left side of the paper
13	P	two	T4Picture12: places hand in the middle of the paper
14	P	three	T4Picture13: places hand on right side of the paper

In order to explore the effect the mode drawing had on the ELLs meaning making, closer inspection of meanings made between Stage 1 (without the mode of drawing) and Stage 2 was warranted. Therefore, a fine-grain method of analysis known as thematic analysis (Lemke, 1990) was used to compare the meanings made between semiotic units within different stages. In particular, we examined the taxonomic relationships of the vocabulary used by the ELLs that were associated with the concepts of force and motion. For instance, “friction” and “gravity” are hyponyms (subsets) of force and “fall” and “at rest” are hyponyms of motion. In this excerpt, we focus on the patterns found between Stage 1 and 2 of the MIA. The results in Table 4.6 show that both groups were able to identify vocabulary associated to the concept of force in Stage 1, believed to be from ELLs prior knowledge of previous lessons or past units. Stage 2, however shows an increase in the identification of vocabulary related to force and motion. Although some inaccuracies were present (in Stage 2), they were seen as positive additions, since it was assumed that more scientific vocabulary meant more concepts had been discussed. This suggests that the collaborative drawing in Stage 2 illuminated additional scientific information regarding the explanation that was untapped in Stage 1.

This finding strengthened the researchers’ assertion that the modes accessible to the ELLs had a direct affiliation to the multimodal discourse and as a result, the meanings that were made. The consequence of the ELLs constructing a drawing facilitated a change to the multimodal integrations of previous discourse. Therefore, modal variance between Stage 1 and 2 was believed to be responsible for difference in information unearthed regarding the forces and motion concepts, thus offering broader and perhaps deeper understandings to develop.

Table 4.5 Group 2 Co-Constructing the Drawing

No	*Student*	*Speech*	*Gesture / Model Manipulation*
1	T	Ok so explain to me how these pictures answer that question	
2	P	Um…	
3	P	If you actually pull sand paper really quickly	
4	T	A can you focus on here	T>A Points to drawing
5	T	How are these pictures answering the question; Why do the coins stay on the bottle?	

			students' drawing
6	T	What are you showing in these pictures?	
7	P	So here's like, you have to pull it really quickly	 points to the place
8	T	Mmm, but is that explaining why the	T > P
9	A	so the force can be, the force	A > T
10	S	because the coin is resting	S > T
11	A	the force can be	A > T
12	T	but have you shown that in the picture	T > S
13	A	Because the coin	A > T
14	T	how can you show that?	T > S
15	P	Can we write it?	P> T
16	A	because the coin can't catch up with the friction on the piece of paper so it just stays at rest	A > T
17	T	is that shown in the picture?	T > A , A > drawing
18	T	you have to help them	T > AL
19	P	can we write it like this small thing here	P> T  shows position it will be written
20	T	No, it's meant to be just the	
21		drawing. Um, what did we use to	

		show force?
22	S	Arrows
23	P	Arrows

4.5.3.2 The Writing Mode allows ELLs to Connect and Sequence Science Meanings

In Stage 3, writing is seen to promote the solidification of connections between the meanings made in previous stages. For example, an examination of Student K's written explanation (Table 4.7) demonstrates how sentences with the conjunction 'because' were used in lines 3, 6 and 8. In fact, the construction of sentences highlighted cause and effect relationships for ELLs. For instance, Student K was able to demonstrate her knowledge of balanced forces through writing of sentences, which is mentioned three times in lines 3, 6 and 7.

In addition, the logical progression of a written explanation required the formation of a sequence of events. This can be seen from a thematic pattern (Lemke, 1990) that shows the causal, temporal and logical semantic relationships of the discourse in Stage 3 (see Figure 4.4). Within Figure 4.4, the semantic relationships can be viewed by the grey lines; these have been identified between the key terms used by the student. For Student K they included subclass and a variety of synonyms, all of which were accurate. However, a teacher is also expected to question what is missing from an explanation, and in Student K's explanation the semantic relationship *contrast* of balanced and unbalanced forces is missing. In fact, Student K does not describe the force of the pull of the bill nor why it moved at all. Nevertheless, what was written is accurate and considered an explanation of quality according to the curriculum level expected for these students.

Furthermore, Student K's written explanation (Table 4.7) supports the assertion that scientific information accumulated through the stages. For example, related concepts (e.g. force) were identified and explored (through gesture and model manipulation) in Stage 1, whereas in Stage 2 more details of concepts were uncovered (e.g. direction and location of forces) and in Stage 3 ideas were sequenced. Therefore, we found that each stage of the MIA was responsible for different meaning making outcomes. These outcomes collectively enabled the ELLs to make connections between scientific ideas providing an in-depth formation of science concepts, thus allowing the ELLs to form deeper meanings. For example, line 4 demonstrates meanings, such as the degree of speed, that were formed within Stage 1 during gestural and model manipulation. Whereas, line 3 illustrates concepts, such as balance that were identified in Stage 1 but explored within pictorial form in Stage 2, through verbal and gestural discussion with another ELL. Finally, Line 8 provides evidence of the information identified in Stage 1, connected in Stage 2 and reasoned (during verbal and gestural discourse) in Stage 3.

Table 4.6 Analysis of Meaning Making within Stages 1 and 2

Group 1		Group 2	
Stage 1	Stage 2	Stage 1	Stage 2
pull	forces	force	stay
force	upthrust	friction	at rest
friction	push down	gravity	don't move
Newtons	heavy	fall	force
balance	pushing		arrow
	Gravity		push
	arrow		gravity
	float		pulling
	Newtons		falls
			forces
			unbalanced

Table 4.7 Student K's Written Explanation with Lexical Strings; Synonym and Contrast

Student K	Synonym	Contrast
1. Everything is resting		
2. when we started the experiment		
3. because the forces are all balanced.	Forces	Balanced
4. The bill is pulled quickly	Pulled	*(Missing unbalanced)*
5. and the coins stayed on the bottle is		
6. because the forces are balanced too.	Forces	
7. The forces are balanced	Forces	
8. because the newtons are the same.	Newtons	

Overall the findings of this study provided insights into how multimodal discourse allowed ELLs to make meanings in science. Specifically, an important point was the translation of meanings into different modes, such as drawing and writing. Drawing added specificity to ELLs' meanings, while writing required ELLs to form associations between meanings. The findings also showed how the MIA provided ELLs with the necessary support structures to learn science, including facilitating a context for inquiry opportunities and language experiences. These structures also promoted the use of scientific language and allowed scientific meaning making to occur.

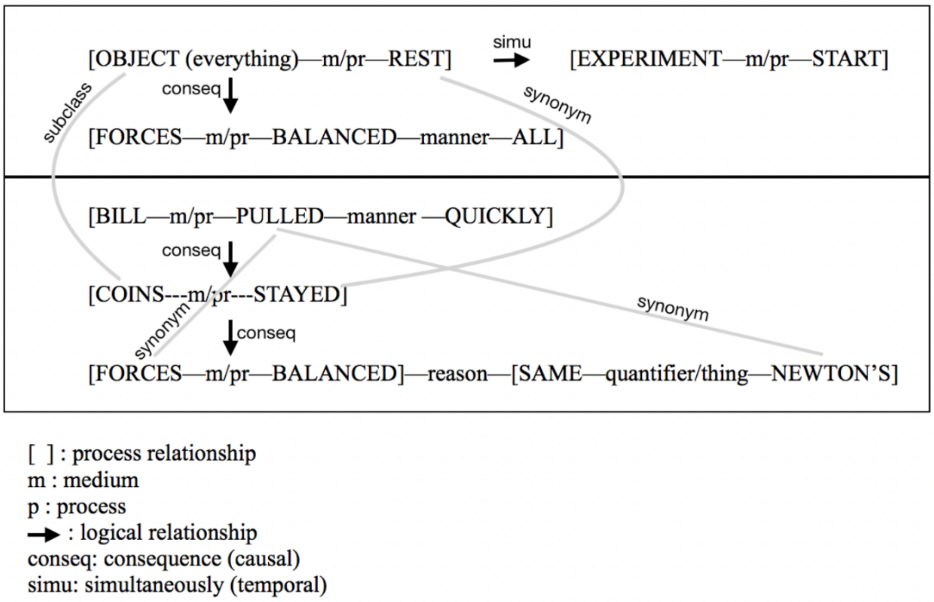

Figure 4.4 Student K's written explanation

4.6 Discussion

This study explored how grade 5 ELLs made meaning of science in a multimodal environment. Our analysis of an inquiry based multimodal instructional approach (MIA) to science showed the value of participating in multimodal discourses to make sense of science learning and the support that inquiry-focused MIA provided to improve science learning experiences of ELLs in a bilingual English school in Hong Kong.

4.6.1 Multimodal Discourses for Successful Science Learning

ELLs made meanings by participating in multimodal discourses, which ensured different scientific information was elicited through the variety of affordances of modes. These meanings were deepened as scientific information accumulated during the translation of modes within the MIA stages. This finding substantiated the idea that in order to understand a science concept, the assembly of modes (Bezemer, Diamantopoulou, Jewitt, Kress and Mavers, 2012) and integration of modes (Lemke, 2000) are necessary. Furthermore, this finding corroborated the notion that the translation of concepts from one mode into another is important when making meanings in science (Ainsworth 1999; Russell & McGuigan, 2001), and presents implications that this action leads to a more enriched understanding of concepts. For instance, the translation into drawing and writing caused more details of science concepts to be revealed. This was found to be due to the different affordances of the modes.

In fact, the meanings made during multimodal discourse were determined to be the direct result of the affordances of modes or modal combinations. This was because the affordances of modes had the potential to illustrate certain details of a science concept better than others. Therefore, providing ELLs with access to a variety of modes ensured that the meanings made were diverse. Furthermore, the accumulation of these meanings permitted the ELLs to gain a more comprehensive understanding and likewise, present a more informed scientific explanation of the phenomenon.

4.6.2 Multimodal Instructional Approach (MIA) to Teaching Science

The MIA provided the necessary inquiry opportunities and variety of language experiences to support ELLs in making meaning in science. In fact, for ELLs the inquiry opportunities provided by the MIA allowed authentic contexts for: (a) connections between prior knowledge and science concepts to be established, (b) ideas to be shared, refuted and tested, and (c) understandings to be collaboratively constructed through multimodal discourse. This finding is consistent with previous research that found inquiry approaches supported ELLs (e.g. Amaral, Garrison, and Klentschy, 2002; Lee, Llosa, Jiang, Haas, O'Connor, and Van Booven, 2016). For example, this study was similar to others that found the collaborative nature of the inquiry task provided the necessary context for the practice of language in science (e.g. Stoddart, Pinal, Latzke, & Canaday, 2002). Likewise, this study corresponded to others that found inquiry ensured ELLs' language and scientific knowledge was supported through social discourse and cooperative learning (e.g. Amaral, Garrison, and Klentschy, 2002). Furthermore, this study was consistent with others that found inquiry provided ELLs with multiple access points to information during multimodal discourse (e.g. Bravo and Cervetti, 2014; Choi & Yi, 2016).

However, this study also expanded current research that used inquiry supports to help ELLs in science by offering more details as to how that support was achieved. For instance, the variety of modes made available ensured ELLs had multiple opportunities to communicate. Moreover, the alternate literacy modes (gesture, model manipulation, drawing) included in the inquiry lesson included affordances less dependent on traditional literacy modes (e.g. reading and writing). Thus, when modes were combined (such as in multimodal discourse), the affordances available to ELLs multiplied. This offered the ELLs multiple ways to express their ideas and increased their ability to participate and access information. Subsequently, this provided the ELLs with an increased chance to understand and support each other. Support in this study ranged from: communication support, such as rewording or translating signs, substituting signs and filling in discourse gaps; to meaning making support, such as the collaborative deliberation of ideas.

Since scientists develop the language of science from the modes of science (Lemke, 1990), it is important that ELLs have an equal opportunity to do the same when learning science. In countries and territories with multiple official languages, such as: Hong Kong, Macau, Singapore, India, South Africa and the Philippines; the opportunity to use multiple modes of science is of even greater significance. This study was conducted in Hong Kong where two different languages (Chinese and English) are official, so the participants (including the teacher) spoke varying degrees of one or more of these languages. However, despite a difference in the languages spoken by participants, all were able to communicate in the science lessons due to the use of science modes. In fact, findings showed that by participating in multimodal discourse during the MIA, all ELLs had the capacity to develop science language. Therefore, the modes in the MIA supported each ELL's ability to communicate and share their scientific ideas and understandings with others. This consequently provided the ELLs with an opportunity to practice the language of science. In essence, the capacity to convey the language of science afforded ELLs the ability to learn science. Therefore, the MIA ensured all ELLs were provided the necessary language experiences in which to learn science. Thereby, using an MIA in science presented a more equitable learning environment because, regardless of students' spoken language/s or fluency in the LOI, students were afforded an equal chance to participate and learn.

4.6.3 Implications for Teaching ELLs

Exploring the meaning making of ELLs during multimodal inquiry science lessons highlighted several important factors for teachers to consider. Firstly, as science language learning is synonymous with science learning (Fang, 2005), then multimodal opportunities provide authentic science learning experiences for ELLs within science classrooms where English is the LOI. Not only do multimodal approaches provide a necessary language learning experiences, they are also consistent with the nature of science, and thus allow ELLs to learn through inquiry. In fact, because exploration of the phenomenon included multiple modes and the production of multiple representations, ELLs most likely developed deeper understandings than they would have if they answered the question immediately following the demonstration.

Additionally, corresponding with the findings of Sandoval, Bell, Coleman, Enyedy, and Suthers (2000) where complex ideas were seen to be explained more intelligently by students if they had the support of representations as opposed to not having them, this study found the production of representations allowed ELLs' understandings, including misconceptions, to be highlighted. In fact, they enable the potential for peers and teachers to deliver guidance because they provide insights into students' thinking. Thus, multimodal methods permit support to ELLs through the uncovering of scientific knowledge, since ELLs can explain understandings in more ways.

Furthermore, the availability of modes impacted the discourses produced and this subsequently effected the meanings that were made. Therefore, access to modes has implications for an ELL's science learning. This study highlighted how ELLs selected modes that aided their communication regardless of the instructions given by the teacher. When participating in discourses, ELLs chose modes of communication that best served their individual capabilities, the subject matter, and the modes available in the given situation. Of significance to teachers is the importance of having a variety of modes available which plays a key part in limiting or enhancing student communication.

Finally, this study revealed how scientific understandings were built within a multimodal approach. This opens possibilities to science teachers housed in bilingual schools, where the LOI in science is English. Despite limitations of time, or the restriction to topics taught in English, following the recommendations from this study may help teachers to support ELLs in science. What is more, this in turn may provide additional support in implementing the bilingual school model.

4.7 Limitation

While the results seen within this study are encouraging, they have been collected within one case study of a small group of students. Considerations for future studies include the need to broaden the scope of this research by using a MIA with cohorts of ELLs in multiple grade levels and in multiple settings where the LOI is English. Furthermore, comparisons regarding the achievement of ELLs before and after this study could not be made and this would be a recommendation for future research as it would elicit further confirmation of the outcomes of a multimodal approach.

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5

Fifth graders' use of gesture and models when translanguaging during a content and language integrated science class in Hong Kong

Preface

Following on from Chapter 4 and the discoveries of how ten emergent bilinguals made meaning, this investigation narrows the research focus to inspect meanings in more depth. This investigation addresses objective 3 of this thesis aimed to explain the outcomes of ten Grade 5 BMLs' use of gesture and tactile modes in science. As a result, the chapter presents the results of an analysis of semiotic units involving gestures or tactile moves.

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5.1 Abstract

Translanguaging in science includes the use of semiotic repertoires complete with non-linguistic modes of meaning (e.g. gesture, tactile) that until recently have gone unnoticed in research into content language integrated learning (CLIL). Currently, there are calls for classroom research in CLIL settings that examines the semiotic processes in the spontaneous translanguaging of emergent bilinguals. In response, this study aims to expand bilingualism research by investigating the ways in which fifth-grade emergent bilinguals' draw from their semiotic repertoires when translanguaging in content-based science lessons. Multimodal transcriptions made from video recordings of the lessons allow a cross-case analysis of the emergent bilinguals' shifts from oral to gestural or tactile modes during a biology and physics unit. Findings illustrate that emergent bilinguals use nonlinguistic modes to aid their science discourse in four distinct ways: replacement, support, demonstration and imitation. For instance, gestural and tactile meanings replace unknown everyday words and science language during demonstrations. A fine-grained analysis of the semiotic units shows that tactile moves, gesticulations, pantomime and imitation each play a role in the semiotic processes involved when translanguaging in a content-based science class. They allow the expression of ideas, the mediation of language and the unaided flow of discourse.
Keywords: Content-based instruction; emergent bilinguals; translanguaging; semiotic repertoire; gestural and tactile modes; science meaning-making; content language integrated learning

5.2 Introduction

In a content language integrated learning (CLIL) science class, where language is developed through content learning, emergent bilinguals draw, gesture, touch and use other semiotic resources to make meaning (Lemke, 1998; Cope & Kalantzis, 2009a; Zhang, 2016). The recent heightened awareness of these semiotic potentials is a direct result of today's societies, where frequent interactions between speakers of diverse backgrounds and new technologies have stimulated a consistent engagement of non-linguistic resources (García & Li, 2014; New London Group, 1996). According to the theory of multiliteracies, societies long-term use of non-linguistic resources can cause them to evolve into modes of meaning (termed 'modes'), which harbour different semiotic potentials than the linguistic modes, speaking and writing (Kress, 2010). Correspondingly, the theory of translanguaging posits that bilingual students draw from a semiotic repertoire including multiple non-linguistic resources, in addition to a linguistic repertoire, as they communicate (García & Li, 2014). This implies the semiotic possibilities of non-linguistic modes are of value and may present emergent bilinguals with beneficial outcomes in CLIL contexts and therefore warrant further investigation.

At present, research investigating bilinguals' use of semiotic repertoires in CLIL settings appears underdeveloped (Lo & Lin, 2015). Studies that draw on the theory of translanguaging continue to favour a linguistic focus, such as code-switching (e.g. Gallagher & Colohan, 2017; Pavón Vázquez & Ramos Ordóñez, 2019; San Isidro & Lasagabaster, 2019). Consequently, the semiotic potentials gestural and tactile modes offer emergent bilinguals remain relatively unobserved in content-based science classrooms despite evidence of their benefits in science education research (e.g. Bracey, 2017; Hampton & Rodriguez, 2001; Jakobson & Axelsson, 2017; Unsal et al., 2018; Williams et al., 2019; Zwiep et al., 2011) and language research (Belhiah, 2013; Dahl, & Ludvigsen, 2014; Gulberg, 2006; Ingerpuu-Rümmel, 2018; Lee, Hampel, & Kukulska-Hulme, 2019; Peng, Zhang, & Chen, 2017; Yen-Liang, 2017). As a result, there are currently calls for more classroom research to investigate the semiotic processes involved when bilinguals use translanguaging to decipher content meaning (Lin, 2019). With this in mind, this study draws on the theory of multiliteracies, which considers language as a semiotic system, to expand bilingual research and the current understanding of translanguaging in CLIL contexts. From a multiliteracies perspective emergent bilinguals' use of non-linguistic modes, such as gestural and tactile modes, come into focus.

This article presents information from a larger nine-month study investigating the outcomes of multimodal inquiry science classes for emergent bilinguals in an independent school in Hong Kong. Independent schools teach national curricula from abroad, offer bilingual models with home languages and hire native speakers to service the educational desires of the expatriate communities that speak at least 27 major and minor languages in Hong Kong (Bacon-Shone, Bolton & Luke, 2015). Increasingly independent schools accommodate local Hong Kong families, who no longer subscribe to the government school policies, as well as immigrants from mainland China who may speak a dialect different from Cantonese (Yamato, 2003). Alternatively, their decision may be influenced by the important socio-economic status English holds in Hong Kong, as it is seen as a pathway to a good university and future career (Lo & Marco 2012, 2015). An independent school offers a distinctive research setting which may illuminate new understandings of translanguaging from inside a CLIL science class. This study explores the translanguaging of 10 fifth graders to ascertain how they use their semiotic repertoires to co-construct meaning in science. To do this, each student's shifts between linguistic and gestural or tactile modes made during science lessons were analysed.

5.2.1 The content-based science classroom

The aim of CLIL is to teach content curricula through a foreign language (Dalton-Puffer, 2011). Subjects such as science are frequently referred to as content-based classes and provide emergent bilinguals with a genuine social context for the meaningful use and application of the target language (Lin, 2019). However, in content-based science classes emergent bilinguals need an advanced knowledge of the target language to decipher science language and the high volume of content-specific academic language related to concepts in and across science disciplines (Bravo & Cervetti, 2014; Fang, 2005). Science language has high lexical density, as well as abstraction, technicality, generalisation and authoritativeness (Bruna et al., 2007; Fang, 2006). Also present in science language is nominalisation, used to condense a large amount of information into a phrase and assuming the audience has prior knowledge of the subject matter, and transitivity, which indicates agency and the relationship between subject and object in a sentence (New London Group, 1996). These aspects of science language may make it unlikely that emergent bilinguals who have not yet achieved the required threshold of a target language will realise the benefits of CLIL (Lo, 2015).

Nevertheless, a content-based science class has a variety of non-linguistic resources that can be used to make meaning including diagrams, drawings, experiments, graphs, mathematical formulas and models (Evnitskaya & Morton, 2011; Lemke, 2000). This is because the employment of multiple modes is needed to communicate science concepts or carry out science processes, which can be described as the doing of science (Lemke, 1990).

For example, the formula for velocity together with a written description will make more sense when combined with a demonstration, diagram and/or model. Consequently, unlike other content areas, the nature of science demands the use of multiple modes. The inclusion of non-linguistic resources in science suggests students must draw upon their semiotic repertoires when translanguaging. This is evidenced in classroom research.

Several studies demonstrate that the use of semiotic repertoires afforded emergent bilinguals the capacity to participate in co-constructing meaning, which is a goal of CLIL (Lin, 2019). For instance, Blair et al. (2018) investigated heteroglossic spaces in grades 2 and 4, that enabled emergent bi/multilinguals to draw upon their entire semiotic repertoires, and countered the perception that English-medium instruction equalled an English only space. Findings showed a teacher was able to create multiple pathways for students to carry out science tasks by using semiotic modes such as music, tactile materials and visuals (Blair et al., 2018). In another study Unsal et al. (2018) explored the gesticulations of emergent bilinguals in grades 3 and 7 in Sweden. Findings showed students drew upon their semiotic repertoire to gesticulate when they were unable to describe a phenomenon in words, or when they used words inaccurately. As other students (and the teacher) adopted (i.e. reproduce) them in the discourse that followed, they maintained the flow of communication, even though at times the gesture required interpretation before the discourse could resume (Unsal et al., 2018).

Likewise, positive effects of non-linguistic modes were found in other studies concentrated on language acquisition and science learning, although not all focused on the discursive practices of bilinguals. For instance, studies in science education reveal that the addition of non-linguistic modes provides emergent bilinguals with alternative avenues for meaning-making (e.g. Williams et al., 2019), scaffolding opportunities (Bracey, 2017), a stimulus for language use (Hampton & Rodriguez, 2001; Zwiep et al., 2011) and an increase in content learning (Jakobson & Axelsson, 2017). Similarly, studies in language demonstrate gesture can support emergent bilinguals in second language comprehension (Belhiah, 2013; Dahl, & Ludvigsen, 2014), meaning construction and translation (Ingerpuu-Rümmel, 2018), complementing oral meanings (Lee, Hampel, & Kukulska-Hulme, 2019; Yen-Liang, 2017), and by reducing the social distance between the teacher and students (Peng, Zhang, & Chen, 2017).

With encouraging outcomes reported in the earlier studies it is logical to assume similar outcomes may occur in a content-based science class. Yet, at present, there is a lack of classroom data exploring the translanguaging practices including the emergent bilinguals' semiotic repertoire in CLIL contexts (San Isidro & Lasagabaster, 2019). Thus, with these potentials in mind, this study aims to expand an understanding of emergent bilinguals' use of translanguaging as they draw from and interact with the semiotic resources, gesture and touch, during science discourse.

The following section describes the theoretical framework in this study. First, the theory of multiliteracies explains the view of language adopted. Next, the theory of translanguaging explains how bilinguals communicate using language and describes their natural discursive practice. Finally, the sociocultural learning theory explains how meanings can be made in a content-based science class.

5.2.2 The theory of multiliteracies: language as a semiotic system

The theory of multiliteracies suggests that within our multifaceted environment are cultural resources called modes of meaning (or simply 'modes') that societies use to communicate and that contribute to form a semiotic system (New London Group, 1996). Meanings are designed using linguistic (e.g. oral and written) or non-linguistic modes, such as gestural, image, spatial, tactile and audio modes (Cope & Kalantzis, 2009a). From this perspective, emergent bilinguals appear to have a multiplicity of semiotic resources to communicate and make meanings in CLIL science classrooms (New London Group, 1996). Of importance in the theory of multiliteracies is how emergent bilinguals can design a meaning through multiple modes. To explain, it is necessary to understand that modes evolve within societies and carry with them cultural, social and material influences. Together these influences shape the meaning-making potentials of modes that can cause representations to differ in different societies, for instance, gestures used as greetings differ in different societies.

In addition, these influences yield parallelisms between modes (Kress, 2010). For example, it is possible for 'gesture and speech [to] express the same underlying idea unit but express it in their own ways' (McNeill, 2005, p. 23). For instance, in a classroom thumbs-up can mean the same as saying, 'Good job!'. However, gestures do not just embellish oral meanings (Vygotsky, 1978). Instead, they work in unison to express a meaning (McNeill, 1992; Roth, 2001). This allows designers to use multiple modes, shift between modes or re-represent meanings as they design them (Cope & Kalantzis, 2009b). With respect to CLIL science classrooms, non-linguistic modes imply emergent bilinguals can make meaning regardless of their diverse language backgrounds. The next step is to comprehend bilingual behaviour with regard to how bilinguals use a semiotic system to communicate; this is part of the following discussion.

5.2.3 Translanguaging using linguistic and semiotic repertoires

With the goal of understanding emergent bilinguals' use of non-linguistic modes in CLIL science classes, this study adopts the theory of translanguaging to explain how bilinguals communicate. Originally, the term 'translanguaging' was coined by Williams (1994) using the Welsh term trawsieithu (later translated into English by Baker, 2001). Since its conception, translanguaging has referred to both the language practices of bilinguals and the pedagogical practices that ensure they occur (García, 2009; García & Li, 2014). More recently García and Li (2014) presented a perspective of translanguaging that moves beyond the knowledge of two distinct languages and suggests that bilinguals harbour only one linguistic system. In addition, they draw attention to the prefix trans, as it relates to the word transculturación (titled by anthropologist Fernando Ortiz) and emphasise its implication as 'a process in which a new reality emerges' (García & Li, 2014, p. 30). Viewed in this way this study defines translanguaging as the dynamic, complex designing of new language practices by a speaker.

While studies investigating the theory of translanguaging are widespread in multilingualism research, studies have remained limited within the context of CLIL (Nikula & Moore, 2019). At present research efforts to investigate the implications of translanguaging in CLIL classrooms remain focused on the linguistic repertoire, with definitions in studies describing separate languages (Gallagher & Colohan, 2017; Pavón Vázquez & Ramos Ordóñez, 2019; San Isidro & Lasagabaster, 2019). For example, Gallagher & Colohan (2017) use the term 'translanguaging' interchangeably with 'code switching' to explore its effectiveness (via dictation) as a technique for grammatical awareness in CLIL geography classes. Similarly, Pavón Vázquez & Ramos Ordóñez (2019) describe translanguaging as 'a general practice involving the utilisation of two distinct languages' (p. 36) and use this definition to categorise the students' use of L1 (their first language). And while San Isidro &

Lasagabaster (2019) employ a definition from key scholars in the field (García, 2009, and Li Wei, 2011), their research interests continue to include a linguistic focus that investigates the role of the L1 in CLIL.

The continued adoption of varied definitions coupled with researchers' gravitation towards the linguistic repertoire, shows 'there has not [yet] been a full shift in epistemological understanding and language, bilingualism and education in the ways in which translanguaging points' (García & Li, 2014, p. 71). As a result there appears to be an unexploited research interest concerned with the outcomes of emergent bilinguals' use of their semiotic repertoire in CLIL (Lin, 2019; García & Li, 2014). More concerning, though, is the notion that since meanings are constructed from a semiotic system, a disregard of the analysis of non-linguistic modes could leave researchers with an incomplete understanding of the semiotic unit (Kress, 2010). The next section describes how the semiotic processes occurring during Translanguaging can lead to learning in a content-based science class.

5.2.4 Making meaning by translanguaging in a semiotic system

Researchers studying emergent bilinguals in science and language fields recommend pedagogies that ensure students make meaning through shared experiences which encourage the dialogic co-construction of language (Karlsson et al., 2018; Lin, 2019). This is because learning, as Vygotsky (1978) argues, is deeply rooted in social action and mediated by semiotic systems such as language. In other words, language is the psychological tool responsible for cognitive development as we internalise ideas using language (Vygotsky, 1978). Viewed in this way, it appears translanguaging can provide essential practices necessary for the learning process of bilinguals, such as metacognition, metatalk and private speech (García & Li, 2014, p. 90).

Likewise, it follows that all modes used when translanguaging in social interactions are potential mediators of learning. This also applies to emergent bilinguals themselves, since when they participate in the co-construction of science meanings they reveal different perspectives of a science phenomenon that conflict with the ideas of others during a discourse (Vygotsky, 1978). This constant confliction of ideas on a social plane, together with additional contributions from those of higher abilities, such as a teammate or teacher, supports internalisation and higher thinking (Vygotsky, 1978). From this perspective, we assume every mode and interaction can add value to the meanings construed. However, the parameters of this research prevent an in-depth analysis of all semiotic modes during interactions. Instead, this study focuses on the use of two non-linguistic modes commonly used during face-to-face interactions: the gestural and tactile modes.

Gestural and tactile modes. Gestures are numerous in form as they frequently accompany oral meanings with respect to timing, meaning and function (Kendon, 1980; McNeill, 1992). In this study analysis focuses on two types expected to most relate to the science discourse: gesticulations, considered to be the movement of hands and arms that accompany talking or mental images of talking (Kalantzis et al., 2016), and pantomime, bodily movements that do not require speech but may present as sequence-like demonstrations (Roth, 2001). While both gesture and tactile modes include spatial meanings such as the movement of hands and arms, tactile meanings also require direct contact with a material object and occur as emergent bilinguals manipulate materials such as three-dimensional models (Kalantzis et al., 2016). Children make tactile meanings from an early age by using their senses (e.g. touch and taste) to explore their world and objects within it (Vygotsky, 1978). Materials can, therefore, help unfamiliar science concepts become familiar (e.g. Whittier & Robinson, 2007). For instance, a model demonstrating the rotation of the Earth (an abstract concept) allows science meanings to be made (e.g. Jakobson & Axelsson, 2017). In addition, by imitating the actions of people using objects, children learn how objects function (Vygotsky, 1978).

The next section presents information regarding the methods and analysis used to discover how the emergent bilinguals use their semiotic repertoire, in particular the gestures and tactile manipulations of artefacts in a content-based science class.

5.3 Methods

5.3.1 Research context

This study was conducted in a fifth-grade content-based science class, taught in English, at an independent school in Hong Kong. Unlike government schools, this independent school entwined Confucian culture with Western culture, which disseminated from two separate departments, Chinese and English. Constructivist teaching and learning philosophies predominantly came from the English department, where lessons were mostly delivered by expatriate English-speaking teachers from abroad. The bilingual school model was considered to be partial immersion (Lin &

Man, 2009). It required the language of instruction to alternate, beginning with 70% instruction in Putonghua (Standard Mandarin) in kindergarten, decreasing to 60% in third grade and then equally shared with English in fourth grade and onwards. Consequently, the language of instruction in science also altered. Science began in Putonghua until third grade, when three lessons in English were added each week. By fourth grade, science lessons in English increased to five a week. The science disciplines were also divided between the languages. For example, the delivery of life science occurred in both languages, whereas the language of instruction in physics and chemistry was English, in Earth science it was Putonghua. By seventh grade all the science lessons were in English.

This paper presents data from two contrasting science units in fifth grade, a life science unit focused on the human body with investigations into three systems, and a physics unit focused on forces in motion with investigations into Newton's laws of motion. The lesson topics (Table 1) linked to the school's science curriculum, which drew from an eclectic mix of international curricula including Hong Kong, Taiwan and the United States. At the time of the study, the Next Generation Science Standards were being incorporated to maintain current shifts such as the adoption of science and engineering practices (National Research Council, 2012). In this study the inquiry science lessons were based on the thinking frames approach (Newberry & Gilbert, 2016).

In the approach, a puzzling phenomenon is presented usually through a demonstration or experiment that explores a real-life phenomenon and is linked to an associated inquiry question (see Table 1). In response, student groups consecutively construct a verbal, pictorial and written explanation. To promote ideas during the initial co-construction of the explanation four placemats (e.g. life, forces, matter, energy) with images, mathematical formulas and words representing science concepts are made available. Translating the verbal explanation into a pictorial image prompts further discourse that enables conceptions to be discussed, argued, and justified until a final consensus is reached. Finally, the students transfer the explanation into a written form by deciphering the sequence.

Table 5.1 The science topic, inquiry question and tactile materials for each lesson

Science lesson topic	Inquiry question	Tactile material
Respiratory system	How do we breathe?	1 working lung model
Circulatory system	Why are cells so small?	1 cube made of smaller cubes
Digestive system	Why can we eat upside down?	None
Newton's 1st law of motion	Why do the coins stay on the bottle?	1 glass bottle, note and coins
Newton's 3rd law of motion	How does the balloon car work?	2 balloon cars
Newton's 2nd law of motion	How does the rocket launcher work?	1 rocket launcher

5.3.2 Participants and data collection

The participants remained consistent for the six months of the study. Purposeful sampling ensured that all of the participants came from one of the 10 fifth grade classes (Creswell, 2014). According to standardised testing, this class had a high percentage of students with below-grade-level English. Out of 19, a sample of 10 students (10 to 11 years old) participated. The participants were typical of those students attending the independent school as all came from affluent families and all had Chinese heritage. This demographic may have been a result of the dominant Confucian culture in the early years of school and the increased exposure to English in the upper years, that attracted families from Hong Kong and mainland China. The emergent bilinguals all spoke various degrees of English and Putonghua and several also spoke Cantonese. In contrast, the 37-year-old teacher was monolingual in English. She was currently managing science in the English department at the primary school.

Two video cameras recorded the six lessons, each was approximately 40 minutes in length. Each camera focused on a group of five participants. The small number of participants ensured they were all visible by the camera. This allowed all the modes used by the students' (from their language and semiotic repertoires) to be recorded. The data formed part of a larger study which followed the ethical considerations of an Australian university.

5.3.3 Approach to data analysis

Recordings were crucial in this study, as the meanings made were multimodal (Kress, 2000, 2010). Thus, it was necessary to view one mode (such as gesture) in context with others to gain an in-depth conception of the meaning (McNeill, 2005). Consequently, the inspection of each mode shift required the identification of the modes surrounding the shift and their projected meanings. To achieve this, the unit of analysis needed to encompass all the signs (or representations) used, from multiple modes, to design a meaning. Therefore, a semiotic unit (Williams, et al. 2019; Wright, 2011), also referred to as an idea unit (McNeill, 2005) or semiotic bundle (Radford & Sabena, 2015), was chosen. The semiotic unit permitted a fine-grained level of analysis (over a shorter time period) of the mode shifts used in the design of each meaning (Tang, et al. 2014).

Semiotic units often occur during discourse with multiple participants. Therefore, they were predicted to differ between the student groups and were expected to be influenced by the arrival of a participant (e.g. the teacher) or a material (e.g. a working model). The semiotic units required the implementation of boundaries, as they did not have definitive ones. Boundaries were added as an idea changed or a new meaning evolved, such as when a proceeding meaning deviated from the previous one. For example, as Anna's group was attempting to draw the diaphragm, she asked, 'why don't we dissect the diaphragm?' The question related to a future experience when they would dissect a heart. The question instigated the beginning of a new semiotic unit that proceeded into a discourse about who had touched a heart or lung. New meanings frequently occurred in this way, following a designer change, a question (by either a student or the teacher), or after the sharing of a personal experience. In this example, Anna was a new designer and asked a diverging question.

5.3.4 Data coding and analysis

To enable an examination of the multiple semiotic units, a diachronic analysis was chosen (Radford & Sabena, 2015). This allowed a cross-case analysis of each participant's mode shifts, since comparisons between multiple semiotic units could be made. To achieve this, it was necessary to use a structuration table to sequence the events from each video in a timeline format (Kelly & Chen, 1999). This helped identify and separate semiotic units that were not related to the science phenomenon, as unrelated discourse frequently occurred in the social setting. Next, the oral, gestural and tactile modes of the related semiotic units were recorded via multimodal transcription, seen in Table 2 (Bezemer & Mavers, 2011). The affordances of the transcription style ensured interpretations were critically reviewed, which increased reflexivity (Cohen et al., 2011). For instance, the oral mode (speech) was transcribed using words, while gestures and tactile moves were represented with still images (from the raw video), written descriptions and, later, codes.

Table 5.2 Example of the multimodal transcription of a forces and motion lesson

Time	Verbal Mode	Gestural & Tactile Modes	Description
1:13	Nick: *air comes in*	 	moves hand along tube in one direction
1:14	Nick: *and*		
1:15	Nick: *if this is there*	  	assembles model correctly

Coding of the multimodal transcripts occurred in two phases. First, gestures and tactile moves were identified within semiotic units by replaying the video in slow motion, sometimes multiple times. Next, each semiotic unit was interpreted to discern in what ways the emergent bilinguals shifted between linguistic (oral) and non-linguistic (gestural and tactile) modes. The mode shifts were coded to allow each emergent bilingual's mode shifts to be compared. The following will explain the coding of gestures, tactile moves and mode shifts.

5.3.4.1 Phase 1: Identification and coding of gestural and tactile modes

Gestures in associated semiotic units were coded according to McNeill's (1992) gesture taxonomy, which is frequently employed in education contexts (Roth, 2001). In it four distinct gesticulations (the movement of arms and hands) are described. However, 'beats', or motor gestures (Krauss et al., 2000) considered to be repetitive, rhythmic, non-pictorial movements used to provide structure to communication, were not considered relevant. Instead, three gesticulations were recorded in this study: deictic gestures used to point to concrete or abstract forms; iconic gestures associated with concrete materials and processes (which as a result have a transparent relationship with what they are referring to); and, in contrast, metaphoric gestures, which give illustrative properties to abstract forms through movement (see Table 5.3). Pantomimes that included entire body movements were also identified and coded (Figure 5.1).

Table 5.3 Coding of the gesticulations

D = Didactic gesture	I = Iconic gesture	M = Metaphoric gesture
		
What's that called?	*air coming out*	*draw those dot dot dot things*

Representations within a tactile mode include the touch, handling, manoeuvring and repositioning of an item. In this study, these are referred to as tactile moves, for example making a working model work. Due to the close relationship between gestural and tactile modes of meaning, representations within a tactile mode may include gesticulations directly related to an item's (e.g. a model's) attributes, for example gesticulating the direction of airflow from a rocket launcher by pointing

(Kalantzis et al., 2016). Similarly, this could also be depicted by retracing the airflow direction by moving a hand or finger along the plastic tube, as seen in Table 1. Therefore at times gestures and tactile moves coincided. Consequently, gestures and tactile moves that occurred simultaneously were recorded as both.

5.3.4.2 Phase 2: Identification and coding of mode shifts

To identify shifts between linguistic (oral) and non-linguistic (gestural and tactile) modes, inspections of semiotic units focused on three things: (1) for incomplete oral sentences;(2) for the use of gestural and/or tactile modes in combination with an oral mode; and (3) for the use of gestural and/or tactile modes without an oral mode. The initial coding of mode shifts evolved as the quantity of shifts examined multiplied. The decision to include mode shifts came from this study's motivation, emergent bilinguals' science meaning-making in a content-based classroom. Therefore, a prerequisite for a shift to be included was that it helped an emergent bilingual to communicate an idea. For instance, in Example 1 a semiotic unit begins following a question by Ajay. Upon answering, two emergent bilinguals (Stacey and Anna) shift modes to communicate their ideas. Although their shifts differed, both aided the communication of their idea and were subsequently included.

Example 1:

1. Ajay: Why can't your skin expand?
2. Stacey: Because then it will break and you will … (gesticulation)
3. Anna: Yeah! It will ... (gesticulation)
4. Stacey: and it will rip it apart

In each instance, interpretations of mode shifts were based on three things: the representation produced, the context of the semiotic unit within the larger discourse, and the knowledge of each emergent bilingual. English levels were imperative to making accurate interpretations, so emergent bilinguals' standardised English assessments (Australian Council for Educational Research (ACER) and Oxford Placement Test) were collected. For instance, in Example 1 it could appear that Stacey gesticulated because she did not have the vocabulary to express her idea in an oral form. However, knowledge of Stacey's English ability and review of the recording showed that Anna spoke enthusiastically (turn 3) over Stacey, which resulted in Stacey pausing until Anna had finished.

5.3.5 Trustworthiness

Interpretations remained trustworthy (Guba & Lincoln, 1989), as the multiple cases allowed for the triangulation of data that enabled credibility of results. For instance, to authenticate the interpretations of mode shifts, raw video footage was reviewed in a timely manner (often multiple times) and compared to the other shifts found. In addition, the teacher-researcher, who had prior knowledge of the participants, had the opportunity to clarify shifts in context. Nevertheless, the collection of information regarding each emergent bilingual's English ability levels preceded the interpretations. Also, if an interpretation could not be authenticated it was removed. The following discussion presents the final interpretations that address the research question.

5.4 Interpretations of the data

This section first presents quantitative data to show how frequently each emergent bilingual shifted to gestural and tactile modes and the ways these shifts occurred. Subsequent results include more detailed and descriptive information from selected semiotic units and provide examples of the mode shifts that occurred through tactile moves, gesticulations, imitation and pantomime.

Table 4 differentiates between gesture types and depicts the frequency with which the 10 students shifted from an oral mode to a gestural or tactile mode. It shows that, of the ten, eight shifted to a gestural mode and six shifted to a tactile mode to aid their science discourse. Most gestures used by the emergent bilinguals were representative (usually iconic), followed by deictic (pointing), while only five students used pantomime. Gestural shifts were utilised more than tactile shifts, though this finding appeared to relate to the students' access to the models. In four of the lessons the two groups shared one model only. The duration each group had with a model varied, and within a group, one individual usually manipulated the model. One lesson on the human body did not include a model (see Table 1).

The results in Table 4 show that Nick (group 1) and Yasmine (group 2) shifted to a gestural mode more frequently than the other emergent bilinguals in their groups. Both students also received the lowest achievement scores in the standardised English assessments. However, due to the small sample size a relationship between these findings cannot be established. In contrast, two students from group 2 (Nadia and Jane) did not appear to shift to gestural or tactile modes during oral representations. This may be a result of Nadia's frequent absence from the science lessons and Jane's lack of participation during science.

Table 5.4 Number of gestural and tactile shifts made by the emergent bilinguals to aid their science discourse

	Gestural				Tactile	Total
	Iconic	Metaphoric	Deictic	Pantomime		
Group 1						
Lavender	4	2	2	0	3	11
Nadia	0	0	0	0	0	0
Nick	13	3	7	0	11	34
Jacinda	1	0	1	0	1	3
Jane	0	0	0	0	0	0
Group 2						
Ajay	5	1	1	1	5	13
Anna	15	2	1	1	0	19
Koko	5	0	2	1	0	8
Stacey	14	1	3	1	6	25
Yasmine	24	1	1	1	1	28
Total	81	10	18	5	27	141

Next, Table 5 shows the ways the students used mode shifts in science and how frequently they did so. It suggests emergent bilinguals across both groups shifted to gestural and tactile modes when communicating or making meaning in science in four distinct ways: (1) replacement, a deictic gesture or tactile move (e.g. touch of an object) used simultaneously with a pronoun (e.g. 'this', 'that') which replaced a noun; (2) support, a gesticulation or tactile move provided with an oral representation to embellish the meaning; (3) demonstration, a movement (iconic, metaphoric or pantomime) that replaced an oral description requiring verbs, adverbs and positional language (e.g. shape, size, location and direction) and actions such as vomiting (for instance, in Example 1, the code for Anna's shift (turn 3) from an oral to a gestural mode was 'demonstrate', because her gesticulation completed an idea she had begun verbally, but the code for Stacey's shift (turns 2 and 4) was 'support', because her gesticulation added further meaning to an idea presented entirely in an oral mode); (4) imitation, a gestural or tactile movement copied from another participant (or the teacher) during a discourse. The data suggests (Table 5) that many emergent bilinguals shifted to gesticulation to demonstrate a meaning, and the majority (seven) appeared to use it more frequently than any other shift.

Table 5.5 The ways emergent bilinguals used gestures or tactile shifts

	Gesture				Tactile shift			Total
	Replace	Support	Demon-strate	Imitate	Replace	Support	Demon-strate	
Group 1								
Lavender	0	5	1	0	2	0	1	9
Nick	3	8	10	0	4	0	7	32
Jacinda	0	0	2	0	1	0	0	3
Group 2								
Ajay	2	0	5	1	2	0	3	13
Anna	0	3	13	3	0	0	0	19
Koko	1	0	6	2	0	0	0	9
Stacey	0	1	15	0	3	2	1	22
Yasmine	0	9	15	5	0	1	0	30
Total	6	26	67	11	12	3	12	137

Table 6 provides details about the timing of the gestural and tactile shifts that occurred relative to an oral representation (a verbal sentence). However, as it was difficult to qualify what movements facilitated the production of speech, there is limited data regarding the gestural and tactile moves that preceded an oral representation. Nevertheless, findings showed that emergent bilinguals more frequently shifted to gestural and tactile modes while simultaneously providing oral representations, for instance in mid-sentence. For the shifts coded as replacement and support this was an expected outcome. However, regardless of their position, demonstrations usually succeeded expressions such as 'this big', 'this way', 'it goes', 'it kinda' and 'like this'. In addition, demonstrations that occurred without an oral mode were usually responses to the teacher's oral questions. On these occasions students frequently answered through a gestural mode only. Likewise, most imitations occurred without an oral mode; instead the students joined the science discourse by unobtrusively imitating the gesture of another emergent bilingual or the teacher.

Table 5.6 The location of gestural and tactile shifts in relation to an oral mode

Relative to oral mode	Replace	Support	Demonstrate	Imitate	Total
Before	0	1	0	0	1
Simultaneously	12	20	39	0	71
Following	6	8	30	1	45
No oral mode	0	0	10	10	20
Total	18	29	79	11	137

The mode shifts replacement, support and demonstration, frequently occurred as emergent bilinguals became confronted with an unknown or an uncertain linguistic representation. At times, the absent everyday words or academic science vocabulary were conspicuous, as seen in Table 7. In most circumstances, a gestural mode (e.g. iconic, metaphoric and pantomime) with its spatial affordances replaced the words that described either a movement or the ways things travelled, including food, force, vomit, the diaphragm, the lungs, air particles, a car and a rocket. In contrast, tactile moves and deictic gestures often replaced the names of a model or of body parts, and the direction of a force or movement. Consequently, gesture types and tactile moves were employed by the emergent bilinguals for different purposes. Examples of each will follow.

Table 5.7 Everyday and academic words replaced by a gestural and/or tactile shift

	Forces in motion	Human body
Academic words	acceleration	deflate
	action	expand
	reaction	contract
	force	forces/move
	air particle	relax
	balance	pressure
	deflate	diaphragm
Everyday words	bounce	bigger
	blast off	tube
	roll	big
	bigger	vomit
	arrow	
	shorter	
	circle	

Excerpt 1: Gesticulation and imitation

Excerpt 1 (see also Appendix 1) illustrates how an emergent bilingual, Yasmine, shifted modes to produce an iconic gesture when experiencing a linguistic obstacle. This allowed her to express her idea. The excerpt comes from the forces in motion lesson 2, where Newton's third law of motion is applied to explain how the balloon car worked. The semiotic unit begins as the teacher verbally asks the students to think about the impact that the wheels have on the movement of the car.

Excerpt 1

1. Teacher: First of all, why do we have … Why don't we have a square wheel? (Holds the car in one hand, and turns a wheel with the other)
2. Anna: because it wouldn't
3. Yasmine: It won't (Interlocks fingers moves each hand up and down like a seesaw)
4. Stacey: It won't turn.
5. Anna: It won't roll. (Rotates her hand with a pointed finger around in a circle)
6. Yasmine: Yeah. It won't roll (Imitates Anna's gesticulation)
7. Ajay: It won't roll.

8. Teacher: so, we actually need …
9. Yasmine: a (Moves her hands into a shape as if she was holding an imaginary ball)
10. Anna: circle
11. Teacher: Aha, and then we also need this thing (Runs finger along the axle)

In turn 3, Yasmine responds to the teacher's verbal question using a linguistic representation ('It won't') to design her meaning. However, shortly afterwards she shifts to an iconic gesticulation and demonstrates her meaning instead. In this case we can assume that the teacher's tactile move (turn 1) of a physical object (car or wheel) or oral representation (square) provides the stimulus that provokes internal representations for Yasmine and the others. The production of multiple internal representations afforded Yasmine the ability to shift between them. This meant she was able to communicate her idea, regardless of her inability to express an accurate word in the target language.

In addition, Excerpt 1 shows that Anna's sharing of an everyday word gave Yasmine the opportunity to hear and visualise other representations. Anna (turn 5) simultaneously represents a matching oral and gestural meaning of the concept 'roll'. In this instance, Yasmine reappropriates both Anna's linguistic and gestural representations to confirm her understanding. It is unclear which of Anna's representations supports Yasmine's meaning-making; nevertheless, to confirm her agreement with the meaning she imitates both, synchronously verbally repeating the everyday word 'roll' and imitating the matching gesticulation.

In a similar circumstance moments later (turn 9), she uses another iconic gesticulation to answer the teacher's verbal question. Again, she demonstrates her understanding through gesture, a representation that matches Anna's academic word 'circle'. In both instances, Yasmine demonstrates her meaning through a non-linguistic mode. Given Yasmine's current level of English (ranked lowest in her group), her choice to gesticulate instead of verbalising her answer may imply she did not have the vocabulary necessary to communicate in an oral mode. Regardless of her English ability, Yasmine's mode shifts afforded her the ability to overcome her linguistic obstacle (the everyday word) and express her meaning.

Finally, the teacher's continuation of the discourse in turn 8 and 11 authenticates the emergent bilinguals' suppositions and gestures. Thereby, their mode shifting sustained the flow of science ideas in the collaborative multimodal discourse.

Excerpt 2: Pantomime and re-representation

Excerpt 2 shows an example of an emergent bilingual shifting to pantomime to re-enact her previous experience. It takes place during a biology lesson focused on the digestive system. The discussion focus is on the ability to drink while upside down. Directly prior to the excerpt, Anna and Yasmine discovered that Koko had tried as well. In the excerpt, they ask if she achieved success.

Excerpt 2

1. Anna: Did you drink it?
2. Yasmine: Did you do it?
3. Koko: (Nodding) And then, and then … (pretends to choke; moves head in jerking motion, mouth open, hands crossed at neck; see Figure 5.1).
4. Yasmine: (Smiles, nods) Choke.

In this excerpt, Koko responds by verbally expressing her experience but shifts to pantomime (gesture with bodily movements) to communicate her entire meaning. Here, pantomime affords Koko the ability to demonstrate her experience without using words and allows her to continue her idea unaided. In this context pantomime also benefits Koko's group, as her demonstration provides necessary evidence for the group's science explanation.

Furthermore, the shift presents the other students (and the teacher) with the opportunity to mediate language by re-representing Yasmine's meaning into an oral representation. In this case, Yasmine re-represents Koko's gesture into an oral one. It can be assumed that viewing the pantomime (including the actions and sounds) instigated an inducer-concurrent pairing that allowed Yasmine to internalise a matching oral representation, 'choke', that was communicated. In doing so Yasmine confirmed she understood Koko's pantomime and introduced the group to a new English everyday word. This gave Koko the opportunity to hear and see a linguistic representation of her actions.

This study found a student or teacher frequently re-represented gestures into an oral mode when the designer failed to provide one, or provided an incomplete oral explanation. In fact, during this study the teacher re-represented seven gestures into an oral mode while the students re-represented five. Although the use of pantomime was infrequent during science lessons this study showed it to be of benefit as it enabled students, regardless of their linguistic skills in English, the capacity to communicate and share their personal experiences, as found by other studies with language learners (McCafferty & Rosborough, 2014).

Figure 5.1 Koko pantomimes her experience of choking

Excerpt 3: Tactile moves

Excerpt 3 shows an example of an emergent bilingual making a tactile meaning. This excerpt is from a lesson on forces in motion that asked ‘How does the rocket launcher work?’. In the excerpt Nick is explaining to his group how the rocket launcher works. To do this he uses a (broken) model launcher to add meaning to his verbal representations.

Excerpt 3

1. Nick: OK so when you smash (hits the empty plastic bottle hard; it deflates) this the air comes out
2. Lavender: you don’t smash it
3. Nick: step on it
4. Nick: The air comes in (touches a tube and moves his hand along depicting the direction the air travels)
5. Nick: and if this is there (grips and holds up the disconnected launch tube and rocket and puts them into correct working position)
6. Lavender: no
7. Nick: I mean I mean I mean, if these two thingies (touches the end of each blocked-end tube with each of his hands)
8. Nick: Is like blocking the air from coming out
9. Nick: so this is like the only way [air can go] and this is broken

(moves hands back to hold launch tube which was broken)

Here, Nick shifts to a tactile mode to allow him to overcome his linguistic gaps, such as the unknown names of model parts. He uses oral representations with demonstrative pronouns such as ‘this’, ‘there’ and ‘these thingies’, as well as tactile moves such as running his hand along a tube, to replace the oral representations necessary to describe the air’s movement and direction. Tactile moves afforded Nick the ability to express himself in science.

Excerpt 4: Non-linguistic discourse

Students were found to imitate other students (and teacher’s) gestures. Imitations were usually silent but sometimes led to oral representations. The following excerpts show the ways gestural imitation supported the emergent bilinguals’ communication by generating vocabulary, teaching science vocabulary and representing science vocabulary.

The excerpt seen in Figure 5.2 came from a lesson on forces in motion which explored Newton’s first law of motion, inertia. The data showed how a shared tactile experience from a past science lesson allowed students to recall and re-enact it. Directly before the excerpt the students attempted to decipher what key science vocabulary and concepts related to the phenomenon in this lesson. In this excerpt Stacey introduces a shared experience from a prior science lesson that she believes relates to the science concepts in the phenomenon being discussed. In the prior lesson the students were required to shake the lid of a bottle up and down until the sauce stuck inside the lid came out. The sauce came out as the downward shake of the lid stopped abruptly because the sauce was still in motion. This excerpt begins as Stacey imitates the past event. Yasmine and Koko observe Stacey and appear to recall the experience (demonstrated by facial expressions) and begin to imitate the action through gesture. Although it is unclear if Yasmine imitated Stacy’s gesture or her prior experience, her iconic gesticulation nevertheless led to an oral representation inclusive of academic language for the concepts involved: ‘I think it’s motion and gravity’. It appeared the shared experience facilitated a discourse that advanced the academic language necessary to explain the science phenomenon. As science vocabulary is often also a science concept, deciphering their meanings means emergent bilinguals are simultaneously learning language and science.

Stacey

0:02-0:04

1


2


3


4


5


Yasmine

0:04-0:06

6


7


8


9


10


Koko

0:06- 0:08

12


13


14


15


16


17	Yasmine (0:09) *I think its motion and gravity*

Figure 5.2 Group two students gesticulate and imitate a shared experience.

5.5 Limitations

From the purposeful class sample only ten students agreed to participate. The small and female-dominated sample prevents generalisations. Video recordings were required to examine the participant's mode shifts on a slower time scale, however, one fixed camera for each group meant a fixed view. Speech from students with soft voices sometimes had to be deciphered and actions (gestures and tactile moves) created outside the recorded area could not be seen, although careful furniture arranging made this an infrequent occurrence. Member checking following the interpretations of data was not viable in this study.

5.6 Discussion

In this study, the consideration of language as a semiotic system legitimised the application of the emergent bilinguals' semiotic repertoires during translanguaging in a content-based science class. The exploration of shifts from oral to gestural and tactile modes led to the categorisation of their different purposes. Some of the functions of shifts coincide with classifications of the gesture-speech relationship by researchers (e.g. Colletta et al., 2015; Yen-Liang, 2017). For instance, 'replacement' often served to reinforce or complement a linguistic meaning, while 'demonstration' and 'support' provided integrating, supplementary or complementary information. Sometimes shifts entertained multiple functions so deciphering the context of each shift was vital during the analysis; viewing a semiotic unit as a whole meaning helped to achieve this.

One major conclusion from this study, revealed translanguaging was an appropriate process for achieving the goals of CLIL. Students were able to use and practice the target language in science as they could replace a noun by touching or pointing to an object as well as continue an oral meaning (in the target language) through gesture. These two shifts, replacement and demonstration, respectively, also confirmed the findings of studies that reported gestures acted as bridges that filled linguistic gaps (e.g. Unsal et al., 2018). From a dominant linguistic perspective, it appeared the students drew upon alternate resources to overcome their limitations in the target language. However, as it is necessary to move beyond a linguistic centric view of language, this study considers the possibility that in certain shifts the semiotic potentials of a gestural or tactile move had more semiotic value and purpose than a linguistic representation. For instance, in the shift 'support' the semiotic potentials of gestures enhanced specific spatial details of a meaning. This shift had further implications for meaning making in science and leads to the next conclusion.

Another major conclusion was that translanguaging functioned as a semiotic process for CLIL. The students' seamless integration of their semiotic repertoire with their language repertoire allowed science discourse to flow and consequently led to the learning of science. Students shifted between oral and gestural or tactile modes spontaneously and purposefully, which corresponded with studies in CLIL contexts that reported shifts from the target language to the students' L1 (e.g. Pavón Vázquez & Ramos Ordóñez, 2019). Moreover, gestural and tactile moves provided students with alternate ways to communicate and make meaning of the science content, also comparable to the use of L1. This confirmed the findings of Blair et al. (2018) who suggested when translanguaging, the use of different modes provided multiple pathways to meaning. As gestural and tactile meanings differed from linguistic meanings, they also provided additional details of a meaning via spatial movements and touch. The additional information shows why the integration of modes is essential for science reasoning and sense-making and suggests the integration of students' semiotic and linguistic repertoires while translanguaging during content-based science class may lead to deeper understandings of the content (Lemke, 2000; Williams et al., 2019).

An additional conclusion showed translanguaging functioned as a pedagogical scaffold which harmonised with the findings of Lin and He (2017). Results showed that, in line with Lee, Hampel, & Kukulska-Hulme (2019) gesture during group interactions afforded the students scaffolding opportunities. The more knowledgeable emergent bilinguals (or the teacher) translated meanings from non-linguistic modes to an oral mode thereby enhancing science and language learning (Vygotsky, 1978). Thus, gestural translations promoted knowledge of the vocabulary and content, corresponding to the findings of Ingerpuu-Rümmel (2018). This occurred in a similar manner as described by Unsal et al (2018). First, as group members actively participated, they drew upon their semiotic resources as necessary to complete an idea. Next, another participant translated the gestural or tactile meanings into either an everyday or academic word in the target language. Finally, the associated science discourse continued. This showed, when learning science in CLIL contexts, the use of non-linguistic modes presented similar benefits to the use of the L1 for emergent bilinguals, such as enhanced comprehension of science content (e.g. Gallagher & Colohan, 2017; Pavón Vázquez & Ramos Ordóñez, 2019). As a multiplicity of non-linguistic modes exists, more exploration of their implications in CLIL classroom settings is recommended.

Finally, a noteworthy discovery in this study was that very few emergent bilinguals drew upon alternate linguistic resources (e.g. L1) from their language repertoire when translanguaging. This may have been the result of the language dichotomy between the teacher, who was a monolingual English speaker, and the emergent bilinguals, who were fluent in either Putonghua or Cantonese. Another possibility encompasses the broader school policies. These disseminated traditional views of learning in separate languages and which have led many schools in Hong Kong to enforce an English-only rule in classes such as science (Perez-Milans, 2017). These policies make it conceivable that in this study, the emergent bilinguals did not realise they were allowed to use their L1. Nevertheless, an assumption can be made that the constraint on their linguistic repertoire caused the emergent bilinguals to draw more frequently from their semiotic repertoire, particularly to overcome deficiencies in the target language. This finding makes more sense when we consider that the emergent bilinguals who most frequently employed their semiotic repertoire were also those severely limited by the target language. This assumption is in accordance with other studies that found a lack of proficiency in the target language was a pivotal aspect associated with the use of gestures (Gulberg, 2006) and use (and overuse) of the L1 (e.g. Pavón Vázquez & Ramos Ordóñez, 2019). However, due to the small sample size, more studies that analyse the use of communication repertoires during translanguaging are needed to confirm this inference.

5.7 Conclusion

To expand current understandings of translanguaging, this study drew upon the theory of multiliteracies that conveyed language as a semiotic system. This viewpoint attempted to uncover the semiotic repertoire and expose the gestural and tactile modes used by emergent bilinguals in a content-based science class in Hong Kong. Based on the results obtained, this study can conclude translanguaging afforded the students the ability to participate in science discourse, practice the target language, mediate the target language and make-meaning of science content. Findings from this study also suggest that the use of gestural and tactile modes may have similar benefits to the use of the students' L1. This study provided information currently lacking on the use of the semiotic repertoire during translanguaging in a content-based science class.

On a final note, this study encourages researchers to move beyond a view of translanguaging as separate language entities and instead move towards a view of language as a semiotic system. Bilingual research investigating the classroom use of Translanguaging must encompass methodologies where the analysis can include semiotic units (such as this study) or speech/action events (Lin & He, 2017) or ensembles of meaning (Lin, 2019). It is these conceptions that will ensure the simultaneous examination of linguistic and semiotic repertoires and will provide a more comprehensive understanding of translanguaging in CLIL settings such as science.

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5.9 Appendix

5.9.1 Appendix A

Mode shifts to iconic gesticulations used to express ideas in forces in motion lesson 2

Table 5.A1

1. Teacher: *First of all, why are the wheels round? Why don’t we have a square wheel?*	
2. Anna: *because it wouldn’t*	
3. Yasmine: *it won’t*	 
4. Stacey: *it won’t turn*	

5. Anna: *it won't roll*	
6. Yasmine: *yeah it won't*	
7. Ajay: *it won't roll*	
8. Yasmine: *roll*	
9. Teacher: *OK so we actually need*	
10. Yasmine: *a*	
11. Anna: *circle*	

6

The outcomes of fifth-grade emergent bi/multilinguals' introduction to a visual metalanguage when constructing scientific explanations

Preface

Continuing from the investigations of meaning making in the previous chapters, this chapter adds to our conception of BMLs' multimodal meaning making by focusing on visual meanings. Chapter 6 investigates objective four of this research to explore the outcomes of ten grade-five BMLs use of the visual mode when exposed to visual metalanguage in science. To achieve this, Chapter 6 presents the results of an analysis of semiotic units during the creation of the visual representations.

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6.1 Abstract

The visual mode provides emergent bi/multilinguals an essential resource to construct scientific explanations. Yet, while a metalanguage is used to describe the written mode of scientific language such as, claim, evidence, reason; there is little research that makes students aware of the metalanguage of a visual mode. We propose an introduction to the visual metalanguage will ensure emergent bi/multilinguals better access to the visual mode. This study employs an instrumental case study to examine the introduction of visual metalanguage to a fifth-grade science class. Two cameras record ten emergent bi/multilinguals as they construct scientific explanations in nine lessons. We use a framework informed by social semiotics to analyse the meanings made. The data revealed that an awareness of the visual metalanguage led to an enhanced commitment to illustrate the explanation of the phenomenon, illuminated key concepts and provided more context to the audience. In addition, teacher questioning became more focused.

Key words: emergent bi/multilinguals, learning science, visual mode, visual metalanguage, representations

6.2 Introduction

Creating and interpreting visual representations is considered an essential requirement when constructing explanations in science (National Research Council, 2012, 2013). Using multiple representations, including visual representations, when constructing explanations has been found to develop students' understanding in science (Tippett, 2016; Tytler & Prain, 2010). This includes students lacking the advanced knowledge of the language of instruction necessary to construct verbal explanations or to participate in verbal arguments (Williams, Tang & Won, 2019; Lee, 2005; Ryoo & Bedell, 2017). These students, described here as emergent bi/multilinguals, require support due to the complex language of science. A sophisticated level of knowledge of the language of instruction is necessary to comprehend the content-specific vocabulary and additional grammatical constructions such as nominalization (Fang, 2005; Halliday, 2004; Lemke, 1990). In contrast, meanings made through visual representation require a lower level of knowledge of the language of instruction (Kress & van Leeuwen, 2006). In this study, we argue that visual representations provide emergent bi/multilinguals with an additional resource to construct explanations in science.

Contemporary language theories confirm the capacity for emergent bi/multilinguals to communicate meanings visually when constructing explanations. As suggested by social semiotics, language comprises multiple meaning-making systems known as modes, which also include visual systems (Halliday, 1978; Kress & van Leeuwen, 2006). A mode is defined in this article as a meaning-making system that evolves with the communicative needs of a discourse community. Recent studies have shown that the use of the visual mode in the construction of explanations plays an important role in supporting emergent bi/multilinguals' learning and meaning-making in science (Williams et al., 2019; Ryoo & Bedell, 2017). This finding is consistent with research in multimodality, which has examined how students make scientific meanings by integrating the visual mode with other modes, notably speech and gesture (e.g., Tang et al., 2014; Kress et al., 2014; Yeo & Gilbert, 2017).

With multiple modes in action during meaning-making, different areas of research have come into focus over time, for example, the use of multiple representations in science, which may include the visual mode (Ainsworth, 2008; Gilbert & Treagust, 2009; Kozma, 2003). Other areas of research have investigated how a learner's knowledge develops using more than one representation, for example, representational competence, which includes the knowledge of the form and function of representations in different modes (diSessa, 2004; Kozma & Russell, 2005). This knowledge is also considered in the construction of representations, such as drawing scientific explanations (Prain & Tytler, 2012). As Waldrip et al. (2010) specified, "learning about new concepts cannot be separated from learning both how to represent these concepts as well as what these representations signify in the world" (p. 68). Other research areas that include the visual mode are Gilbert's (2007, 2008) investigations of external representations and Lemke's (1998) explorations of visual communication in scientific language.

Despite our increasing understanding of the visual mode, few educators have explicitly taught emergent bi/multilinguals how to utilize the visual mode as an additional resource to construct scientific explanations. Yet studies on visual representations in science have shown promising results for students constructing scientific explanations. Sandoval et al. (2000) noted that students were able to explain complex ideas more intelligently if they had the support of visual representations than if they did not. Furthermore, the visual representations created by students, even inaccurate ones, helped illuminate students' understanding. In other research, the process students used to depict visual representations was found to help deepen their scientific understanding (Ainsworth & VanLabeke, 2004; Gilbert & Treagust, 2009; Tippett, 2016). From these encouraging results in the use of visual representations in science, it seems reasonable to suggest that the visual mode has potential for emergent bi/multilinguals. Thus, a visual metalanguage presents a currently unexplored potential resource for emergent bi/multilinguals.

To investigate the visual mode as a potential resource for emergent bi/multilinguals, this study aims to raise students' awareness of the form, function, and constraints of the visual mode, a need that has been reported in previous research (e.g., Ainsworth, 2006; Prain & Tytler, 2012). An awareness of representations in the visual mode requires an awareness of a visual metalanguage, which is defined in this study as a "language for talking about language, images, texts and meaning-making interactions" (New London Group, 2000, p. 24). A metalanguage makes explicit the terminology used to describe any symbolic system (Ellis, 2004). The potential of teaching and using a metalanguage can be seen in second-language acquisition and literacy education (e.g., Basturkmen et al., 2002; Hu, 2010) and in science education focusing on literacy (e.g., Tang & Rappa, 2010). While few studies to date have investigated the impact of metalanguage on emergent bi/multilinguals in science, beneficial outcomes have been found, such as making emergent bi/multilinguals' needs explicit, ensuring meaningful interaction, and enabling a sense of accomplishment (Borg, 1998). Consequently, exposing emergent bi/multilinguals to a metalanguage of visual elements appears warranted. Therefore, we ask the question: "How does an explicit understanding of the visual mode through a metalanguage help emergent bi/multilinguals in science?"

This research endeavor may be of significance as emergent bi/multilinguals are one of the fastest-growing school populations today (Tereshchenko & Archer, 2014). In the United States it has been predicted that by 2030, 40% of school students will be learning English as an additional language (Thomas & Collier, 1997). In Hong Kong, most local schools use English instruction in science due to social and economic influences (Perez-Milans, 2017). These influences also attract local citizens to seek independent schools with English instruction. This study takes place in an independent bilingual school in Hong Kong and is founded on the notion that the visual mode presents communication opportunities to emergent bi/multilinguals in science. As a result, we surmise that supplementary knowledge of a visual mode will broaden the students' range and capacity for representing scientific meanings when constructing visual representations. To achieve our aim, this study adopts a visual metalanguage created by Tang, Won and Treagust (2019) that embraces the visual mode conceptualized by Kress and van Leeuwen (2006). The metalanguage was introduced to the teacher and then to her fifth-grade science class via a student checklist. Over a 9-month period, we investigated the teacher's and 10 emergent bi/multilingual students' use of the visual metalanguage as they constructed visual representations that sought to explain an unknown phenomenon.

6.2.1 Overview of learning when constructing visual representations

According to Vygotsky (1978), constructing visual representations is an active experiential process involving language and mediation. We explore the essential connection between language and learning through social semiotics, as exemplified in sociocultural learning theory. From this perspective, language is seen as a semiotic system (Halliday, 1978; Kress & van Leeuwen, 2006). Apart from oral language, multiple semiotic systems include "algebraic symbol systems, works of art, writing, schemes, diagrams, maps, and mechanical drawings, all sorts of conventional signs and so on" (Vygotsky, 1981, p. 137). However, regardless of the type of semiotic system, meanings are made with the purpose of communicating that meaning: A producer (seen as a social agent) creates signs that a reproducer interprets (Kress, 2010; Kress & van Leeuwen, 2006). The participants involved in the meaning-making process internalize the signs; signs provide the medium for thoughts to occur, revealing the integral link between language and learning (Vygotsky, 1978). As signs are created for a social purpose, it seems reasonable that learning necessitates a social experience to provide a context and means for language (Vygotsky, 1978).

As diagrams are a form of language, constructing visual representations collaboratively in science is one of the essential ways that emergent bi/multilinguals learn science effectively. However, to comprehend how emergent bi/multilinguals communicate in a visual mode, we must first understand how they use language to communicate. The theory of translanguaging offers an explanation that posits signs that evolve in social and cultural contexts and accumulate to form part of an emergent bi/multilingual's communicative repertoire. In addition to other signs from non-linguistic modes such as audio, gesture, and tactile, visual signs are said to form part of emergent bi/multilinguals' semiotic repertoire (García & Li, 2014). Emergent bi/multilinguals draw upon and construct signs as they communicate. In other words, to make meaning, emergent bi/multilinguals create and combine signs from verbal systems (from different national languages or dialects) and non-verbal systems. This corresponds to a social semiotic notion that all meanings are multimodal (Kress, 2010).

During the process of construction, the visual representation becomes a tool of semiotic mediation in two distinct ways. First, constructing a scientific explanation through a visual representation can expose unseen mechanisms, components, and concepts that allow students to unearth and organize complex ideas (Coll et al., 2005); uncover relationships between components (Schwarz et al., 2009); and allow ideas to become visible (Forbes et al., 2015). Furthermore, materiality means visual representations are autonomous and transferable, which makes it possible for them to mediate between reality and theory (Knuuttila, 2005; Morgan & Morrison, 1999). When a visual representation takes the form of an explanatory tool, it is likely to include a combination of practical, representative, and theoretical meanings (Ainsworth, 2006; Maschietto, & Bartolini Bussi, 2009). This can be further understood by considering the meaning-making functions of all representations. In social semiotics, there are three major meaning-making functions or metafunctions (Halliday, 1978): presentational—how ideas are deployed in relation to the world, orientational—what motivates a viewpoint or interaction, and organizational—the connections between the design of elements in the larger representation (Lemke, 1998).

Second, constructing representations collaboratively mediates meaning as it enables more knowledgeable others to confront previously held assumptions of their peers. For example, Bracey (2017) found that during the constructing of visual representations, English learners drew support from their communicative repertoires as well as each other as they argued. This action facilitated their sense-making of galaxy collisions, which is a complex abstract concept. Students scaffolded ideas by building from one another until a more comprehensive understanding was produced

(Bracey, 2017). Constructing representations therefore has the potential to facilitate language learners' higher order mental functioning as they challenge each other's ideas with their own language (Brooks, 2009). This enhances a student's explanation by giving rise to new knowledge while generating further questions (e.g., Williams et al., 2019). Thus, the purposeful act of explaining a scientific phenomenon by constructing representations means semiotic processes are at work that cause students to build and revise scientific knowledge.

In this study we adopt the position that constructing visual representations is a fundamental part of the semiotic processes in science and that, in addition to being transferable entities, they present communication avenues for emergent bi/multilinguals.

6.2.2 A metalanguage for describing visual elements in diagram

Constructing visual representations is not only an integral part of science, it is also a discipline-specific skill that students need to successfully participate in science (Tang & Moje, 2010). As such, drawing scientific representations is not an innate skill that children already possess; it is a literacy skill that must be acquired or developed through their formal education, much like reading and writing. For instance, there are many conventional and symbolic ways of meaning-making in scientific diagrams that are not obvious to most people. Some students could discern the "visual language" on their own, but most children do not unless they are guided by a teacher or an expert (Lemke, 2000).

To teach and learn the conventions of interpreting and creating visual representations, teachers and students need a shared metalanguage to explicitly talk about the form and function of the visual mode. A metalanguage is defined as a set of terminologies for describing language use and functions (Basturkmen et al., 2002). For example, to learn the English language, a metalanguage that includes terms such as *verb*, *noun*, and *clause* is often used by language teachers and specialists to teach the grammatical conventions of English. Metalanguage is not confined to describing verbal language. The New London Group (1996) expanded the concept of metalanguage to include language for talking about images and all meaning-making interactions.

In science education, Tang, Won and Treagust (2019) developed a metalanguage for describing scientific images based on Kress and van Leeuwen's (2006) initial work on visual grammar. This metalanguage was originally developed for researchers and analysts to describe and categorize a range of ideas represented in students' scientific drawings. The theoretical basis of this metalanguage is derived from social semiotics, which suggests that meanings are made by creating and putting together signs in each mode in meaningful relationships.

In social semiotics, researchers often examine how various "symbolic units" from a mode are integrated to form meanings. In a verbal-linguistic mode, the symbolic units are comprised of words that are combined in various ways to form a unit of meaning according to what Lemke (1990) called a semantic relationship. For instance, saying "friction is a type of force" and "an example of a force is friction" are similar ways of putting different words together to make the same semantic relationship of hyponym (classification). In a visual mode, the symbolic units are visual signs comprising dots, lines, curves, and basic geometrical shapes. In the same way that we can analyze verbal language through the choice and combination of words into sentences, we can analyze diagrams by examining how these visual signs are selected and joined into the larger diagram. For instance, a smaller circle inside a larger circle can denote a "type of" relationship similar to a hyponym. We call this arrangement of the signs the "visual elements" of the diagram.

The metalanguage used in Tang, Won and Treagust' (2019) study comprised a description of several visual elements that can be made with drawings that were grouped into seven categories: association, spatial, movement, perspective, modality, connective, and textual contextualization. For instance, *association* is the term to describe the visual elements of joining objects to one another through the drawing of lines or proximity. Objects that are visually joined often signify some kind of physical connection, whereas an object drawn within a larger object can signify some kind of inclusion relationship, either as a composite relationship (e.g., an atom *inside* an enclosing space) or a set-subset relationship, as with a Venn diagram. Examples of visual elements from the other categories can be seen in the results section.

In this study, we modified the metalanguage by Tang, Won and Treagust (2019) and transformed it into a pedagogical tool for teachers and emergent bi/multilinguals to make explicit the visual elements in an elementary science classroom. First, some of the terminologies were renamed or simplified to make it easier for elementary school students to use. For example, *association* became *relationship*, and *modality* became *believability* as this was a measure of how closely it resembled reality for the viewer. Second, the metalanguage was introduced to the students in the form of a checklist, as shown in Figure 6.1. Every item in the checklist focuses on one aspect of the visual elements (i.e., relationship, spatial, movement, perspective, believability, connection, and text, as presented in the first column) and poses guiding questions (the second column), with a corresponding selection of answers (third column) illuminating the representational options. This enables the students to tick the elements used and circle the details applied in their representation (as shown in Figure 6.1). The guiding questions, representational options, and checklist are the instructional methods of how we make explicit the visual elements to the emergent bi/multilinguals during their construction of visual explanations.

Relationship	Are your images connected?	○ Not, connected, joined to each other, intersecting
	Do your images have other images inside them? Are they filled with images or just have some of them	○ Yes / No ○ Filled completely, some of it is filled
Spatial	What position is your drawing	○ Top-bottom, or left-right, other
	What direction are your drawings?	○ parallel, angled, or 90 degree angle
Proximity	Are your drawings close to each other or far away?	○ Close, or Far away Spread out
	Did you draw in a pattern?	○ Pattern or No pattern
	Was there is difference in size?	○ Size difference, or No difference
	What scale did you use?	○ Not real, real, drawn with measurements
Movement	How did you show movement? Heat is movement vibración	○ Arrow, dotted line, wavy lines, no movement
Perspective	What dimension did you use?	○ 1D, 2D, 3D
	From what angle?	○ Bird's eye view, side, projected
	What view?	○ Real life, under microscope, symbol
Believability	How real is your drawing?	○ Cartoon, realistic, symbolic
	Is your drawing simple or not?	○ Sharp lines or shading
Connection	Is there a sequence? How did you show it	○ Numbers, arrows, side by side, comparison
Text	Did you use labels? Did you use captions?	○ Inside the image, beside the image, connected with a line ○ Yes / No

Figure 6.1 The checklist of visual elements used by the teacher when planning the matter lesson

6.3 Method

6.3.1 Research Design and Research Question

This paper uses an instrumental case study (Stake, 2000) to examine how a teacher and 10 emergent bi/multilinguals responded to knowledge of the visual elements by using the introduced metalanguage in three science topics. The purpose of this case study was not to make decontextualized claims about the use of visual representations for constructing explanations; instead, it aims to reveal insights into the affordance of a visual system and its metalanguage in supporting science learning for a group of emergent bi/multilinguals. With this purpose in mind, the research question that guided the investigation was:

1. What are the outcomes of introducing the visual metalanguage for:

(a) students to construct explanations and

(b) teacher to influence students' construction of visual representations?

6.3.2 Research Context

The study was conducted at an independent school in an affluent area of Hong Kong. The bilingual model at the site was unlike government schools and was considered partial immersion (Lin & Man, 2009). This meant that the percentage of English delivery compared to Putonghua (standard Mandarin) increased each year through different subject areas, from 30% in the early years to 50% in the fourth and fifth grades. As a result, science was not taught in English until third grade. The eclectic school science program encompassed curricula from Taiwan and Hong Kong and had recently integrated parts of the Next Generation Science Standards (National Research Council, 2013) from the U.S.

Convenience sampling was used to select appropriate participants for the research, which meant the participants came from the first author's fifth-grade science class, which was delivered in English. As a result, the teacher-researcher, as a participant observer, could clarify meanings as they occurred in context, consistent with an instrumental case study (Stake, 2000). This enhanced the credibility and trustworthiness of the study, as the teacher-researcher managed elementary science in the English department at the school. She had revised the science curriculum, conducted previous research in her department, and developed science learning experiences. She also knew and had taught the participants prior to the research. She was 36, monolingual, and an expatriate of Anglo-Saxon descent. In contrast, the 10 student participants came from families with Chinese heritage and spoke varying degrees of English. Nine of the student participants had listed Chinese as their first language but did not specify between Putonghua or Cantonese, the local Hong Kong dialect. Some participants knew both. Due to the unspecified language backgrounds of the student participants, they were separated randomly into two groups for the entirety of the study.

Altogether, nine science lessons (listed in Table 1) were adapted from the Thinking Frames Approach (Newberry & Gilbert, 2016), which included explanatory drawing and provided an opportunity for visual communication. This approach was considered multimodal as each of the three phases of the lesson demanded the use of a different dominant mode (Figure 6.2). The nine lessons were divided into three units: human body, forces in motion, and matter. Each unit was covered in one academic term. In the lessons, the student groups created representations to explain several puzzling phenomena demonstrated in the classroom. For each lesson, the student groups were required to construct a verbal, visual, and written explanation to answer a *how* or *why* question (see Table 6.1). Thus, prior to the visual explanation, the students collaboratively deciphered the science concepts involved in the phenomenon and verbally constructed an explanation to answer the question. In the visual explanation, the students represented their explanation in the visual mode.

Table 6.1 The science focus and the question requiring an explanation for each lesson

Unit	Lesson	Science lesson focus	Question requiring an explanation
(1) Human Body	1	Respiratory system	How do our lungs work?
	2	Circulatory system	Why are cells so small?
	3	Digestive system	Why can we eat upside down?
(2) Forces in Motion	4	Newton's first law of motion	Why do the coins stay on the bottle?
	5	Newton's third law of motion	How does the balloon car work?
	6	Newton's second law of motion	How does the rocket launcher work?
(3) Matter	7	Kinetic model of matter	How does the scent travel?
	8	Physical change: mixtures and solutions	Why does sugar dissolve but sand does not?
	9	Physical change: melting ice	Why does the ice cube melt quicker on the ceramic tile?

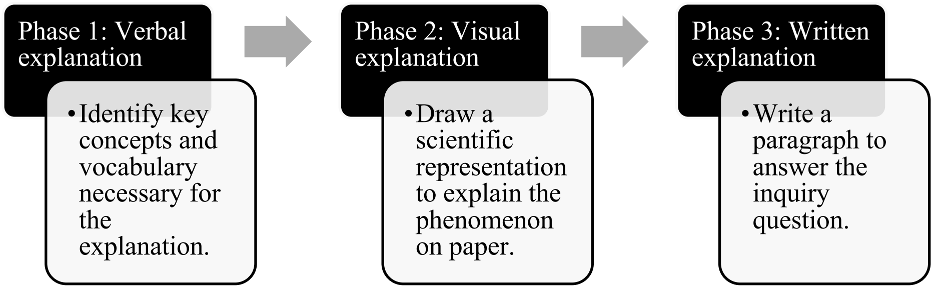


Figure 6.2 The multimodal approach used in the science lessons

In this paper we limit our focus to the construction of the artifact produced for the visual explanation in each lesson. The students were provided with an A4 template for individual explanations and an A3 template for collaborative explanations. During the inquiry lessons, the objective was to draw an explanation of the phenomenon to address the inquiry question (see Table 6.1). If the students expressed their explanation in other modes, they were redirected by the teacher to represent their meanings visually. As the students drew their response, the teacher questioned the students to help them consider their ideas.

In the first two units, the teacher had access to the visual metalanguage and used it to plan her lessons. In the final unit, the students had access to the metalanguage via the checklist of visual elements constructed for this study. The checklist was introduced to the students in an additional science lesson (prior to the final unit) in three parts. In Part 1: Learning about drawing affordances, the teacher drew two perspectives of a familiar object on the board, one was regularly used by the students, whereas the other was rarely used at all. She asked the students why they used a top-down view to explain how the balloon car works. Next, she added a projected view to show how to magnify areas of the car. In Part 2: Identifying drawing affordances, the students became familiar with the visual elements by using the checklist to review their own representations from previous lessons. Their self-assessment led to discourse about the best way to explain the concepts and the phenomenon in each representation. In Part 3: Drawing with affordances in mind, the teacher led a new experiment that provided the students with an opportunity to use the checklist to construct a visual explanation. Following this lesson, the students had access to the checklist in all their science lessons.

6.3.3 Data Collection Methods

The data in this case study are from a 9-month study aimed at supporting emergent bi/multilinguals in science. In this paper we draw on several sources, including artifacts such as annotated checklists, the students' visual and written representations of their explanations, lesson plans, interviews, and video recordings. Multiple data sources are necessary for three reasons. First, as we assume that all meanings are of value and add to the visual representations (Kress, 2010), to capture the variety of signs made during the process of constructing the visual representations, data have to be collected from multiple viewpoints. For instance, video recordings capture tactile and gestural signs, including movement. As a result, two cameras were used, one focused on each student group. Second, multiple data sources provide a thorough convergence of evidence with which to explore the aims of the study and arrive at an in-depth conception of the phenomenon. Finally, multiple data sources provide an opportunity for multiple outcomes to become clear.

In response to the research question, we first constructed a multimodal transcript of the recordings of each lesson and obtained the times when each student group constructed the visual representations. If the teacher revealed the visual elements or information relating to the visual elements to the students in the semiotic units, we reviewed this to see if the teacher's meaning had been translated into the student's verbal or visual explanation. In the first two science units, the analysis focused on how the teacher influenced each group's construction of the visual representations. In the final science unit, as the students were now exposed to the visual metalanguage, our analysis broadened to include the multiple meanings (verbal and visual) leading to each group's explanation of the phenomenon in each lesson.

To determine if the elements in the visual framework influenced the students' representations, we followed the process shown in Figure 6.3. First, we elicited an accurate written explanation of each phenomenon and used Lemke's (1990) thematic analysis to examine the semantic relationships of the explanation. The verbal meanings established from the semantic relationships were translated into visual meanings to establish which visual elements would be considered essential in providing an explanation of each phenomenon. For example, an explanation of "Why we can eat upside down" in Lesson 3 must include the process of peristalsis, that is, the contraction and relaxation of muscles in the esophagus to send food to the stomach. The semantic relationships would consist of several transitivity processes (e.g., muscles *contract*, food is *swallowed*) joined in a temporal sequence through conjunctions (e.g., first, then). To translate these relationships into visual meanings in a drawing, it is necessary to choose equivalent visual elements that establish the same pattern. Therefore, this visual explanation must show the movement of muscles and food through the visual element of *movement* represented by arrows, lines, or labels as well as the transition of time through the visual element of *connection* via visual sequences. Together, the verbal explanation and translated visual elements became the aim of the students' explanations in each lesson.

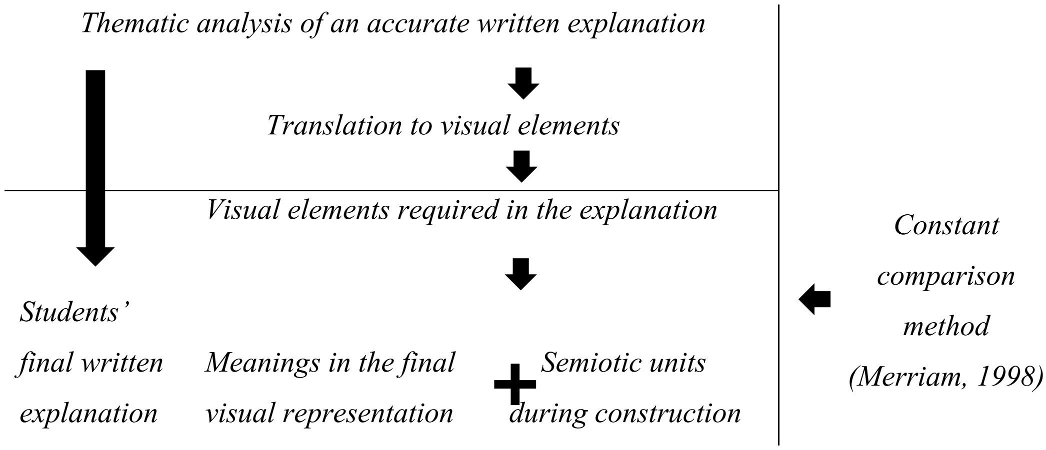


Figure 6.3 Framework for Analysis

Next, we analyzed the video recordings and students' representations to inspect the meanings made by the students during the construction of visual representations. Here, we created *multimodal transcriptions* (Bezemer & Mavers, 2011) and used a fine-grained analysis to examine the multimodal combination of signs, known as semiotic units (Tang et al., 2014; Williams et al., 2019), created during the construction process. Examples of the multimodal transcription can be seen in the Results section. Similar to the process described earlier, we analyzed the verbal discourse using Lemke's (1990) thematic analysis and the visual elements using Tang, Won and Treagust' (2019) visual framework.

Following the analysis of each group's visual representation, the visual elements were identified and counted. Two analysts were involved in the counting process, and the Cohen's kappa coefficient of the interrater reliability was 0.758. This data allowed comparisons to be made: first, by considering the visual elements chosen by the different groups in their explanations of the same phenomenon; second, by comparing each group's application of visual elements with the visual elements perceived necessary for each explanation, allowing a measure of accuracy for each group's visual explanation; and, finally, by reflecting on the number of times a particular visual element was perceived necessary and the number of times it was chosen by the different groups in their explanations. Making comparisons enabled variations to be found, which directed the investigation and inspection of the subsequent results. Discrepancies and equivalences warranted a more detailed examination and ensured more descriptive information was unveiled.

Throughout the entire process, the analysis remained trustworthy by using multiple methods (Guba & Lincoln, 1989). First, the analysis was conducted in a timely manner. Second, the researchers critically reviewed the interpretations of others. For example, if an interpretation of the transcript was in question, the raw video material was viewed and for any disagreements about interpretation(which were rare), the data in question were not included. Third, the implementation of three lessons in three science units ensured triangulation of the data, certifying the results were credible. Finally, the teacher-researcher had prior knowledge of the participants, which offered an insider's perspective and also meant they were able to clarify the intended meanings in context during the lesson. The following presents a discussion of the findings that address the research question.

6.4 Interpretations of Results

6.4.1 The Students' Construction of Visual Representations

This section presents the quantitative data, which show the number of visual elements highlighted by each group in their visual representations for each lesson, followed by descriptions of the semiotic units and visual representations produced in two lessons. In the discussion, the results are summarized to address each part of the research question directly. The data chosen are representative of the visual representations and semiotic units found in each group for each science unit. Episode 1 is taken from the forces in motion unit, which preceded the teaching of the visual elements, whereas Episode 2 presents the findings from the matter unit, which followed the implementation of the checklist. Episodes 3 and 4 depict the teacher's influence and, as such, revisit each of the lessons shown in Episodes 1 and 2, respectively. In the episodes, the letter "T" represents the teacher and an ellipsis (…) represents truncated transcription.

To ascertain the outcomes of the visual metalanguage for the students, it was necessary to inspect the students' use of the visual mode before their exposure. Table 2 shows the number of visual elements found in the students' visual representations and compares this with the number of visual elements believed necessary for an accurate and complete (visual) explanation of the phenomenon in each lesson. If the student groups were unable to include all the necessary visual elements, their visual explanation of the phenomenon was considered incomplete or inaccurate. An inaccurate explanation was associated with either inexperience in drawing or a misunderstanding of the science. Thus, at this point in the lesson, the ability of the students to show the visual elements became a measure of the effectiveness of their visual explanation. The drawing required the application of the students' ideas through visual elements. However, as the visual elements were still new to the students, they were free to explore the use of them. Throughout the process, the students remained unaware and uninformed of the set of elements necessary for the explanations of each phenomenon. At this point in the lesson the teacher was mainly focused on students' visually demonstrating their understanding.

Table 6.2 The number of essential visual elements required in each representation to accurately explain the phenomenon and the number found to be present in each group's representations

		Visual elements	
	Required	**Group 1**	**Group 2**
Human Body			
Lesson 1: Lungs	10	5	5
Lesson 2: Cells	7	7	4
Lesson 3: Digestion	6	3	2
Total	23	15	11
Forces In Motion			
Lesson 4: Bill	6	6	6
Lesson 5: Car	9	5	5
Lesson 6: Rocket	8	7	8
Total	21	18	19
Matter			
Lesson 7: Salt	6	5	5
Lesson 8: Scent	7	5	5
Lesson 9: Ice	6	3	5
Total	19	13	15

The results showed that the emergent bi/multilingual students communicated science meanings through visual representations before and after the visual metalanguage was introduced. Table 2 illustrates that prior to introducing the students to the checklist, they used a range of visual elements to explain the unknown phenomenon. For example, the data showed that three visual representations produced an accurate explanation of the phenomenon in human body Lesson 2, where Group 1 had all the necessary elements; forces in motion Lesson 4, where both groups were accurate; and forces in motion Lesson 6, where Group 2 included all the necessary visual meanings. It is noteworthy that these explanations were created prior to the introduction of the metalanguage to raise students' awareness of the visual elements. Thus, the data show that unbeknownst to the students, they were already applying the visual elements in their diagrams to some extent. Nonetheless, the data also show inaccuracies did occur in the majority of the lessons. On inspection we see the largest number of inaccuracies (i.e., the highest number of missing elements) occurred in explanations for the human body unit. In the other two units, most of the explanations were missing only one or two necessary visual meanings. We reveal the types of common inaccuracies and specific missing visual meanings in Table 3.

The results also show that each group included the entire repertoire of visual elements in their representations throughout the entire study. This indicates that the students were able to make meaning using all the elements from the visual mode. This is shown in Table 3, which compares the total number of visual elements required in the explanations of the phenomenon for all lessons with the total number of visual elements used in each group's representations for the entire time. (A more detailed analysis of each group's accuracy for a specific visual representation can be seen in Table 4.) Presentational meaning, specifically association, was the most frequently required visual element in the explanations. This is likely because associations portray the relationship and connections between lines and images and, as such, depict subject matter. For example, the lungs must be inside the chest cavity. However, this visual element appeared to be missing in several of the visual representations from each group.

Table 6.3 The total number of visual elements required for all lessons compared to the total number of visual elements applied in visual representations by each group for all lessons

	Required	Group 1	Group 2

Presentational			
Association	12	5	7
Spatial	10	8	6
Movement	9	8	5
Orientational			
Perspective	7	6	6
Modality	9	8	8
Organizational			
Connective	5	3	5

Further details of how the visual elements were used by students in their visual representations will be explored in the subsequent sections.

6.4.1.1 Episode 1

The first episode is taken from the Forces in Motion unit. It illustrates that the visual mode provided the emergent bi/multilinguals a way to represent details regarding their explanation that they were unable to represent in the written mode, even before the metalanguage was introduced. We infer reasons for why certain visual meanings were unable to be, or were inaccurately, translated into a written mode. For this lesson, the students were asked to explain how the balloon car works. The visual elements necessary for a good explanation of how the balloon car works, as well as whether each group's drawing showed those visual elements, are listed in Table 4.

Table 6.4 Analysis of elements used in Group 1 and 2's explanation of how the balloon car works

Category of Meanings	**Visual Elements**	**Use of Visual Elements (Y/N)**	
		Group 1	**Group 2**
Presentational			
Association	All parts connected	Y	Y
Spatial	Particles randomly space out outside balloon (distribution)	N	N
	Particles close inside balloon	N	N
	and inside straw (proximity)	Y	Y
Movement	Two arrows showing car and particles moving in opposite direction	Y	Y
Orientational			
Perspective	Side-view of car	N	N

	Real-life and microscopic	Y	Y
Modality	Schematic	Y	Y
Organizational			
Connective	Sequence of events	N	N
Number of visual elements	9	5	5

In this episode, we surmise that the spatial element (unique to the visual mode) afforded the students a way to explain science meanings. As the data show, the students presented details of an explanation visually that many did not describe in their writing. For instance, both groups applied multiple presentational and orientational meanings that made clear their assumptions of the position and movement of air particles inside the balloon and the straw. One of the meanings employed by both groups in their visual representations was spatial elements. On closer inspection, we noticed the use of proximity and distribution (sub-categories of the spatial element) to visually describe the movement of air particles. For instance, the small green circles (particles) inside Group 1's balloon and the different sized circles in Group 2's balloon are spaced apart in a random distribution, except at the balloon opening. The particles at the opening form a pattern with two solid rows of touching circles. The contrast in particle distribution within the balloon demonstrates a misconception held by the students, as all particles should be positioned closely together. However, the notable variation in distribution and proximity of the air particles implies that the students knew a change in density is necessary for the explanation of how a balloon car moves. Their assumption is accurate, as the difference in the density of the particles inside and outside the balloon was necessary to show a change in pressure. The students' ability to share their meanings visually exposed both their misconception and a potential relationship in their visual representations (see Figure 6.4) that most were unable to depict in their written explanations (as shown in Figure 6.5).

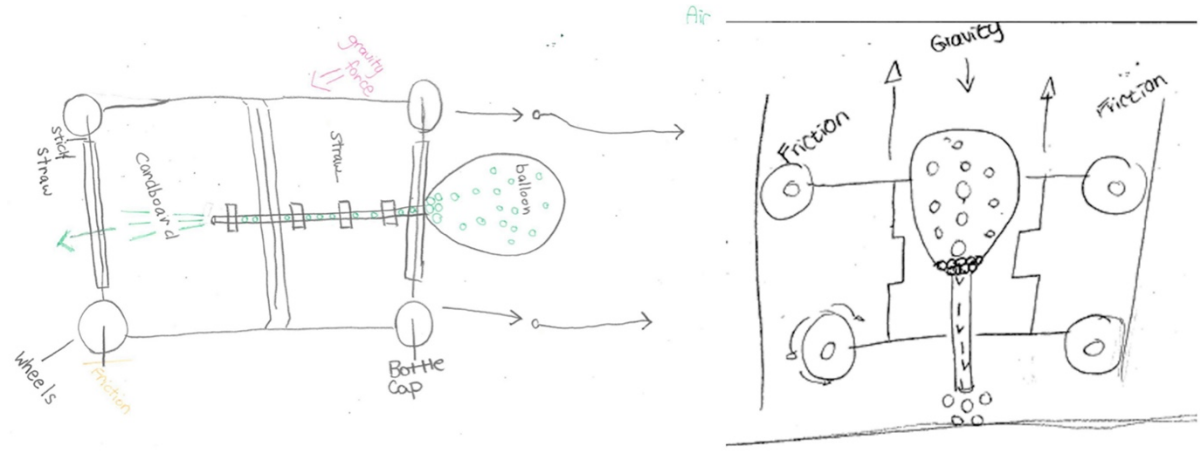
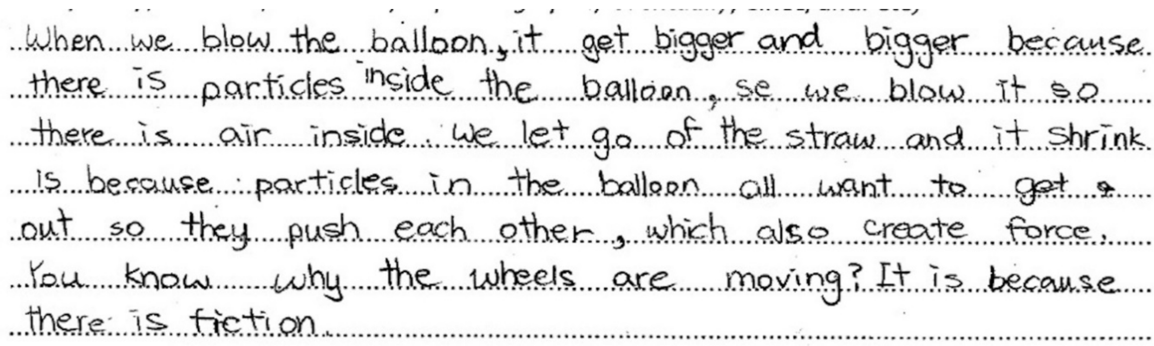


Figure 6.4 Group 1 and 2’s visual representations of a balloon car at work

In another example, we noticed the visual depiction of movement, which is an important presentational meaning necessary for this explanation. Both groups depicted the directional movements using arrows to accurately identify the contrast in the directions of the air from the balloon and of the car. However, this visual depiction is juxtaposed with the students’ written explanations. For instance, seven students did not mention the contrasting direction of the car movement. Of the three students who verbalized the movement, two wrote that the car moved in the “opposite way,” and only one described it as the “opposite direction.” However, the most common description provided was “move forwards,” which was not entirely correct. Nor is the reference of movement comprehensive enough to determine whether the students understood that the action, the push of the denser air molecules out of the balloon in one direction, is responsible for the reaction, the push of the car in the opposite direction. In addition, several students did not mention the car’s movement at all, as demonstrated in Figure 6.5. Instead, this explanation described merely the force created by the release of air in the balloon. The visual mode provided more information than the written mode regarding the students’ explanation. For this reason, we infer that the visual mode appeared a more appropriate way for students to explain this phenomenon.



When we blow the balloon, it get bigger and bigger because there is particles inside the balloon, se we blow it so there is air inside. We let go of the straw and it shrink is because particles in the balloon all want to get out so they push each other, which also create force. You know why the wheels are moving? It is because there is fiction.

Figure 6.5. Group 2 student's written explanation for how the balloon car works

The data also show that not all necessary aspects of each explanation were depicted in the students' representations (see Table 4). For example, an orientational meaning necessary for an accurate visual explanation of how a balloon car moves is a side-view perspective. Yet both groups chose to represent the phenomenon with a top-view perspective. This choice of perspective limited the students representations of the movement of the wheels and the surface friction. Thus, while Group 2 attempted to add vertical lines on each side of the car to depict a wheel turning (with arrows), this mix of top- and side-view depictions is quite confusing and inaccurate. Furthermore, a top-view perspective limited the accurate depiction of the force of gravity, as the arrow appears to point in an inaccurate direction due to the position of the car (Figure 6.4).

Another example is the visual elements in the *connective* category, which is a type of organizational meaning. A good explanation of how a balloon car works should describe or show a temporal sequence of events: from the buildup of pressure due to the air particles inside the balloon to the release of the particles resulting in the car moving forward. To show such a temporal sequence visually, a balloon car at some time in the future can be drawn side by side (typically on the right) with the car in the present time to depict the passage of time (Tang, Won and Treagust, 2019). This application of a connective visual element was not observed in Episode 1.

6.4.1.2 Episode 2

Episode 2 is from the matter unit, which followed the students' exposure to the visual metalanguage and includes data from Group 1. The key idea of this lesson was why ice melts faster on a ceramic tile than on foam. In this lesson, the students first created individual representations before combining their ideas to produce a group explanation.

It appeared that an awareness of the visual metalanguage provided the students with a way to demonstrate a key concept in their visual explanations. An analysis of the students' individual representations showed a commonality in how microscopic aspects were represented. For example, all students in Group 1 (Figures 6.6–6.8) depicted microscopic images of each material using a projected view. As the students had not regularly used this element in their previous explanations, we inferred that this technique was borrowed from the teacher's illustration when she introduced the visual metalanguage. As such, this demonstrated that the students' awareness of the element was accurately applied. Moreover, the students' application of a projected view provided the necessary contrast between the two materials. As a result, a crucial aspect of the explanation was highlighted: the difference between the spacing (or density) of particles in each material. Jane even made use of this comparison to show the passing of time and the melting of the ice by drawing before and after diagrams (see Figure 6.6, representation on the left), another visual element on temporal connectivity not seen in previous lessons. Thus, the visual metalanguage had an impact on how the students represented the meanings visually.

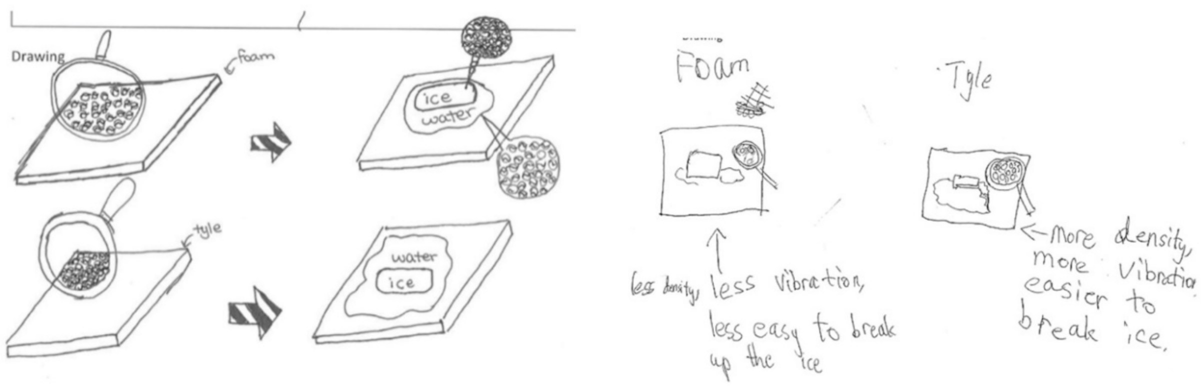


Figure 6.6 Jane's and Julia's representations, left and right, respectively, explaining

why ice melts quicker on a tile than on foam

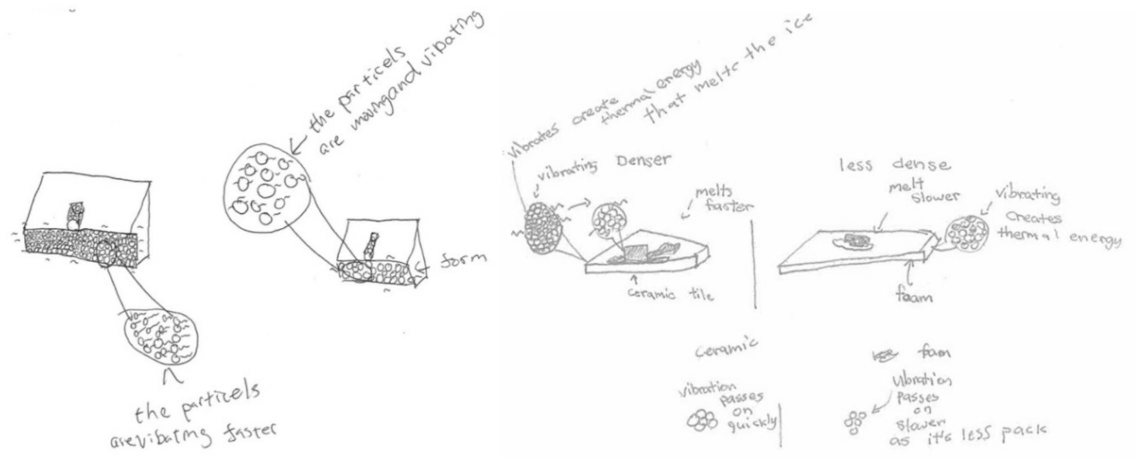


Figure 6.7 Nick’s and Josie’s representations, left and right, respectively, explaining why ice melts quicker on a tile than on foam

Figure 6.8 Nicola’s representation explaining why ice melts quicker on a tile than on foam

To further understand how the visual metalanguage shaped the students’ visual representations, we examined their group discourse as they discussed how to draw. At the start of their group drawing, Group 1 were sitting in a circle and were almost at the completion of their collaborative representation. They were discussing the vibration of particles. The excerpt presented in Table 5 details a conversation between the emergent bi/multilingual students in Group 1, with the “action” presented in the right image in Figure 6.9.

Table 6.5 Conversation excerpts between emergent bi/multilingual students in Group 1 during the Matter unit

Line	Name	Speech	Action

1	Julia	Don't we have to say it vibrates.	
2	Josie	Yeah, we can draw the vibration.	
3	Jane	Just use that one to draw this one's vibration.	*Points.*(left image Figure 6.9)
4	Nicola	Why don't you just write vibrate there?	*Writes "vibrates less".*
5	Jane	 Can you give me another color?	*About to draw and stops.* *Nick gives dark blue.*
6	Julia, Josie, Jane		*Draw squiggles to show particles vibrating.* *Nick offers a red pen.*
7	Josie	We have to tell people that the vibration is creating thermal energy.	
8	Nicola	Then draw like squiggly lines coming out.	*Waves her hand.*
9	Nick	There is.	
10	Josie		*Begins to write "thermal energy" on the close up.*
11	Nicola	No. From the actual thing (tile).	*Points to tile.*
12	Josie	Oh.	*Writes "thermal energy" next to tile and draws waves coming off tile.*
13	…		
14	Josie	No! We have to tell them that the more packed they are the more…	
15	Nick	The more steamier.	
16	Josie	The more, the vibration is like…	
17	Nick	Stronger	
18	Jane	Easier	
19	Josie	The faster, its quicker then it takes.	
20	T	Yeah, it's the faster it spreads not the stronger.	
21	Josie	Yeah but how do we show that?	
22	T	That is a good question.	
23	Jane	No, you start over there, it's like draw them together. Then draw a line going through and the other	*Begins drawing next to tile.* *Indicates near foam.*

		draw it far away.	
24	Josie	OK. This is the ceramic thing OK, and this is the foam.	*Adds a different image.*
25	Josie	So, then this has more stuff right? Cause it vibrates quicker. And this has less stuff.	*Adds squiggly lines above the tile.* *Adds lines above the foam.*
26	Nick	Huh, still not making sense though.	
27	Jane	What I meant was, "ice" like get them together.	*Adds label.* *Draws circles.*
28	Nick	What is that? Huh?	*Jane adds a line.*
29	Jane	So, like it melts.	*Draws ice and pool around it.*
30	T	So, like it is passing on is that what you're trying to show?	
31	Jane	Yeah. Like that and it goes…	*Adds another circle and line.*
32	Josie	No. You have to draw the same amount of particles because ...	
33	Jane	No. This is like, the squiggles.	*Points to squiggles.*
34	Josie	Oh. OK I get it. Kind of.	

This excerpt demonstrates that the emergent bi/multilinguals' cognizance of the visual metalanguage enhanced their determination to achieve their objective: to visually explain the science phenomenon. Although the students did not discuss the visual metalanguage directly in their discourse, they were aware and determined to *show* the necessary concepts in their visual explanations. For instance, several students identified what the image should *show*, although they said "tell" (Lines 7 and 14) and "say" (Line 1). Josie commented, "We have to tell people that the vibration is creating thermal energy" (Line 7). They were also discussing how to depict them. Josie (as with the others) grappled with how to depict the science concepts through the visual elements, using statements such as "Yeah, but how do we show that?" (Line 21). They attempted to represent the concepts in new ways by introducing symbols not stated on the checklist, such as squiggly lines (Line 6; Figure 6.9) to show the vibrating movement of the particles (Lines 1 and 2). These questions, statements, and actions demonstrate a heightened awareness among the students regarding the importance of communicating the visual mode to a particular audience instead of assuming their drawing was self-explanatory. This type of awareness and discourse was not observed in the previous two units.

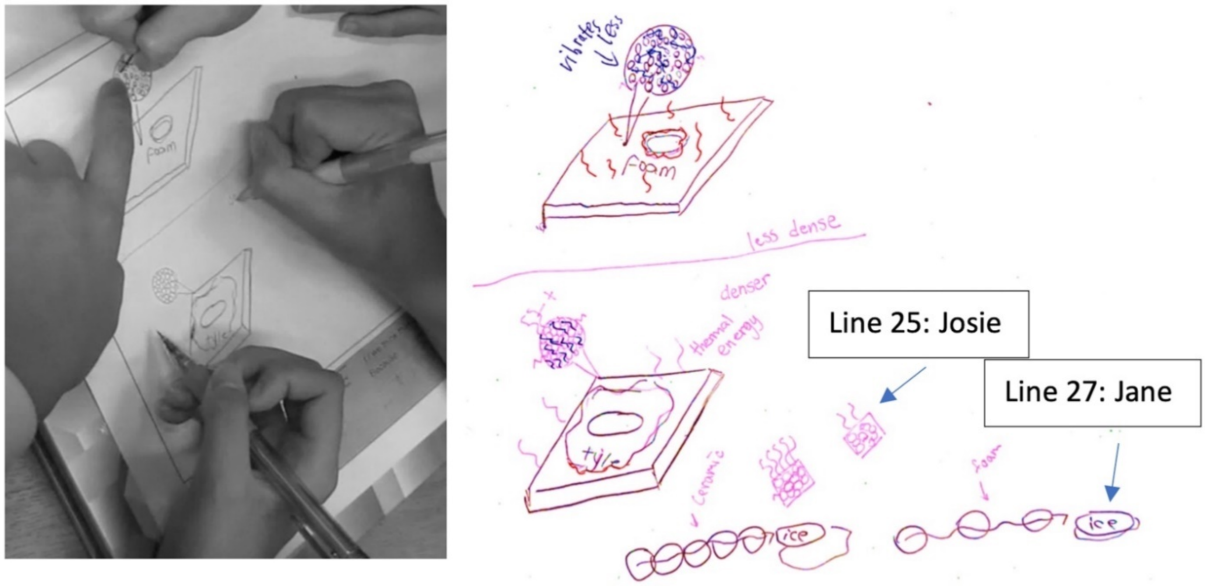


Figure 6.9 Group 1's representation explaining why ice melts quicker on a tile than on foam

To deliberate on how to best represent the science concepts, the students used the visual mode. As they represented ideas, they applied the visual elements. For instance, in Line 23, Jane used the connective element to show a comparison as she verbally described: "Start over there, it's like draw them together … then draw a line going through and the other draw it far away" (Line 23). She drew a line to show the connection between the particles and the direction the vibration (energy) was moving (Line 31; Figure 6.9). Here Jane used association elements to position the particles left to right and applied spatial elements to show the contrasting proximity of particles to each other, in both materials. Similarly, Josie used visual meanings to present her idea (Figure 6.9). First, she focused on the macro-level and identified the subject matter, "OK, this is the ceramic thing OK, and this is the foam" (Line 24). Next, she added details of the microscopic level, "So, then this has more stuff right?" (Line 25). Thus, Josie also applied a contrast between the two materials. As such, despite their differing depictions, both Jane and Josie accurately identified the necessary visual meanings for the explanation of this phenomenon. As the teacher was able to make meaning from the image, we inferred Nick's lack of understanding in this situation (e.g., Lines 26 and 28) arose from his lack of conceptual knowledge. It is clear that the emergent bi/multilinguals' ability to demonstrate understanding and ideas through both the visual and verbal modes ensured that they were able to participate in the discourse and gain access from the meanings presented.

Moreover, the emergent bi/multilinguals' heightened awareness of the visual mode, via an introduction to the visual metalanguage, appeared to alter their perception of visual explanations in science. This was seen from the comments of the Group 1 students. For example, in her self-recorded video reflection following the matter lessons, Yasmine said, "My favorite part of the lesson is using drawing to represent my information. This is the first time I know I can use drawing to represent my information without using any words, which is really surprising and interesting." Similarly, the students present in the group interview agreed that the checklist should be given to the next Grade 5 students. In response to the teacher's query about whether the checklist was helpful, one student replied, "This helped me drawing [*sic*] a diagram a lot. It taught me the procedures of drawing a diagram" (Jeffery). Another student added, "and also sometimes I forgot to use labels, and those things [visual elements] and close-up pictures [projected view] [help me to] remember" (Kirsty). Thus, the visual metalanguage was perceived by several students as enhancing their ability to present meanings in science.

6.4.2 The teacher's influence on the students' construction of visual representations

This section illustrates how the teacher's attempts to aid the students' creation of the visual explanations subsequently enhanced their communication of science meanings. It includes two episodes. Episode 3 occurred after Episode 1 in the forces in motion lesson and presents an example of a semiotic unit made during the explanation of how a balloon car works. Episode 4 occurred after Episode 2 in the matter unit and follows the students' introduction to the visual metalanguage and asks the students to explain why ice melts faster on a tile than on foam.

6.4.2.1 Episode 3

This episode demonstrates how the teacher's knowledge of the visual elements allowed her to direct her prompts and guidance during group discussions.

We deduce that the teacher's prior knowledge of the visual system enabled her to consider the meanings necessary in the visual explanation, which equipped her to respond to the student groups as they constructed their representations. The excerpt also demonstrates how her prompting and questioning subsequently led the students to improve their visual communication, as evidenced by their completed representation. For example, prior to the following excerpt (Table 6), Group 1's visual representation (Figure 6.4) depicted only the subject matter that could be seen, such as the car and balloon.

Table 6.6 Conversation excerpts between emergent bi/multilingual students in Group 1 during the forces in motion unit

Line	Name	Speech	Action
1	T	OK, what have you got for forces now?	*Points to representation.*
2	T Nick	I'll take the car now while you focus on what you're drawing.	*Moves car out of reach.*
3	Nick	Well, we have a… wait let me draw something.	*Nicola begins to draw.*
4	T	So, I noticed when we discussed it, what did you think was in the balloon?	*Nick holds pen ready to draw*
5	Josie	Air.	
6	T	Air what?	
7	Jane	Molecules.	
8	T	OK great, air molecules, Jane.	
9	T	So, I don't **see** any of those. Did you show me what those look like?	*Points to representation.*
10	Nick	Use green.	*Josie switches color pens and begins to draw.*
11	T	Show me some of what's going on. What happens to the molecules when they're in the balloon?	*T touches the balloon on the car.*

12	Julia	They're floating.

As illustrated in the excerpt, the students' visual representation did not yet provide any microscopic details. However, for an accurate visual explanation, a depiction of the movement of air particles is called for to show the force that moved the car, otherwise it is incomplete. Despite an earlier verbal discussion of the movement of particles (molecules), the students neglected to add microscopic meanings in their visual representation. Following the teacher's prompting in Lines 4 and 9, the students added particles using a green pen (see Figure 6.4). Of significance in this episode is that the students appeared to already understand how to represent these meanings and accurately portray their movement out of the balloon. However, without the teacher's expectation of visual meanings and prompting during the discussion, these meanings might have been overlooked.

6.4.2.2 Episode 4

This episode follows the implementation of the visual metalanguage in the checklist and occurs in the same matter lesson as Episode 2. In this lesson, the students observed a demonstration of ice melting quicker on a tile than on foam. Following this, each student constructed an individual visual representation. The following excerpt (Table 7) began as the students were about to draw their individual representation.

Table 6.7 Conversation excerpts between emergent bi/multilingual students in Group 1 during the matter unit

Line	Name	Speech	Action
1	T	When you are putting it down remember there are different ways to show what you want to show.	*Holding drawing checklist*
2	T	First of all, we talked about density so what would we need to show for that?	
3	T	We talked about two different things, so we might talk about comparing one thing to another.	
4	T	When you talk about density it's about the particles doing what…	
5	T	Why would we… What do we show in density? What do you have to show in drawings? When you compare them?	
6	Nick	Purple.	
7	Josie	You compare them to like the "impact"	
8	Julia	Maybe you could…	
9	T	How would you draw the particles in an object that was really dense?	
10	Josie	You just colour them in black.	
11	Nicola	Make it.	*Gestures the OK signal to represent a circle.*
12	Nick	Lots of both.	
13	Jane	More, more.	
14	T	Yeah, lots more than another one. Yeah. And are they together or far apart?	
15	Nick	Together, way together.	
16	Nicola	Together.	

This excerpt illustrates how the introduction of the visual checklist mediated meaning by allowing the teacher (and the students) to verbalize their thinking when explaining how to represent their ideas and concepts visually. A good illustration can be seen in Lines 1 to 5, where the teacher showed the drawing checklist as she provided the students with the metalanguage necessary to verbalize their visual meanings. The teacher probed their ideas by asking them how they would use the visual elements in their drawing. In particular, the questioning was mediated through a shared language using the term "density" (a spatial category) to focus on the "different ways" of "comparing one thing to another." This form of questioning stood in contrast to her requests prior to the introduction of the checklist in Episode 3 for students to simply *show* the phenomenon in vague terms, for example "Did you show me what those look like?" (Line 9) and "What happens to the molecules when they're in the balloon?" (Line 11). Furthermore, in episodes prior to the introduction of the metalanguage of visual elements, the changing spatial qualities (proximity and distribution) of the particles was not discussed. However, in this episode, we see a difference in the discussion. For instance, in Line 3, the teacher mentioned making comparisons (referring to *connection* in the checklist) and in Line 9 she alluded to the need for spatial awareness of the particles within the models, with suggestions of spacing in Line 14: "Are they together or far apart?" Thus, when discussing the visual explanation, the teacher attempted to make associations between the visual elements and the science concepts before the students began to draw their representations.

The teacher's highlighting of the relationships between the science concepts and the visual elements prompted the students to consider their explanations. For instance, Josie mentioned comparing the two images (Line 7). Later, the students in Group 1 agreed that adding more molecules into one of the objects would show it was denser (Lines 12–13). The teacher's support in navigating the visual metalanguage thus enabled the students to apply the visual elements.

6.5 Limitations

One of the limitations of this study is the sample size, which remained deliberately small to ascertain an in-depth understanding of the phenomenon and conduct a detailed analysis of semiotic units. Subsequently, the generalizability of the results is limited. Another limitation was that by using fixed cameras, the signs outside the recorded area were missed. However, placing tape on the table to provide a boundary for the students to stay within reduced the chance of missed signs.

6.6 Discussion

To investigate whether supplementary knowledge of the visual mode supported students in communicating science explanations, we made the visual elements explicit to a fifth-grade science class through a shared metalanguage. We recorded 10 emergent bi/multilinguals' construction of visual explanations of an unknown phenomenon, both before and after the introduction of the metalanguage. We found that exposure to the visual metalanguage heightened their awareness of visual meanings and motivated their desire to illustrate science concepts in explanations. Furthermore, making the visual elements explicit in the form of a checklist helped them to demonstrate key concepts in their explanations and indirectly increased some students' confidence levels when learning science.

This results of this case study coincide with other research demonstrating that the visual mode provides an outlet for emergent bi/multilinguals' meaning-making (e.g., Ryoo & Bedell, 2017). Yet this study extends our understanding. An argument has been made for the importance of representational competence in science (diSessa, 2004; Kozma & Russell, 2005); in response to this, we discussed how the visual elements affected the construction of visual representations. To gain representation competence, the students must know the form and function meanings can take in a mode of representation. The visual elements offered students an insight into the form of 2D visual meanings. However, without an understanding of how they function, a student's meaning can be impeded. For example, one element that provided crucial information in these explanations was not found in the written mode. The students appeared to have prior knowledge of the spatial element as they were able to organize particles appropriately in most representations. However, an element that we found constrained meanings in the visual system was the use of an orientational meaning perspective, and students appeared to have a lower level of knowledge of this visual element. In one explanation in this study, we found the choice of perspective encumbered the intended direction of forces depicted and the wheels creating friction with the ground. We argue that knowing how visual elements function in science classrooms could improve students' visual explanations. This has further implications for emergent bi/multilinguals, who may prefer this form of communication.

6.6.1 The implications of the visual mode for emergent bi/multilinguals in science

The results have shown that visual elements provide a medium for meaning-making, even when they are implicitly used by young emergent bi/multilinguals. However, when visual elements are explicitly discussed using a metalanguage, they can raise an awareness of the form and function of visual elements and thereby provide the students with an alternative way of illuminating key concepts in their visual explanations. In doing so, the visual system offered a window into the emergent bi/multilinguals' understanding of science, which was not always uncovered in their writing. This suggests that the visual mode can provide assessment possibilities once the students know more about it through the visual metalanguage. Through the explicit metalanguage, the teacher gained an expectation of which visual elements should be seen in the students' visual explanations. Consequently, the students' misunderstandings became noticeable. In this study, any misunderstanding may be attributed to an insufficient knowledge of the visual elements due to the students' limited exposure to the visual metalanguage. Nevertheless, the use of the visual framework to analyze each representation may help teachers identify emergent bi/multilinguals' understanding and any potential misunderstanding.

In the same way, the students used their understanding to their advantage as they accessed semiotic resources when translanguaging to produce visual meanings in unique ways. This meant different visual representations could still depict the required visual elements. As a result, the visual metalanguage afforded the students a way to value their cultural and language backgrounds. Furthermore, the checklist of visual elements provided learners with a selection of possibilities for making visual meaning. By asking learners to choose from among these possibilities, the checklist ensured they had representational agency, and enticed them to participate. In essence, the checklist could potentially mediate meaning as it questioned what forms were best to represent meanings and elicited responses from the students. Comparing the students' actual representation with their completed checklist of the elements perceived to be included may provide an area for further study. In principle, the checklist became an artifact associated with the representation; yet in this study its potential remained unexplored. Broadening the research to include this avenue in future studies is a recommended goal.

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7
Discussion and conclusion

This research had a bifold agenda. The fundamental goal was to generate new knowledge to support bilingual and multilingual learners (BMLs) in science due to their rapidly rising number in classrooms around the world. The success of this aim was reliant on informing the science education research and science teacher communities of the outcomes of this research. As a result, a subsequent goal was to educate the science education research community and teachers. To achieve these goals, four objectives were established, which were addressed by four separate manuscripts. The first section summarises the findings from the four inquiries (manuscripts) that fulfilled each of the following research objectives;

1. Expose the outcomes of non-linguistic modes to inform on the evidence already in studies.
2. Explain how multiple modes benefit BMLs to show the need for non-linguistic modes in meaning-making.
3. Explore the potentials of non-linguistic modes in science to expand research boundaries and demonstrate a bridge to language.
4. Explore BMLs' exposure to an non-linguistic metalanguage in science to validate non-linguistic meanings for all.

First, a review was conducted that provided the necessary grounding of research into how modes were applied with BMLs in science classrooms. The findings from this inquiry illuminated the many beneficial implications modes offered to BMLs and exposed a gap in the research. The second inquiry filled this gap by answering *how* the use of multiple modes supported BMLs in science and applied a multimodal lesson plan in a science classroom with BMLs. The third and fourth inquiries took a closer look at specific modes and offered further understandings for how gestural, tactile and visual modes helped BMLs in science. In addition, the fourth inquiry presented the students with explicit information regarding the visual mode that they could apply to their representations. This manuscript challenged the less useful conceptualisations common in educational science research with a next step for how frameworks for meaning-making in modes could be applied in science classrooms. This research has contributed to the literature as evidenced by the growing number of citations building upon this perspective. The next section discusses the implications of these findings for science educational researchers and science teachers of BMLs. Following this, recommendations are presented to the science education researching community and new paths are set for future research. The final section acknowledges the limitations of this research and concludes the research.

7.1 Addressing ways to support BMLs using a reconceptualised language lens

This study reconceptualised the issue of learning science for BMLs through a renewed contemporary theoretical lens. The renewed lens satisfied the first research goal by unearthing new possibilities for BMLs learning science. A summary of the findings addressing each of the four objectives will now be discussed. Investigations to achieve objectives 1 and 2 were conducted simultaneously but will be discussed separately.

7.1.1 Outcomes in response to objective 1

Objectives 1 (and 2) were formed during an initial examination of the literature on BMLs in science education, in which a consistent theme was discovered. Frequently, multiple modes were used (sometimes recommended) and listed in the lesson design, content mapping or the results of studies. Due to the description of multiple modes, the non-linguistic modes were exposed, yet they were infrequently described. This was because the findings of most studies focused on linguistic modes, and as a result their discussions did not bring attention to the potentials of non-linguistic modes (Bravo & Cervetti, 2014; Cervetti et al., 2015; Lo et al., 2018; Purcell-Gates et al., 2007; Rupley & Slough, 2010; Santau et al., 2011; Tong et al., 2014). As a result, the possibilities non-linguistic modes presented for BMLs' meaning-making appeared uncertain. Thus, to understand the implications of non-linguistic modes for BMLs, a systematic literature review was carried out to infer what outcomes non-linguistic modes presented from the results accessible in the studies (Williams & Tang, 2020). In the review, three search concepts and their associated keywords were applied: science education, BMLs and multiple modes. The renewed and eclectic theoretical lens (multiliteracies and translanguaging theories) ensured all modes were accounted for as each in this lens each mode has meaning-making value.

The review showed that the renewed lens directly extended the BMLs' meaning-making possibilities and altered the perspective of a BML's plight, from an issue regarding linguistic shortcomings to an issue concerning value, access and planning (Williams & Tang, 2020). In other words, when BMLs' communication practices are valued, the semiotic and linguistic repertoires they use to make meaning will also be of value (Garcia, 2009). As a result, resources from multiple modes (for example, visual images and gestures are regarded as potential meaning-making tools (Kress et al., 2001/2014). So, if all semiotic resources are of value, then all must be accessible for BMLs during meaning-making opportunities or learning experiences in science. This leads to the adequate planning of learning experiences for BMLs in science and the management of semiotic resources in science classrooms. It became clear from addressing the first research objective that applying a contemporary language lens pointed the BMLs issue in a positive direction (Williams & Tang, 2020).

The re-examination of findings from studies showed, as expected, that there were beneficial potentials of non-linguistic resources for BMLs (Williams & Tang, 2020). Perhaps the most influential outcomes for the science education community were the inferences showing the different ways that non-linguistic modes facilitated BMLs' learning. The research showed that non-linguistic modes promoted translanguaging (Bracey, 2017), bridged linguistic gaps (Ünsal et al., 2018) and scaffolded academic science language (Lee et al., 2008; Robinson, 2005). This was a significant outcome because it implied the BMLs could increase their academic language that they needed to gain access to written science material. Thus, this result helped to answer the question of how we can support BMLs to develop academic language. Thus it can be deduced that if non-linguistic modes promote academic language, they may indirectly support a BML.

Of the studies reviewed, over half evidenced positive gains that they attributed to the multiple modes employed, inclusive of non-linguistic modes, including the use of academic language (e.g. Lee et al., 2008; Robinson, 2005). As anticipated, the tactile and visual modes featured predominantly in the studies investigated (Williams & Tang, 2020). This came in contrast to the representation of the spatial or auditory modes which were rarely seen. In fact, the tactile mode was found to be used more than any other mode. This distinction was due to the materials and investigations used in the science lessons. Yet, while these results showed the important implications for the use of non-linguistic modes in BML's meaning-making, unexpected outcomes also surfaced. There appeared several unforeseen outcomes of the use of multiple modes that were not focused on meaning-making.

The identification and classification of these unexpected inferences was connected to the addition of the theory of translanguaging (Williams & Tang, 2020). Through a translanguaging lens, any imbalance previously documented between different learners in a science classroom shifted. In translanguaging theory, all communication resources are of value and multiple linguistic resources are considered beneficial (Garcia, 2009; Garcia & Wei, 2014). So, as the results of studies were observed, other aspects were also considered, for instance, recognising translanguaging spaces and the opportunities students had to create these spaces. Likewise, identifying when the BMLs and their semiotic repertoires were valued and how their ideas were shared with others.

Overall, achieving objective 1 broadened the science education and research community's knowledge of the benefits for using multiple modes when teaching BMLs. The consequence of this new and varied knowledge provided the rationale for further inquiry into the non-linguistic modes to discover in what ways BMLs used them.

7.1.2 Outcomes in response to objective 2

Objective 2 made attempts to focus on one aspect of the issue, the multimodal meaning-making of BML's in science learning experiences. Like objective 1, objective 2 evolved from the early review of the literature on BMLs in science. In the research, a pattern was discovered regarding the ways to support BMLs in science. Studies showed the use of multiple modes when teaching BMLs was commonly applied and sometimes encouraged by the science education and researching community (Lee et al., 2016). However, upon closer examination the studies lacked an explanation for why or how multiple modes benefited BMLs. This research objective aimed to discover why multiple modes were important for BMLs. Thus, an empirical investigation in a Grade 5 science classroom was employed to satisfy the second objective (Williams et al., 2019).

To conduct this investigation, a multimodal instructional approach (MIA) was used in the science lessons. The MIA was adapted from the Thinking Frames Approach (Newberry & Gilbert, 2016), as it stipulated the use of an arrangement of multiple modes including a non-linguistic mode. The arrangement was devised to support students' written explanations in a UK study and was not specifically created for BMLs. The MIA dictated that each lesson begin with a verbal discussion, move to a visual representation, and end with a written explanation. The multitude of dominant modes (verbal, visual and written) in the approach required the use of multiple meanings in each phase that could be observed for this study. To expand the possibilities of meanings, the inquiry lessons were designed (where possible) with tactile resources.

Though the outcomes of the MIA inquiry lessons were similar to those expected from an inquiry approach (see 4.3.4.2), this study benefited the science teaching and research community as it revealed the intricacies behind how this occurred. That is, how the BMLs made connections to their prior knowledge, discussed and scrutinised ideas, and developed knowledge entirely through multimodal discourse (Williams et al., 2019). As this information was revolutionary, and as recordings provided a plethora of data, it was difficult to ascertain what to disseminate to the science teaching and research community. The dilemma caused a substantial findings section to exist in the manuscript (Williams et al., 2019). For this summary, to explain how multiple modes support BMLs in science, the main outcomes will be provided in relation to objective 2.

Overall, results showed multiple modes supported BMLs by providing them with access to their full repertoire of linguistic and semiotic resources (Williams et al., 2019). Since the BMLs shared meanings in individual ways, the diversity of modes gave them opportunities to *participate* in the discourse. In addition, the act of shifting between modes or translanguaging promoted the continued use of language. So, regardless of whether a change of mode came via the choice to use a mode or via a limitation in a mode, the use of multiple modes meant the BMLs were able to *maintain* the science discourse. Thus, the results showed the use of multiple modes allowed the BMLs to use language in science. Since language appeared the barrier to BMLs' learning of science, this beneficial outcome was influential and worthy of further research.

Another noticeable outcome was that translanguaging with multiple modes in science ensured the BMLs were applying both their science knowledge and their science skills (Williams et al., 2019). Interestingly, non-linguistic modes were found to be of greatest use when the BMLs disagreed or when they had to justify or explain their point of view. This appeared to be because the non-linguistic modes promoted the re-enactment of phenomena through gestural and tactile movements. At times this explanation created the inspection of concepts on a deeper level. What is noteworthy here is that the use of multiple modes ensured the BMLs were participating in science practices, such as by justifying or explaining their ideas. Thereby, multiple modes provided opportunities for BMLs to share knowledge and become scientists who defend their theories.

The accuracy of the BMLs' theories became more conspicuous during the progression of the MIA (Williams et al., 2019). This is because the concepts necessary for the explanation of the phenomena became more detailed as representations were created in each mode. Analysis of the multimodal meaning-making showed this was due to each mode's semiotic affordances, or the ways meanings were made, which illuminated different aspects of the phenomenon. For instance, the visual mode revealed the spacing of objects in relation to one another in a drawing more easily than the linguistic mode, which required considerable verbal description. Thus, the diversity of meanings made in each mode clarified the different aspects of the phenomenon for the BMLs that may not have been considered before.

Thereby, this research uncovered more about how BMLs use multimodal discourse and offered answers as to how BMLs benefit from access to multiple modes. The results provided a much-needed rationale for why multiple modes should be provided to BMLs in science and led us logically to the next research objectives. A closer inspection of two of the non-linguistic modes, gestural and visual, was carried out in the following two investigations.

7.1.3 Outcomes in response to objective 3

The third objective investigated the non-linguistic modes that had become more apparent and visible in the study earlier. Results showed that the BMLs drew largely upon gestural and tactile meanings from their semiotic repertoires (Williams et al., 2019). An in-depth inquiry was necessary to explore the potentials of the gestural and tactile modes for BMLs. Thus, the investigation aimed to find out in what ways the participant BMLs used the gestural and tactile modes.

The results showed there were four distinct ways BMLs used gestural and tactile meanings to support their science learning: replacement, support, demonstration and imitation (Williams, 2020). The most frequent way was *demonstration* whereby the

BMLs reverted to a movement from an oral meaning. The function of this method appeared similar to that of how BMLs draw upon a known language (L1) or their mother tongue (e.g. Gallagher & Colohan, 2017; Pavón Vázquez & Ramos Ordóñez, 2019; San Isidro & Lasagabaster, 2019). A similar execution was *replacement*, whereby the students replaced a noun by pointing or touching the necessary object. Demonstrations and replacements explained why the BMLs with the lowest level in English language used the most gestural and tactile meanings. Though the use of gestural and tactile modes in these ways was predicted, the results reinforced the knowledge that a sign, whether from a linguistic mode (Putonghua) or gestural or tactile mode, had meaning-making potential in science.

What was unpredicted was that the BMLs chose to use non-linguistic modes in this way instead of Putonghua, the known language of the group (Williams, 2020). Why draw upon non-linguistic modes when a shared linguistic mode exists within each group? A possible explanation for the BMLs' selection could be due to the language policy in place at the time of the study. The policy separated two languages between subject areas, thereby compelling the use of a specific language in a certain class. Though the practice of language separation is of little value in a translanguaging lens, the school site may have afforded an occasion to examine the potentials of other semiotic resources.

In making attempts not to view the world through merely a linguistic communication perspective, it was rational to surmise that another way of using gestural and tactile modes existed (Williams, 2020). *Support* was discovered when gestural and tactile meanings were used by the BMLs to accentuate a meaning. This method was used most frequently simultaneously with verbal signs. This technique offered the students multiple opportunities for learning science, as it broadened the possible meanings provided by a student. In a similar manner to the occurrence found in the previous manuscript, the use of multiple semiotic resources exposed more meanings and/or aspects of the phenomenon. This had the potential to provide a more robust explanation than if the meaning was in only one mode. For a phenomenon with movement or forces, the addition of gestural and tactile meanings appeared to provide clarity to others.

Presented with this new clarity, the students themselves sometimes translated each other's signs (Williams, 2020). A noticeable practice that occurred during the multimodal discourse involved several BMLs, who translated the meanings of gestures into other modes, such as verbal. A natural consequence of this process was the students' re-evaluation of the science concept involved in the explanation of the phenomenon. Sometimes, in their reassessment, new meanings and explanations developed. In the process the students acquired new language. So, if the BMLs were limited by their command of English, the gestural or tactile meanings ensured they could express their idea and perhaps even discover the equivalent meaning in English. A presumption can be made that the gestures or tactile moves replaced the more arduous academic words in science. However, upon closer examination in the two units (Forces In Motion and Human Body) gestural and tactile moves were found to replace both everyday and academic words.

A final way the BMLs used gestural and tactile modes that has not yet been discussed was *imitation*, when a BML borrowed the action of another (Williams, 2020). At times, it appeared in a manner much like that of a child mimicking an adult as they take on a new role. For instance, as the teacher attempted to provide more information through gesture, several BMLs imitated her actions. The changes in the shape of her hands provided vital details regarding the movement of the diaphragm.

An awareness of the ways BMLs used gestural and tactile modes was helpful to ascertain the potentials of non-linguistic modes. It appeared that the BMLs were able to participate and express ideas in scientific discourse, provide more comprehensive ideas when paired with other modes, and motivate new ideas and language, due to the semiotic affordances of the gestural and tactile modes. The next inquiry focused on the potentials of the visual mode.

7.1.4 Outcomes in response to objective 4

The response to the fourth objective evolved from the earlier studies addressing the first three objectives. The diverse potentials of non-linguistic modes had been unearthed in all of the studies. With such beneficial results, the next step was to ensure the BMLs had access to these potentials via the metalanguage of a non-linguistic mode. The visual mode was chosen as the teacher-researchers had knowledge of the visual metalanguage prior to the study (Tang et al., 2019). To achieve this the researcher used two lessons to pre-teach a checklist of visual elements to students. As a result, the BMLs were continuing to decipher the visual metalanguage while using it. Nevertheless, the BMLs' lack of knowledge of the visual metalanguage did not deter their objective to explain the phenomenon

(Williams & Tang, 2021). As the results showed, the students continued to inquire into how to achieve a detailed explanation in the visual mode.

The major benefits of the visual mode included the ability for the students to portray meanings they were unable to communicate in other modes (Williams, 2020). For instance, when drawing a visual explanation, the students were able to accurately represent the required spacing. As a result, the visual images were able to show objects that were touching or to represent the position and alignment of other objects. In the written mode, language describing spatial positions was seen to be more difficult for the students to navigate. In a similar way, arrows provided an essential tool to depict the movement of objects or the direction of forces. Again, information regarding direction and movement appeared to be more prevalent in the visual mode than the written mode.

Another beneficial outcome found in this investigation was that the students' knowledge of the visual metalanguage provided them with a way to better illuminate concepts such as microscopic aspects (Williams, 2020). This noticeable shift occurred following the introductory lesson where the teacher had introduced a projected view. The projected view illustrated events at a microscopic level. This technique was reproduced by most students in their individual explanations of phenomena during the matter unit. This enhanced exposure to this microscopic level enabled further consideration of microscopic scientific concepts. The students' willingness to depict this level of detail demonstrated their ability and commitment to provide a thorough explanation in the visual mode.

Finally, that the students drew upon a relatively unknown visual element from the checklist showed the benefit of the checklist (Williams & Tang, 2021). Knowledge of the visual mode provided the students with insights and the agency to communicate in the visual mode. Additionally, the visual checklist appeared to mediate meanings when used as a prompt to discuss visual representations. The opportunity to choose visual options of how to represent elements of an explanation ensured that consideration was given to how to accurately represent the scientific concepts thought to be involved in the phenomenon.

Similarly, the teacher's knowledge of the visual elements in the visual checklist enabled her to narrow her focus when prompting students in each lesson towards the visual elements necessary for an accurate visual explanation (Williams & Tang, 2021). Following the students' exposure to the visual checklist, the teacher had the added ability to discuss specific elements that illuminated the scientific concepts. Teaching the metalanguage of a visual mode promoted discussions of the scientific concepts within the phenomenon, as well as how to represent the concepts best via visual meanings. As a result of the prompting during the construction of the students' explanations, more elements from the phenomenon were included. This showed that the elements once overlooked in the BMLs' visual explanation were not always missing due to an inability to communicate in the visual mode. As an awareness of the missing elements revealed, the BMLs could accurately represent many of these elements, such as microscopic features like air movement, in their visual explanation.

7.1.5 Summary

From uncovering the implications of past research to analysing the data in this study, it appears that multiple modes are of benefit to BMLs. In particular, the addition of non-linguistic modes offered BMLs advantages in learning science, such as providing access to scientific discourse, making scientific meanings, improvement of science knowledge, and valuing BMLs as learners by respecting their communication repertoire. Using a contemporary theoretical lens, all the BMLs semiotic resources were brought into focus and appreciated. Thereby, the issue shifted perspective from language limitations to an issue about missed meaning-making opportunities. Providing BMLs with access to multiple modes, including non-linguistic modes, allows BMLs access to science and agency over their meaning-making (Cope & Kalantzis, 2009). Likewise, facilitating opportunities for BMLs to embrace these modes with purpose by understanding their forms and functions is also important (Ainsworth, 2006; Prain & Tytler, 2012).

7.2 Addressing ways to reconceptualise the issue for the science education community

In this study, the consideration of a BLM's entire communication (semiotic and linguistic) repertoire ensured all resources were seen as possible meaning-making tools. As a result, a gesture, visual image, or manipulation of material was seen to communicate meaning. The theoretical lens reframed the context of studies away from an issue about the lack of linguistic resources to an issue about recognition of meaning and access to modes.

7.2.1 Outcomes in response to objective 1

The reconceptualised lens positioned the BML using a surplus instead of a deficit model, as they harbour multiple linguistic and semiotic resources (Kress, 2010). This change may have inadvertently caused a shift in the classroom. Instead of viewing the BML as a deficient learner, we can view them as an efficient communicator as they utilise their semiotic resources (Williams et al., 2019; Williams, 2020). The review responsible for accomplishing objective 1 was broadcast, via poster, to a wide international audience through the European Science Education Research Association conference. Next, the review was published in the *International Journal of Science Education* (Williams & Tang, 2020). The hope was that the information would allow researchers (including the authors of studies in the review) to discover the potential of applying a contemporary lens and to observe the value of focusing on the non-linguistic modes when searching for answers in the future. Citations of the review, show that some researchers have continued to unearth the value of multimodal meaning-making for plurilingual students in science (Wilmes & Siry, 2021) and continued investigations into translanguaging in science (Garzón-Díaz, 2021), while other researchers have built upon the outcomes of multimodal meaning-making and linked it to students' creative reasoning in science (Cabello et al., 2021; Ferguson, 2022).

7.2.2 Outcomes in response to objective 2

To continue to achieve the concurrent goal, to educate the science education and researching communities about the beneficial implications of multiple modes for BMLs, the information was distributed in multiple forums, widening the audience reach. First, a presentation was given at the 2018 Australasian Science Educational Research Association conference. The presentation received encouraging and constructing feedback from a large audience, several of whom were cited for their work in multiple representations. Next, a manuscript was published in the *Asia-Pacific Science Education* (*APSE*) journal (Williams et al., 2019). *APSE* was chosen from a desire to give back to the community where the research was conducted. Since *APSE* is an open-access journal it meant anyone, including teachers, had access. Furthermore, the likely readership of *APSE* may have populations akin to the one in this research, making the findings more transferable. Lastly, due to the auspicious timeline of publication in *APSE*, this manuscript was included in the review, satisfying objective 1. Since the review was published in *IJSE* this appeared a windfall for objective 2, as it meant a wider, more international audience gained access to the information as well.

7.2.3 Outcomes in response to objective 3

The aim of objective 3 was to demonstrate a bridge between language and science in the research community. To achieve this objective the research was disseminated to a wider audience by two methods. First, by reporting the findings to the European community where the predominate bilingual model, content language integrated learning (CLIL), has featured predominant since the European Network of Administrators, Researchers and Practitioners (EUROCLIC) in the mid-1990s (Coyle, 2007, p. 545). Second, by reporting the findings to a language research discipline. Therefore, the outcomes of objective 3 were published in the *International Journal of Bilingual Education and Bilingualism* (Williams, 2020). For this manuscript, the investigation flowed from the results in outcome two and expanded the investigation by narrowing the focus to gestural and tactile modes only. The investigation of gestures with their connection to the verbal mode provided a natural place in which to discuss the development of language theory. Gestures and paralinguistic signs have been an area of discussion for linguists for centuries (Kendon, 1980; 2014; McNeill, 1985). So, with a contemporary theoretical language lens (multiliteracies) united to a contemporary bilingual communication theory (translanguaging) a space was created to inspect how gestures and tactile moves were used by BMLs to communicate in a science classroom.

7.2.4 Outcomes in response to objective 4

The final objective completed the research on non-linguistic modes featured in this study. This objective focused on making the visual mode explicit to the BMLs (Williams & Tang, 2021). There was an element of risk in achieving outcome 4 as this area of investigation had not been ventured by researchers before and could be described as unconventional or innovative. For this reason the manuscript was the most difficult to publish, and this explains why it received such mixed evaluations from reviewers and editors. Though the need for students to comprehend non-linguistic modes had been suggested by researchers in the past, the realisation of teaching a metalanguage for a non-linguistic mode was progressive. The outcomes of objective 4 were finally able to circulate in *APSE*, an avenue of dissemination to which both researchers and teachers have access. However, this last publishing experience, for this study, confirms there is room for the validation of non-linguistic modes in science. To truly embrace the contemporary language theory in the field of science, exploring and naming non-linguistic forms and functions is a necessary first step (Ainsworth, 1999; Prain & Tytler, 2012). Moreover, for the shift to contemporary language theory to be effective, teachers must make non-linguistic modes explicit to students. Further implications of this research for teachers and researchers are discussed in the following section.

7.2.5 Final words

In sum, the research goals aimed to reconceptualise the issue for the science community were achieved. However, success in the science community requires change and that may be a slow process. The moments of revolution witnessed in this study were at conferences when researchers appeared genuinely curious to find out more about the research by asking questions. They appeared surprised to realise the diversity of potentials non-linguistic modes offered to BMLs and interested to know how to cater for BMLs in science. A manuscript, seen in Appendix 4, had been created to address these queries and was sent to a national science journal believed to entertain the widest reach of elementary science educators in the world. The journal was fitting due to the corresponding curriculum applied at the school site. The purpose was to inform science educators of the beneficial lesson format for BMLs. However, despite the rigorous reviewing process (see Appendix 1) and acceptance for publication, the decision was overturned two years later. Nevertheless, the published manuscripts offer several implications for educators as discussed in the following section.

7.3 The limitations of this research.

A limitation of this study was that I was monolingual. An investigation into bi- and multilingual students' learning may be best served by researchers who are multilingual themselves. This is because knowledge of making meaning with more than one national language or dialect would align to the participants' translanguaging practices and would provide an added dimension to the researcher's perspective in the analysis of findings. However, it is also important to recognise that regardless of the number of national languages or dialects spoken by an individual, language remains multimodal (Kress, 2010). As a result, all speakers communicate through languaging practices with multiple semiotic resources. Hence ‘monolingual’ does not mean ‘monomodal’. Nevertheless, as I had worked at the research site for five years and taught BMLs in multiple global contexts I delivered an insider’s perspective to the issue.

Another limitation of this study was that I had to meet the expectations of both a researcher and teacher. In practice this meant I taught each MIA lesson to the entire class, consisting of five student groups. When non-participant groups had disagreements or issues managing their time appropriately, I found myself with conflicting demands. As the only teacher in the room, I was responsible to solve the issue, and thus was unable to focus solely on the discourse of the participant groups. This meant that on a few occasions some groups waited longer than anticipated for my permission to move into the next phase of the MIA. The waiting slowed the progression of the learning experience as unrelated discourses were generated. This usually happened between the phases of the MIA. Upon reflection, having another teacher in the room during the MIA lessons for classroom management purposes would have been beneficial.

An associated limitation was due to the power imbalance between me and the students. For instance, the student-participants in the MIA lessons may have wanted to impress me by becoming extroverted or, in contrast, becoming docile. Though this may have been possible, the fact that the students had already built a rapport with me made this less likely. Likewise, maintaining my consistency as the teacher made the students’ transition to the MIA lessons less confusing. This is because my presence in the study prevented an unfamiliar observer from entering the class. From my viewpoint the discussions with the student groups felt natural, and during my discourse with the students the students appeared to behave as they did in other lessons.

Another possible limitation in this study was that of researcher bias. Because I was also the teacher-researcher, I formed part of the data. Thus, critics would comment that I was unable to report objective results. However, in an interpretivist epistemology objectivity is believed to be unattainable, and instead an insider perspective is justified (Denzin & Lincoln, 2005). Nevertheless, to reduce research bias, I ensured the case study adhered to quality standards such as trustworthiness that included credibility, transferability, dependability and confirmability (Guba & Lincoln, 1989). Similarly, I made sure the research approach allowed for triangulation to occur, which added to the credibility of the interpretations.

The main difference in the students' classroom came from the use of cameras. Cameras were vital for capturing the meaning-making, but they also enabled me to achieve my ethical responsibility to teach all students by circulating the room during the lesson, instead of recording. However, due to the addition of the cameras I discovered an unforeseen result upon the transcription of a Human Body lesson. As I was busy with students elsewhere in the classroom, one participant student group pretended they were on a science television program. Throughout the lesson, several students spoke to the camera as if they were being filmed on a set and pretended to teach science to a young audience. This may have limited the depth to which they concentrated on their science explanation. Despite this incident the groups generally ignored the camera in other lessons.

The fixed camera angle proved to be a limitation in this research. This became most noticeable during the multimodal transcription process, when success was dependent on viewing the participants' meaning-making. All the students' faces and hands needed to be in full view to document the signs they made. However, at moments when the students moved from their places around the table, their non-linguistic modes could no longer be seen. Similarly, my signs had to be documented in the discourse. During the MIA lesson, I circulated the room and moved from group to group to support each group's scientific explanations of the phenomena. When I approached the tables, I frequently did so from the front so I was in full view of the students. As a result, my gestures were not always visible to the camera. Following the transcription of the early MIA lessons I repositioned the camera, though even this was unable to capture all of my signs. In future I would consider adding a second camera, at a different angle, to clarify the signs unseen by the first.

An additional limitation concerned the small sample size. As this study aimed to answer 'how?' and 'what?' questions, a small sample size was sufficient for an in-depth investigation. With only ten student participants the results were not generalisable. However, in the interpretive domain, results may be transferable if the context is provided through accurate and detailed descriptions of the case, which appear like other contexts, though this is a decision for the readership. To support the reader with this task and to maintain the triangulation of data, results were compared between the two small groups and across MIA lessons. Likewise, the signs of one participant could be compared with another to check for patterns or distinctions. This permitted the use of quantitative data that was included in each manuscript to show how common the meaning-making practices discovered in this study were.

Finally, a frequently described limitation of a case study is the flexibility it allows in research. The researcher can change focus within the case bounds to inquire into the multiple phenomena. However, this flexibility was found to be pertinent to this study, as I was able to notice multiple outcomes of the multimodal meaning-making in the multimodal transcription. This ensured multiple aspects of the phenomenon could be explored in more depth. For instance, the investigations of gestural and tactile moves were inspired through the results of the first study and have been effective in answering the research questions. Likewise, the addition of the visual checklist was motivated by the teaching and reflection of the first two units. As a result, the addition of the visual checklist provided a crucial and original area of investigation. Therefore, I found the flexibility of a case study an asset to this research.

7.4 Implications for science educators of BMLs

The implications of this research are varied, so I will focus the discussion for teachers on two areas: designing learning experiences for BMLs and the role of the science teacher. To begin, I describe the implications of this study for the design of science learning experiences and of the sequencing of modes.

7.4.1 Designing learning experiences to support BMLs

Several models used to support BMLs in past studies have integrated language (Lee & Buxton, 2013) or integrated hands-on practices (Amaral et al., 2002). However, this study sought to offer a solution by changing the viewpoint using a contemporary language lens. The theoretical framework for this study highlighted the importance of multimodal meanings, which are meanings created from more than one mode (García & Li, 2014: Kress, 2010; New London Group, 1996). What this research illuminated was the ways modes functioned together to allow BMLs to produce meanings (e.g. Williams et al., 2019). Relatedly, during the study the research interests moved to focus on specific ways BMLs manipulated non-linguistic modes when making meaning (e.g. Williams, 2020). To fulfil this research agenda, this study drew upon an MIA harbouring a mode sequence with three dominant modes, oral, visual, and written. The MIA was based on the Thinking Frames Approach (TFA) which had an original aim to support students' written explanations (Newberry & Gilbert, 2016).

This study revealed that despite the intentional mode sequence presented in the MIA, greater benefits arrived from the multimodal integration produced by the BMLs themselves (Williams, 2020). When the students in this study were motivated to participate (to explain or defend ideas) they drew upon varied resources from their communication repertoire (Williams et al., 2019). In phase 1 of the lessons, the BMLs integrated verbal signs with gestural and tactile signs. In phase 2, they integrated visual signs with verbal and gestural signs, and in phase 3, their written signs were negotiated using verbal and, less frequently, gestural or tactile signs. These results inform us that regardless of the dominant mode required by a phase, the BMLs used a combination of modes to produce their meanings (Williams et al., 2019). This fits with the description of communication given in the contemporary language theories, such as translanguaging (Garcia, 2009; Garcia & Wei, 2014).

Consequently, modes were found to grant BMLs access to learning in science, but not necessarily the means to show their learning in written assessments. This was because they were not always able to translate the knowledge constructed in one mode into another mode (Williams et al., 2019). For instance, a meaning from a drawing was not always acknowledged in the written representation that followed (Williams & Tang, 2021). Instead, this study showed that the different modes granted different access points for the BMLs to make meaning (Williams et al., 2019). This is due to the unique semiotic affordances of each mode that were found to illuminate aspects of a phenomenon better than others (Prain & Tytler, 2012). So, while the BMLs' explanations became more comprehensive from exposure to multiple meanings, not all meanings were translated into a form used regularly for assessment, such as writing (Williams et al., 2019). The ability for students to translate meanings to the written mode once they have established meanings therefore appears to be a different skill.

What does this mean for the teacher? The following sections discusses the shifting role the science teacher faces.

7.4.2 Reconceptualising the science teacher's role

Following this study, it appears necessary to reconceptualise the science teacher's role as a facilitator of translanguaging spaces (Garcia & Wei, 2014). As this study showed, multiple modes offered the BMLs beneficial features (Williams et al., 2019), benefits that appeared dependent on the co-constructed and multiparticipant discourse that occurred as the meanings were being made (Vygotsky, 1981; Williams, 2020). This suggests that BMLs benefit from shared spaces in science where discourse is encouraged and multiple resources are available (Lemke, 1990; Williams et al., 2019). This study showed that when these spaces were created the BMLs drew from their semiotic repertoires to solve science problems (Williams, 2020). Another reason to encourage these spaces in science is because language is multimodal (Kress, 2010; New London Group, 1996). This includes the language of science (Lemke, 1990). As a result, the affordances of different modes helped to constrain science meanings and narrow students' focus (Prain & Tytler, 2012). Likewise, the re-representation or translation between modes builds science knowledge (Gooding, 2005). As a result, this study confirms that meaning from one mode, such as drawing, does not allow a BML to realise their full meaning-making potential or understanding of a concept (Kozma & Russell, 2005; Lemke, 1990). Opportunities must be provided for the use of other modes to ensure BMLs have opportunities to make meaning and learn science concepts. Access to multiple resources allows for translanguaging (Garcia & Wei, 2014).

This study showed that translanguaging is not a simple practice of substitution between modes. Instead signs from multiple modes were created and used in diverse ways by the BMLs (Williams, 2020). At times of integration some modes appeared unified, as oral and gestural meanings accompanied one another (Kendon, 1980). However, on closer examination this research showed there were at least four distinct ways in which gestures were employed by the BMLs to support their meaning-making (Williams, 2020). Similarly, inspection of the visual mode showed visual meanings granted the BMLs exposure to some meanings that were not discovered in any other mode and deepened their understanding (Ainsworth & Van Labeke, 2004; Gilbert & Treagust, 2009; Tippett, 2016). It is fair to deduce then that gestural, tactile and visual meanings were pertinent to the BMLs production of scientific explanations of an unknown phenomenon (Williams et al., 2019; Williams, 2020). Since non-linguistic modes were found to add value to BMLs in the science classroom, science teachers are encouraged to model the use of multiple resources and provide meaning-making links between modes that include gestural, tactile and visual modes (Williams & Tang, 2020). This has been observed in a study focused on competent science teachers from around the world (Tytler et al., 2017).

7.5 Conclusion

With a growing number of BMLs in science classrooms to date, this research aimed to address the BMLs' needs. In an initial examination of the literature intended to support BMLs, a pattern was uncovered that set this research agenda. Researchers and teachers used multiple modes consistently for BMLs in science but were unable to clarify in detail why and how these modes were used. To provide answers, a contemporary language theoretical lens combining social semiotics, multiliteracies and translanguaging presented the possibilities of non-linguistic modes, yet few studies had applied a comparable framework. Similarly, few studies had provided detailed data regarding how BMLs use non-linguistic modes in science.

Thus, a bifold research agenda was established. First, to apply contemporary language theory to investigate ways to support BMLs in science. Second, to educate the science community of what a contemporary language lens offers BMLs. Four objectives were created to achieve this research agenda. The first research objective, to reconceptualise the results of past studies through a contemporary language framework, was achieved following a systematic review of the literature and corresponding empirical study (manuscript 1). The investigation uncovered ten inferences that suggested non-linguistic modes offered support to BMLs. The inferences were categorised under the following headings: aid science discourse, accommodate multicultural learning spaces, and ensure equitable learning for diverse science communities.

The subsequent three objectives aimed to discover more empirical evidence for how BMLs make meaning. A case study was constructed to observe ten Grade 5 BMLs' meaning-making in science in a bilingual school. Each remaining objective, and subsequent manuscript, focused on a different area of the BMLs' meaning-making. First, the outcomes of multiple modes, then the uses for gestural and tactile modes, and finally the use of a visual metalanguage. To satisfy these objectives and ascertain in-depth details of the use of modes, a multimodal instructional approach

(MIA) was developed from the Thinking Frames Approach (Newberry & Gilbert, 2016). Each MIA lesson required the BMLs to construct a scientific explanation of an unknown phenomenon. To achieve this, they constructed meanings through three dominant modes including, oral, visual and written modes.

For objective 2, a thematic analysis was conducted using the semiotic units found throughout the sequence of modes in the MIA. Results showed the approach offered BMLs multiple beneficial outcomes. This was because the semiotic potentials of the different dominant modes offered BMLs a varied source of meaning-making. Stage 1 of the MIA with a dominant verbal mode ensured that concepts were identified and discussed that prompted the students to re-enact the phenomenon in question via model manipulation with further reliance on gestures. Stage 2 of the MIA, with a dominant visual mode, demanded the students choose what to depict. This required an inspection of the necessary participants in the drawing. During the drawing taxonomy relationships were formed, forces were named, and the direction of movements or forces was provided. Finally, in stage 3, information was positioned into a sequential order and relationships between participants solidified. The findings suggested that the students' awareness and information regarding the phenomenon became more detailed as they progressed through the stages of the MIA. This multimodal combination provided the necessary inquiry opportunity and language experiences for the BMLs to make meaning in science.

For objective 3, a detailed analysis of the gestural and tactile moves instigated by the BMLs was conducted. Results showed that representational gesticulations and pantomimes made by the students were frequently used in place of verbs and adverbs. In addition, the students used deictic gestures to point at body parts or models which often replaced nouns and positional language. BMLs employed gestural and tactile moves in four different ways. Interestingly, not all ways acted as a substitute for verbal meanings; several ways ensured that gestural meanings illuminated their ideas more comprehensively. For instance, the students gestured when describing the movements of participants in the phenomenon or the direction of forces. At times, these gestural and tactile meanings were translated by students or the teacher into everyday and academic words. As a result, the BMLs' use of the gestural and tactile modes appeared beneficial to their science meaning-making and learning of new words.

For objective 4, a visual checklist was implemented to explore BMLs' exposure to a non-linguistic metalanguage in science. The students' awareness of the visual checklist promoted a discussion of how to effectively explain meanings in visual form. This frequently led to discourse on scientific concepts. Furthermore, their knowledge of the visual metalanguage provided the students with new ways to present science meanings, which in turn exposed microscopic details. Results showed the teacher's prompts to include missing elements ensured meanings in the phenomenon were not forgotten by the students. As the newly added elements were accurately represented, this indicated that the missing elements in a visual representation were not always an indication of a student's lack of knowledge.

For this study, unearthing the issue of BMLs learning science from the deep-rooted beliefs of long-standing language theories was required to expose a renewed lens and innovative solutions. Innovation was necessary to advance this agenda as the issue warranted a solution appropriate for today, the 21st century. Thereby, this study enlisted theories that described the multimodal communication used currently in the everyday life of individuals in diverse societies, and which accounted for the technological advances in communication growing increasingly in significance. As a result, the adoption of such theories appears crucial in this area of research going forward.

As a result of this study, several recommendations for this community have been added in the next section.

7.6 Recommendations to the science education research community

This study has implications for the science researching community due to the combination of eclectic contemporary theories introduced. A contemporary language lens allowed the reconceptualisation of the BML issue in science and broadened the scope of the inquiry (Williams & Tang, 2020). The foundation of inclusivity within contemporary language theories in this study enabled an appreciation of language learners' resources, perspectives and ways of making meaning (Williams, 2020). This shift has the potential to validate all learners and create multicultural learning communities in science. To continue to validate the BMLs in future research, science education researchers are recommended to employ a contemporary theoretical lens.

It is impossible to respect BMLs using theoretical frameworks with epistemologies that consider their language resources as limited rather than growing.

The theoretical framework in this study modelled an ability to produce heterogenous integrations between science and language research (Williams, 2020). This study presented some of its findings to the bilingual education researching community (Williams, 2020). The next step required for the expansion of research on this issue is the incorporation of diverse researching teams from both language and science communities. This would ensure a study has researchers with expert knowledge and conceptions of each area. What was limiting in this study was analysing the results without the interaction of researchers with expert knowledge in the specific modes—yet the addition of experts solely for an analysis purpose could have limitations, as it may prevent open-minded and broad thinking. This may limit the research as new conceptions of the issue are warranted. A more favourable hope is to include an eclectic mix of researchers from the conception of the study, to ensure that multiple perspectives are encompassed.

Bilingual education researchers have already recognised science classrooms in CLIL contexts are a model subject area (Lin, 2006). This is likely because the practice of doing science is multimodal (Lemke, 1990). Contemporary language theories appear to describe that which is already known in science: multiple modes are necessary for doing science (Lemke, 1990). This puts the science education research community in a unique position for studying BMLs, as resources and opportunities to study BMLs' use of multiple modes are available in science. For instance, this study employed an MIA with a sequence of modes to maintain consistency across the lessons to allow comparisons to be made (Williams et al., 2019). The MIA mandated the use of a different mode in each of its three phases, oral, visual and written. This was because in its original context, the objective of the MIA sequence was to support students written science explanations (Newberry & Gilbert, 2016). It is recommended that the order of dominant modes in future studies are grounded in context. This means observing the BMLs prior to the study with the aim of supporting their learning. Making the lessons purposeful for the BMLs from the beginning maintains their respect and values their participation.

Finally, when conducting research that investigates BMLs' meaning-making, caution is recommended to researchers who consider enlarging the sample size. When recording multimodal meaning-making at a sign-based level in this study, analysis of a few minutes of video sometimes took hours to record and interpret each mode. The inclusion of more participants should be balanced with either the addition of researchers or the allowance of more time. Quantitative data, no matter how time-consuming, provided further details that were combined with the qualitative data transcribed in the manuscripts to produce a robust case study.

The advice for the research community continues in the next section, outlining the paths for future research of this issue. With multidisciplinary research teams, including experts in specific modes, future research can provide more focus on each mode. Nevertheless, the integration of modes in translanguaging spaces continues to be important.

7.7 New paths for future research

Following from this study, several next steps are warranted. One step that would be of value to BMLs includes more research into translanguaging spaces in science. A beneficial outcome of the translanguaging noticed in this study was when students translated each other's non-linguistic meanings into academic words (Williams, 2020). Proficiency in academic language is an indicator of school success and university entry. Since this study focused solely on the meaning-making of BMLs, this outcome warrants further investigation. An approach to this might be inspection of multimodal discourse occurring between integrated student groups of BMLs with non-BMLs, as this was an area that appeared underdeveloped in the literature review (Williams & Tang, 2020). From the findings in this research, it seems likely that non-BMLs will add their knowledge of academic words, via academic verbal meanings, in discourse with BMLs. Research that is focused on what multiparticipant multicultural collaborations have to offer BMLs in science, and vice versa, appears worthy.

Another step is to refine the visual checklist used to provide visual metalanguage to the BMLs during the investigation and aimed to achieve the final objective (Williams & Tang, 2021). In its current state the checklist does not show any visual meanings to define the categories. The addition of visual meanings may enhance the checklists' effectiveness for the BMLs as it is clear that multiple representations are better for understanding (Prain & Tytler, 2012). In addition, the final investigation was limited by time, so the BMLs had only one introductory lesson. In future, a longer interval between the introduction of the checklist and a study focused on meaning-making is warranted. BMLs should comprehend the visual elements prior to their use. Likewise, a comparative study of visual explanations from a class exposed to the visual metalanguage and one that is not would be of interest. This leads to another research path, the consideration of a metalanguage for other non-linguistic modes.

An additional consideration for future research focuses on the gestures used in the classroom. The gestural mode played an important role in the meaning-making in this study (Williams, 2020). Yet the investigation of the ways BMLs used gestural meanings led to more questions. For instance, the students sometimes copied and repeated their teacher's and other students' gestures. Usually this was directly following the gesture, but sometimes it was days later in another science lesson. Exploration could include how gestural meanings provide ways for BMLs to make meanings and provide the teacher with a communication path. For this inquiry, research is needed that tracks the use of teachers' and BMLs' gestures over the course of a science lesson and/or science unit. In addition, as language is a cultural construct it can be inferred that the students' use of gesture in this classroom was somewhat encouraged by the teacher's frequent use. However, it would be of value to know *if* and *how* other teachers in different contexts use gesture for teaching science.

Building on the implications of this study, an area of inquiry could be the form of assessment for BMLs in science. When the science teacher embraces a contemporary language framework then they must also reconceptualise their expectations for assessing knowledge. For this study showed that many of the BMLs were able to share their ideas and knowledge by using multimodal discourse, rather than through a conventional form, such as solely a written explanation. Further questions arise. What forms of assessment work best in science for BMLs? Options for inquiry could include a structured multimodal sequence used for an assessment, or how a teacher draws information from a collection of science experiences that allow BMLs to use multiple modes. Also, if discourse is not permitted in assessment situations, how can BMLs use translanguaging to contribute their knowledge and are they disadvantaged in this form of assessment compared to others?

Another implication from this study was the beneficial outcomes of non-linguistic modes. It seems reasonable to suggest that research embrace all modes found in science. This study focused on three of the non-linguistic modes found regularly in science. The BMLs' use of gestural, tactile and visual modes were accounted for. However, another mode that exists in science is the mathematical mode, which was not explored in this study. This decision not to report on mathematics was largely due to the age of the participants and their curriculum level. As this mode is likely to be relevant in the quest to support BMLs of all ages, studies focused on middle or secondary schools are recommended to include the mathematical mode in their inquiries.

Finally, from the onset, this research was a timely study as was identified by two factors: first, the increasing diversity of school populations around the world, and second, the growing number of schools with bilingual models. For Hong Kong and similar communities, this research is transferable where this model of bilingualism is apparent. Since the BMLs were in Grade 5 in this study, all had some level of English from their previous two years in English science. Perhaps conducting similar research when students are making the transition into English science when they have no knowledge of English, such as in a local Hong Kong school, would be another area of interest that would offer new perspectives.

7.8 References

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Appendix 1 Peer reviews of the published articles

1.1 Peer review of manuscript 1

Reviewer's comments to author

1.1.1 Reviewer 1

Presented article deals with very important and very wide topic of non-linguistic modes of meaning for learners. But this it is very challenging to put such big amount of information into a single article. For now - of course only in my opinion, article needs much more work.

First of all the abstract doesn't give to the reader what is new in this review, why would you like anyone to read it? What is your goal? What is take home message from the article. Why theory of multiliteracies was chosen as a basic one? The last question is the one that applies to the introduction section as well.

Introduction section with all with all sub-sections appearing in it seems to be very chaotic and without a main idea that could lead the reader through the text. Additionally in the section called: Multiliteracies: Language Reconceptualised the author/s refer to the idea of affordances as a diversity of designed elements. While the term "affordance" was recall by James Gibson coined in 1977, (not Kress, Jewitt, Ogborn, & Tsatsarelis, 2001/2014) and according to him (Gibson) it refers to "all action possibilities depending on users' physical capabilities. Affordances are an object's properties that show the possible actions users can take with it, thereby suggesting how they may interact with that object. For instance, a button can look as if it needs to be turned or pushed. The characteristics of the button which make it look "turnable" or "pushable" together form its affordances." (eg. see https://www.interactiondesign.org/literature/topics/ affordances)

So from its origin affordances should be non-linguistic, should refer to pre-linguistic cognition, If the authors would refer to researcher such as McNeil or Adam Kendon where they state the idea that the body expresses certain concepts faster than the mind. Or on the other hand if you want perceive affordances as a meaningful part in meaning-making than Evert should be on the list.

To sum up this comment I see a gap in the wider theoretical framework that would introduce more philosophical and integrative perspective on presented paper. I am also convinced that the authors do not fully understand the idea of synaesthesia, since they call it a process and they attribute a role of translation (or re-representation) to it. Meanwhile it is a specific disorder, that occurs in some minds, and in the article by eg. Simner J (2012). "Defining synaesthesia". British Journal of Psychology (Review). 103 (6): 1–15. everyone can read about problems and misconceptions also among scientists with this term improperly described as eg. “ union of the senses”.

As a reader of such article I would like to know :

- Did the author/s have any hypothesis before starting your analysis?
- Would you call your approach as contributing, heuristic or just reporting?
- What change would you expect to achieve with this article after presenting it to the public?

What is the novelty? Why your approach is interesting/new/worth reading?

- The last question leads us to the commonsense methodology of review, that includes making explicit such elements as:
- objective of the work,
- justification of the choice of the topic of the work and its meaning for a given discipline or field of science, (this includes justification of chosen theoretical framework not just its description)
- the author's point of view adopted when grouping materials source
- purpose and method of using the study.
- novelty of chosen point of view

Some of the mentioned elements are missing in presented article, others are rather implicit in the text.

Additionally, the text is about non-linguistic modes and it has very limited number of such support. I would highly recommend use more visual elements to support your results - even in the form of mental maps – it would help the reader to follow your argument. Especially that by looking at the quality of English language used in the text I might assume that for the author/s English is mother-language, but it is not the case for most of their readers.

1.2 Peer review of manuscript 2

Reviewers' comments to author

1.2.1 Reviewer 1

In the context of Hong Kong where the English language is both an integral part of instruction and of political reality, the study contributes in that way. Also, the increasing demand of English in countries like China for knowledge sharing and economic growth, the importance of understanding the challenges and opportunities of teaching science in a foreign language (English) in K-12 is of value. However, the author/s should consider following suggestions for improvement:

1. Page 3. "The decline was linked to the politically motivated decision to return to a Chinese LOI in 1997…"
2. Page 4. "Studies of ELLs in English science have yet to inspect in what ways meanings were made." This sentence and the subsequent assertion of "exploring the gap" is not clear. Is the author/s exploring the "meaning making" in science classroom with ELL students or is it about "what kinds of provision are required for ELLs in science?" What is also not clear is what does the author/s mean by "provisions"?
3. Page 4. "This study, interested in exploring the learning of ELLs, was positioned in the sociocultural paradigm…" I encourage the author/s to state what they want to explore in a more direct way because that allows for better communication with the reader. One way to make a more direct and clearer statement could be with active voice in writing. I encourage the author/s to find ways to state their thinking and arguments directly rather than in a more round about manner.
4. Author/s would benefit by expanding the ideas, presented example/s, and specific concepts. Instead at a number of places the ideas are not explored to strengthen the argument in the literature review sections. For example: (page 6) "For example, Kress, and van Leeuwen, (2006) draw on metafunctions to support their examination of images."; (page 7) "…the ability to do so can be described as "representational competence".." etc.
5. I encourage author/s to be express in a manner that is not too deterministic. Page 9-10, I would encourage that the sentences be restructured so that the assertion is a bit more tentative rather than deterministic "Moreover, there is currently no research which examines how multimodal approaches actually 1 offer support to

ELLs. This study seeks to rectify this assertion by ascertaining how meanings are made by ELLs within a multimodal approach in science lessons." As researchers we can't know all the research carried out by many researchers so instead of stating that "currently no research", I suggest saying "currently more research is needed" and also instead of "to rectify this assertion by ascertaining", I suggest "This study seeks to add new understanding as to how ELL students make meaning in science lessons when teachers use multimodal approaches to teaching and learning." Obviously author/s can decide other ways to expressing this. One written above is one way to state.

6. Methods:

(a) Authors would benefit by writing their question just before the Methods section with a title "Research Questions". This is more of a stylistic thing.

(b) Authors need to expand a bit more stating why and how a "case study" approach is suitable for this study. Also the authors need to be careful that Yin and Marriam's ideas of "case study" are different and also are based on different paradigms. Yin's method takes a more positivistic view of case study but Marrian's takes more of an interpretive and constructivist view. Therefore I encourage the authors to not mix them up at one. There is a wonderful reading readily available on the web that discusses differences in case study methodology/methods between Yin, Marriam, and Stake titled "Yazan, B. (2015). Three Approaches to Case Study Methods in Education: Yin, Merriam, and Stake. The Qualitative Report, 20, 134-152.

Participants: Some more information about the researcher-teacher would add to the depth as well as to the understanding of the analysis later. For example, language ability (English etc.), educational background, what is the status of Putonghua language in HK and larger Chinese community, etc. Similarly some more description of the students and their background, in general, would be useful. I'm not suggesting description of all 10 students but some sense of overall social, cultural, linguistic, economic background would help a lot. May be a table could suffice this too.

7. Figure 3: Print needs enhancement as some of the writings are missing such as instead of "coin" the drawing only shows "ion". Also, the drawing itself needs enhancing, the authors could retouch the photo or ask the student/s to retouch so it's clearer.

8. Data Collection:

Please describe the lengths of video recordings and how many lessons in total including the lengths of each lessons recorded or an average. If field notes were taken that would be good to describe too. Were artefacts of student works collected from all students or just a few and whatever is the case, please describe the rationale for the decision.

9. Analysis:

Most of the details of analysis are good; however it needs to include some concrete details. (a) I encourage the authors to state what is semiotic unit?; so a reader not in linguistics would understand.

(b) an example of how the unit was analyzed would immensely help a reader to make sense of how findings are arrived at.

(c) page 14, "…metafunctions (described earlier) common to all signs, ideational and textual;" but the author does not say anything about "signs". This needs to be included as it is part of the analysis. Also if "signs" is imbedded in the other two (ideational and textual) then the authors would be better off stating that too.

(d) Finally a sentence or two at the end of this section stating the findings that would be presented in the next section would help the transition from "analysis into Findings". Thank you this was a necessary addition to help the article flow and it has therefore been added.

10. Findings:

(a) The introduction to the findings could be shortened and some of the writing could be moved to discussion sections pages 15-17. This could be shortened to 1 page. I encourage removing the first paragraph and may be utilizing it in discussion sections. Beginning with paragraph 2: "These findings will be discussed in four episodes below. The episodes were…"

(b) The title of the findings as Episode 1, 2, … could be enhanced by adding a more descriptive title. For example it could be "Episode 1: Multiple modes and meaning making" etc.

(c) Episode 1: Page 20, "… model manipulation as a representational mode to test his own theory." I encourage the authors to be careful about using the word "theory". The meaning of "theory" in science is different from how we use in everyday language. So in this case, it would be better to replace "theory" with "idea" or "suggestion" etc.

I encourage authors to give as short summary (couple of lines) at the end of episode 1 before moving to episode 2 and do the same for each of the episodes.

(c) Suggestion, "Episode 2: Interactions of Modes for ELL Learning". The episode 2 could be enhanced by drawing portions of quotes from table 1 and 2 to help the reader. What I find missing is how multimodal explanation is helping build meaning for students while learning.

(d) Episode 3 is how engagement and questioning pushed students to come up with an answer showing understanding. What the authors could have further elaborated in this section is that how students made meaning and what that meaning making fit in the drawing-text-oral interactions in learning science.

(e) Episode 4: Page 27, "Initially, Stage 1 provided a 1 n opportunity for ELLs to identify concepts and share prior knowledge as seen in Tables 1-3." The findings before this section haven't presented anything related to "prior knowledge" and also the authors haven't really pulled out "prior knowledge" in earlier episodes. There is enough to pull this out in earlier sections so I would like the authors to do that. If not then adding "prior knowledge" in episode 4 and connecting to previous episodes is misleading and confusing. "Model manipulation" (page 27) is not talked about in episode 1, so I would like the author to do so in that section before adding here. "drawing prompted students to think more critically" needs to be added in the episode 3 as the authors haven't said anything about critical thinking in that section. So adding here comes out of nowhere. I encourage authors to add this in their finding section/s.

(f) Episode 4 seems to be about summarizing the findings from episode 1-3. But I would encourage the authors to pull Episode 3 to Discussion sections. The layout is more like a quantitative study paper rather than qualitative, thus the variation. I'm not saying this is not do able but the qualitative analysis suffers from more nuanced presentation. I encourage the authors to enhance the analysis in a deeper way in episodes 1, 2, & 3 rather than cover in Episode 4.

11. Discussion:

This section is weak and needs to match \the evidence from the findings sections.

For example the authors state that "MIA was found to support the development of deeper meanings for ELLs because it ensured a multitude of semiotic units and scientific representations were constructed."; but in the findings the authors do not present anything related to "deeper knowledge" that a reader could figure out. If there is then the authors didn't make that clear. Similarly, "..ensured variety in the meanings that were made.." the authors aren't clear about meaning making in the analysis. Its implied but not clear. Is meaning making is about learning concept or is it about application or connections to real life situations. Similarly, what is not clear and not presented in the findings is "language experiences" that ELL go through or have opportunities for. Language use in class for ELL is not clear: Is language use for social interactions in class or scientific language for presenting or showing science learning. In another word what is the purpose of learning language the way science demands vs everyday social interactions.

12. Implications:

Seem reasonable in that they present the importance of multimodality of instruction for ELLs.

13. Language:

Please edit language (grammar and syntax). At some places word choices are distracting.

1.2.2 Reviewer 2

This research is a meaningful study that explains the process of ELL's meaning making of scientific concepts through case study methodology. There is an increasing interest in how multiple representations and language learning are related in the context of science education.

Even this case study does not provide enough exploration on the phenomenon.

However, it is not enough to deal with various types of science learning situations as research topics. It is thought to be a stepping stone.

Since the English sentences of the expression which cannot be easily understood throughout the manuscript were found several times, it is thought that the correction is necessary.

In addition, it is helpful to explain the behaviour and meaning of each picture with the figure in the study results.

Therefore, it is recommended that authors modify the article so that it can be read more easily to the reader.

1.3 Peer review of manuscript 3

Reviewer's comments to author

1.3.1 Reviewer 1

The manuscript offers an interesting look at communicative repertoire as a mechanism for language and content learning among Chinese fifth graders in a science class. The specific focus on the use of linguistic and non-linguistic modes and their usefulness for learning is particularly interesting and deserves more attention in the literature. The overall quality of the manuscript, show potential for publication in BEB if the article is carefully revised. Below, I offer several suggestions for revision.

Title: The title is confusing. I would recommend something much less loaded with jargon to welcome readers to this very interesting and carefully executed study. I do not think the term synaesthesia relates especially to the study and would remove it entirely from the manuscript or really explain what it is and why this concept is important here.

Introduction: The first sentence is confusing because of the mid-sentence citations and acronyms. I recommend focusing on making a readable first sentence and if desired putting Garcia 2009 in a foot note—although it is hardly necessary at this point, being the default nomenclature for this group of language learners.

Pg 3 (author pagination) the authors state that the LOI for Earth Science is Chinese while the LOI for physics is English, but I wasn't sure if this was for a particular school, since the authors previously stated that preferred schools create their own unique bilingual models.

I was also unsure if there are political ramifications to referring to bilingual students in Hong Kong as Chinese? Is this a specific group of migrants that are being discussed or are these simply natives of Hong Kong who are multilingual? More information would be helpful in understanding the study.

Pg. 4, it is not really accurate to say that the theory of multiliteracies "offers language features". It is an unwarranted claim that few studies focus on the benefits of non-linguistic modes (pg. 4). There are literally hundreds of studies on this topic. The authors need to complete a thorough systematic literature review. This will make the contribution of this study doubly relevant because it will connect to the literature in the field.

Overall, this section does not set up a good case for the study and needs to be rethought. Why is this research important? Where does it fit into the literature in our field? How do the setting and methods make it unique?

Theory & Literature: The literature review is inadequate in its current state (see note above). A theory of multiliteracies is well done but not really enough here because it does not fully establish how these modes form part of a system of communication that can be used for learning. I recommend looking carefully at the literature on multilingual repertoire (Gumperz) and communicative repertoire (Betsy Rymes) as well as Garcia and Wei's recent book on translanguaging. Each of these theoretically rich frameworks can complement the way that multiliteracies is used in this study and better frame the study.

Finally, there needs to be some mention of collaboration and collaborative learning in science. That is the setting for this study and for the recommendations that follow from it. In research on language use and language learning, context matters.

Method: More information is needed about the sample. Who are these students? Who are they in comparison with the school they are in and other schools in Hong Kong? Was the sample the whole classroom or only some students? How was the sample chosen?

More about the curriculum in this science classroom would also be useful to set the stage.

Examples of coding would be helpful in understanding how coding was developed and applied to these data. Your description is thorough, but it is abstract. The example that you provide on page 13 is very helpful and I think a bit more of this type of detail would really help.

Findings: I really enjoyed reading through the findings section. I learned a lot. There were several instances where clarity could be improved.

Conclusion: The limitations section should be more specific. The two sentences there were not particularly informative about the actual limitations of this study.

The first sentence under the heading "implications for content-based science classrooms" is ungrammatical as is the sentence following it. The implications section is long and not particularly compelling. I would recommend carefully editing this to include only implications that directly link to the findings in this study.

Overall: Although the writing is generally readable, there are many line editing issues that should be addressed, including an extreme number of midsentence citations, random capitalization (and lack of capitalization), redundancies (e.g. varied in the 3rd line of the manuscript), meandering sentences (e.g. the first sentence in the manuscript), use of determiners, quotations, and citations.

I hope that these comments are helpful in revising your manuscript.

1.4 Peer review of manuscript 4

Reviewers' comments to author

1.4.1 Reviewer 1

This paper is dealing with the outcomes of introducing the visual metalanguages in science learning and I really enjoyed reading it. This paper is well-written and provides very insightful result to science education. I think this paper can be accepted with minor revision.

It would be better to show this research has been done in Hong Kong in the title. This might help readers get some sense of the context where these fifth graders have. In addition, as our journal covers the issues in Asia-Pacific area, showing that this paper dealing with students in Hong Kong can help researchers in similar situations (Asia Pacific regions). Personally I think this paper very fits to APSE journal.

Authors revealed that the teacher-researcher as limitation of this study. However, I don't really think this is a limitation. Please explain more about the author who was teacher-researcher and this might help to make this paper stronger. For instance, how knowledgeable is this teacher-researcher about this topic and how long their relationship have been lasted and so on.

This is all my suggestions and look forward to reading it in APSE website soon.

1.4.2 Reviewer 2

This manuscript presents an interesting study on the use of visual representations for constructing scientific explanations, guided by the proposal of a visual metalanguage for science education drawing from the authors' previous work. Thank you for sharing this interesting research, I found the focus on working to support students' awareness of the form, function and constraints of the visual mode intriguing, and this study has the potential to contribute new perspectives to the field. I recommend revision of the manuscript in three ways prior to being considered for publication: i) to better situate it in a broader literature base, ii) to critically unpack objectives for students' science, and ii) to have a careful copyediting for clarity throughout. The sections that follow elaborate these three points and also provide further points for consideration. I hope the below comments are useful towards revision.

The focus on working to support bi/multilingual students' access to the visual mode is valuable, and the implications of this research can extend to a diversity of APSE readers. The manuscript begins by making a point that the focus on metalanguage for science literacy is underexplored in the field, and while there is certainly a very limited research literature as regards metalanguage for science literacy specifically, there is a fairly extensive literature base on metalanguage in education research in general, in particular research targeting literacies. Consider drawing on some of the broader research literature on multiliteracies to clarify some grounding perspectives on how metalanguage can contribute to students' understandings before making the point that metalanguage is underexplored in science education specifically. For example, the third paragraph currently begins with "Despite our increasing understanding of the visual mode, few educators have explicitly taught emergent bi/multilinguals how to utilize the visual mode as an additional resource, besides the LOI, to construct scientific explanations", without much elaboration on what these increasing understanding in the field are. Here there could, for example, first be perspectives from the wider research literature before then moving into how this is an underexplored area as regards students' construction of scientific explanations.

Further, although it is accurate that few researchers "have explicitly taught emergent bi/multilinguals how to utilize the visual mode as an additional resource, besides the LOI, to construct scientific explanations", there are researchers in science education that have elaborated the value of teaching students how to use visual representations as resources. Indeed, the focus on the visual mode as a resource beyond the LOI is an underexplored area explicitly, and this manuscript has the potential to make a strong contribution, especially given the dearth of literature in this area. However, there are certainly scholars that have underscored the value of working with students to understand the role of visual representations and their construction. For example, some of Wolff-Michael Roth's earlier work from the late 1990s and early 2000s regarding representations comes to mind. Elaborating related perspectives from the literature could provide a further basis for understanding the contribution of metalanguage for science education and with bi/multilingual students specifically. Consider elaborating a bit on the work that has been done in science education which emphasizes the value of students understanding the form and function of representations, and then drawing links to this work and metalanguage with bi/multi-lingual students.

Methodologically the manuscript is solid. The social semiotics perspective is appropriate, the research questions are appropriate, the data is presented in a compelling way and the methods are well elaborated. In particular, the layered approach provides a complex view on students' collaborative construction, (p. 20) "To further understand how the visual metalanguage shaped the students' visual representations, we examined their group discourse as they discussed how to draw"

The aim of the study is to"reveal insights into the affordance of a visual system and its metalanguage in supporting science learning for a group of emergent bi/multilinguals" yet it is not clear how 'science learning' is positioned here. It would be interesting to read more about how the expectations for the collective construction of the representations were made clear to the students. "…groups were unable to include all the necessary visual elements, their visual explanation of the phenomenon was considered incomplete or inaccurate". What was the objective as presented to the students? It is stated that "The excerpt shows that the bi/multilinguals cognizance of the visual metalanguage enhanced their determination to achieve their objective - to visually explain the science phenomenon", what further guidelines were they provided with? Did the students know how many elements should have been included to be "accurate"?

Relatedly, "We reveal the types of common inaccuracies and specific missing visual meanings". Did the students know that there was a given set of visual meanings expected as a product?

Consider elaborating how the assignment was introduced to the students. For example, missing elements are a central point of inaccuracy in the students' representations, how was the expectation of how many elements to include made clear to them? A similar question arose in reading: "For example, the lungs must be inside the shape of the chest, yet this visual elements appeared to be missing in several of the visual representations from each group". It would be interesting to read more about what the guidelines were for the students as to how to complete the representations.

Other points for consideration:
The point that "drawing is not an innate skill that children already possess" (p. 5) was surprising given the perspectives of the manuscript on representing as social practices, perhaps this is intended to refer to scientific drawings / representations?

How did the choice of new terms emerge when renaming the constructs for use in teacher education? For example, while I can understand how association became relationship, I wonder how modality became believability? (p. 8) Consider unpacking a bit.

"All lessons were multimodal in nature" (p. 9) What does this mean? It seems that with the frameworks guiding this manuscript all lessons would be multimodal in nature. Consider elaboration.

The manuscript will benefit from a careful copyediting for grammar as well as clarity.

1.5 Peer reviews of manuscript 5 (see Appendix 4)

Reviewers' comments to author

1.5.1 Reviewer 1

Thank you for addressing some techniques for ELLs in science - this is an increasingly important area for all science teachers! Your focus on inquiry science and engineering design for ELLs is commendable - thank you!

Most manuscripts I read I grasp quickly what the author is presenting. I found this manuscript confusing and even with multiple readings couldn't quite figure out what the author is suggesting. I would welcome more ideas for successfully worked with ELLs, especially with the added focus on this population under ESSA, but I couldn't quite sort out what was being offered in this manuscript.

The author suggests grouping students with all levels of English speakers in each group and gives pointers on how to encourage good cooperative learning skills, such as using a talking stick and considering all input prior to action. The manuscript would be greatly strengthened with additional explanation of how the "extensions" are added to the lesson - are they done outside regular lesson time? Does the author spend an additional class lesson on each extension? The actual science lesson is not described, thus materials are not described; it is assumed the techniques presented are applicable to science notebooks and engineering design.

NGSS is referenced, but the connections are to specific science activities which are not clearly described in the manuscript. The ESL techniques presented in the manuscript draw on a lesson the author has correlated to the NGSS, but the techniques themselves are not directly correlated to the NGSS. The only way to resolve this is to either exclude NGSS altogether or add a full description of the lesson in which the ESL techniques were employed. It is my opinion the ESL techniques are a pedagogical suggestion, rather than a content activity, and maybe don't need to be connected to the NGSS...?

I struggled to fully comprehend what the author was offering. Because the technique was supposed to apply to any science lesson, and this was illustrated with one lesson while other lessons were also referenced, I found the manuscript confusing. Items described, such as the "placemats" were not pictured, yet items that were not directly discussed in the manuscript were pictured (like boats and cars - briefly mentioned but not presented in the full context of the extensions).

Assessment is addressed, but I once again struggled to understand how this description was tied to the ESL techniques the author was presenting.

1.5.2 Reviewer 2

This was a wonderful article and I enjoyed reading it! The illustrations on page 15 from the science journal of one of your EL students is amazing. Has that student had the opportunity to share that artwork with his/her classmates? If so, that could be reciprocal teaching and could be added to the article. You might consider talking more about the Hong Kong project, since you have tables and photos with that content included in the manuscript.

I am not sure page 27 is necessary unless there is an explanation of why it is included.

1.5.3 Reviewer 3

The content of your manuscript is through and informative. I would like to see a short section added that tells a cohesive storyline of the events.

Consider aligning to ELL standards instead of CC.

More photos.

1.5.4 Reviewer 4

Good visuals, using a talking object is a good idea, I teach ELLs and this is helpful as well as the questioning.

I would suggest a more specific outline for use with ELLs and their student dialogue so that the photos would match all of the activities. The only activity I read about was the ball drop but the photos showed more activities that were done for force and motion. I teach ELLs, though not in a school for ELLs. I had to read this several times to get the flow. I know it is about making science accessible and allowing the first language to be used also but I do think it would be hard for a newer teacher to follow. Basically the idea is a good one.

The assessments are anecdotal notes, videos, 2D models and photos. There aren't rubrics but the manuscript describes how a teacher would use the student work to assess and the student dialogue would be included as assessment. A beginning teacher may have a difficult time at first since the manuscript is not as specific. I don't think an in service teacher would have a problem.

Safety wasn't included in the manuscript. The activities do need safety issues addressed. The photos didn't show safety although no faces, etc were shown.

1.5.5 Field editor comments

Please consider all comments given from the reviewers. A more clearly defined storyline with specific connections to NGSS is needed.

At this time, you may add 500 words to your manuscript.

Appendix 2 Peer reviews of the conference proposals

2.1 ASERA 2018 conference proposal review

Dear Melanie

Your abstract entitled Using a multimodal teaching approach to support the meaning making of English Language Learners in science has been accepted for presentation at the ASERA 2018 Conference.

Your presentation time slot is strictly 40 minutes, including Q&A.

To be scheduled as a presenter in the conference program you must register. If you have not already done so, please **CLICK HERE** to register. Early bird closes on the 26th April 2018.

Once the program has been finalised, we will advise your presentation date and time.

We look forward to seeing you on the Gold Coast at the end of June.

If you require any assistance, please do not hesitate to contact
Samantha Turner at samantha@conferenceonline.com.au.

Regards

ASERA 2018 Organising Committee

2.2 ESERA 2019 conference proposal reviews

Dear Melanie Williams,

the revision of your proposal has been completed and we are pleased to inform you that your abstract ID **4364271** entitled **GESTICULATIONS AND PANTOMIME REDUCE THE LANGUAGE GAP FOR CHINESE EMERGENT BILINGUALS IN SCIENCE**
has been accepted for Single Oral Presentation at the 2019 ESERA Conference, that will be held in Bologna, Italy, from 26 to 30 August 2019.

Your proposal was comprehensively reviewed and the details of the review are now available here below.

Reviewer comment: It is a very interesting article on a subject that is quite pertinent in many countries.

Reviewer comment: Very interesting study. It would be interesting to know whether bilingual students have to 'invent' alle gesture modes themselves, or whether the teacher might model or support such modes

Reviewer 1 score: **28**

Reviewer 2 score: 26

We would like to thank you for being part of this international event and look forward to your contribution to the 13th ESERA Conference and to welcoming you in Bologna.

Yours sincerely,

The ESERA 2019 Scientific Committee

Dear Melanie Williams,

the revision of your proposal has been completed and we are pleased to inform you that your abstract ID **4365746** entitled **IMPLICATIONS OF NON-VERBAL MODES OF REPRESENTATION FOR LANGUAGE LEARNERS** has been accepted for **Interactive Poster Presentation** at the 2019 ESERA Conference, that will be held in Bologna, Italy, from 26 to 30 August 2019.

Your proposal was comprehensively reviewed and the details of the review are now available here below. The author is invited to take into account reviewers' suggestions and implement them in the presentation**.**

Reviewer comment: The research is relevant and the methodology is adequate to answering the research questions. The arguments are not clearly presented, especially in the introduction. The paper needs to be revised for English language.

Reviewer comment: 1. Research questions: The research questions are answerable based on the study's context; however, the second research question may be reformulated to represent the purpose of "re-conceptualization" or " reinterpretation" of past studies' findings. 2. Findings : Further clarifications are needed regarding the analytical - interpretive scheme that entailed a transition from the first to the second research question and eventually resulted in the emergence of themes and their corresponding inferences.

Reviewer 1 score: 22

Reviewer 2 score: 19

We would like to thank you for being part of this international event and look forward to your contribution to the 13th ESERA Conference and to welcoming you in Bologna.

If you have any questions, please email scientific@esera2019.org.

Again, congratulations on having your presentation selected for the Conference!

Yours sincerely,

The ESERA 2019 Scientific Committee

Appendix 3 The nine multimodal inquiry approach lesson plans

3.1 Biology: The Human Body

Within the Grade 5 Human Body unit the curriculum included the exploration of three human body systems: the respiratory system, the circulatory system and the digestive system. Each of the TFA lessons reflected one of these systems. The skills highlighted in this unit included the ability to ask inquiry questions and create and use scientific models to communicate information and/or elaborate on explanations.

3.1.1 Lesson 1

Human Body	**Lesson 1**
School Curriculum Objectives this Week	C1. The respiratory system supplies oxygen and removes carbon dioxide through the lungs C2. Design and revise a thinking model of how the lungs work, or how oxygen goes in. C3. Develop form and function models of the respiratory system and the lungs. C4. Use simple models to describe phenomena, eg. Form model- showing 3D model of the lungs connected to the heart in a human torso model C5. Use simple models to test cause and effect relationships, C6. Identify limitations of models C7. Identify the evidence that supports an explanation, when constructing explanations of the functioning of the respiratory system. C8. Construct explanations of the functioning of the respiratory system including; how we breathe, and how the exchange of gas (oxygen and carbon dioxide) occurs.
Lesson Objective	To understand how the lungs function and the limitations of models
5 mins	**Engage**: (Whole class) *Setting the Question*: Using the students model they made of lungs the lesson before, tell them that this is closely related to how our real lungs work. **Elicit**: Ask them to place their hands on their chest and breathe in and out. Now ask if they can explain using the model and themselves, how their lungs work? ***How do your lungs work?***
10-15 mins	**Explore**: (Table Groups) *Brainwave*: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* phase; students think about how they can represent what they think happened visually, what should they draw in the to show what is

	happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconceptions: We breathe oxygen, when actually, it is sucked into our lungs as our diaphragm contracts and changes the pressure. Lungs work alone, when actually, the brain senses a buildup of CO2 and tells the heart to beat faster.*
10-15 mins	**Explain**: students (given individual worksheet) attempt to explain in words through the *Sequence* step and then *Paragraph* step **Evaluate**: teacher checks student understandings as they are writing and marks their paragraphs on completion
5 mins	**Elaborate**: Students present in groups there reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend**

3.1.2 Lesson 2

Human Body	**Lesson 2**
Curriculum Objectives this Week	A1. Cells have common parts that help it to function A2. Cells are in every part of every living thing A3. Cells are too small to be seen with the naked eye A4. Cells are shaped differently as they perform different tasks A5. Cells are organized to form a multicellular organism, including tissues, organs, organ systems and the whole organism.
Lesson Objective	To understand our body cannot function without cells and that a cells form is dependent on its function.
5 mins	**Engage**: (Whole class) *Setting the Question*: Show students a model of a cell made out of blocks, one is only one block small the other is 9 x 9 blocks. Ask students why cells must be so small? **Elicit**: Student discussion and first thoughts. ***Why are cells so small?***
5 mins	**Explore**: (Table Groups) Give students the blocks at their tables. *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening.
10 mins	**Explain:** *If students have difficulty recognising the surface area to volume ratio with the cubes, give them a stadium analogy. A small stadium with many entrances is easier for the crowd to get in and out of than a large stadium with few exits.* *See* step; students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from

	beginning. *Misconception: Cells are small to fit in the body, when actually they need to maximize the surface area to volume ratio.*
10 mins	Student (given individual worksheet) order their information and explain in words through the *Sequence* and *Paragraph* phases **Evaluate**: teacher checks student understandings as they are writing and marks their paragraphs
5 mins	**Elaborate**: Students present in groups there reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend**

3.1.3 Lesson 3

Human Body	**Lesson 3**
Curriculum Objectives this Week	D2. Design and revise a thinking model of how food moves through the body. D3. Develop form and function models of the digestive system. D4. Use simple models to describe phenomena, eg. Function model showing the breakdown of oats. D5. Construct a model using an analogy, example, or abstract representation to explain a scientific principle D6. Use evidence (e.g. observations of models, research) to construct a scientific explanation of the functioning of the digestive system including how food is broken down.
Lesson Objective	To understand that muscles are responsible for the movement of through the digestive tract
5 mins	**Engage**: (Whole class) *Setting the Question*: Discuss with students if astronauts eat in space? How? What's the difference between space and Earth? So can we eat upside down? **Elicit**: Short discussion of student first responses ***Why can we eat upside down?***
10-15 mins	**Explore**: (Table Groups) Students inspect the car and its parts and try it again *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* step; students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: Gravity causes food to move,when actually, we eat upside down or in space due to peristalsis; wave like muscle contractions that move the food along.*
10-15 mins	**Explain**: student (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* step

	Evaluate: teacher checks student understandings as they are writing and marks their paragraphs
5 mins	**Elaborate**: Students present their reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend**

3.2 Physics: Forces in Motion

The Grade 5 physics unit was a STEM unit. The knowledge component focused on Newton's three laws of motion as well as understanding the forces on Earth and how to represent them pictorially. The skills section focused on applying the engineering process to solve multiple real-world investigations. Particular emphasis was placed on the importance of defining problems and collecting, analysing and interpreting data.

3.2.1 Lesson 1

Forces in Motion	**Lesson 1**
Curriculum Objectives this Week	A8. Plan and carry out engineering investigations that test Newton's three laws of motion= 1st Law of motion - Inertia - An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
Lesson Objective	To apply Newton's first law of motion to explain a real-world situation
5 mins	**Engage**: (Whole class) *Setting the Question*: Show the stack of coins on the bottle. Ask what will happen if I pull out the HK$100 note. **Elicit**: What do you think happened? Why? Now pull the money out and demonstrate what happens. Was it what they predicted? ***Why do the coins stay on the bottle when the note is pulled?***
10-15 mins	**Explore**: (Table Groups) *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* phase; students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: Friction is only present when something is rubbing against a moving object. Friction can use up the force.*
10-15 mins	**Explain**: student (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps Evaluate: teacher checks student understandings as they are writing and marks

	their paragraphs
5 mins	**Elaborate**: Students present their reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:**

3.2.2 Lesson 2

Forces in Motion	**Lesson 2**
Curriculum Objectives this Week	**A8.** Plan and carry out engineering investigations that test Newton's three laws of motion Be able to explain what Newton's 2nd Law of Motion is - expresses the relationship between force, mass and acceleration.
Lesson Objective	To apply Newton's 2nd Law of Motion to explain a real-world situation.
5 mins	**Engage**: (Whole class) *Setting the Question*: Place the car made in the previous lesson on their desk. **Elicit**: Ask why it moves? ***Why does the car move?***
10-15 mins	**Explore**: (Table Groups) Students inspect the car and its parts and try it again *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* step; students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: Heavy objects will slow down (need less time to slow down) than less heavy items*
10-15 mins	**Explain**: student (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps **Evaluate**: teacher checks student understandings as they are writing and marks their paragraphs
5 mins	**Elaborate**: Students present their reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:** Optional individual research

3.2.3 Lesson 3

Forces In Motion	**Lesson 3**
Curriculum Objectives	**A8.** Plan and carry out engineering investigations that test Newton's three laws of motion Be able to explain what Newton's 3rd Law of Motion is: For every action there is an equal opposite reaction.
	To apply Newton's 3rd Law of Motion to a explain a real-world situation.
5 mins	**Engage**: (Whole class) *Setting the Question*: Build the rocket launcher in front of the children and demonstrate what it does. **Elicit**: Ask them how it works? ***How does the rocket launcher work?***
10-15 mins	**Explore**: (Table Groups) Students inspect the rocket launcher and try it *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* step; students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: An object a person is sitting or standing on doesn't push back with equal force. The person is just resting on it. The reaction force doesn't exist.*
10-15 mins	**Explain**: student (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps **Evaluate**: teacher checks student understandings as they are writing and marks their paragraphs
5 mins	**Elaborate**: Students present their reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:** Optional individual research

3.3 Chemistry: Matter

The Grade 5 matter unit built upon the Grade 4 matter unit and emphasised what matter is, and how it behaves, as well as the differences between a physical and a chemical change. The skills component for this unit was interested in the independent creation of a fair test and manipulation of variables to demonstrate a chemical or physical change.

3.3.1 Lesson 1

Matter	**Lesson 1**
Curriculum Objectives this Week	A1. Matter is made of atoms and molecules. A2. Atoms are too small to be seen with a microscope. A3. Scientists use theories to explain observations. A4. Elements are made of one type of atom and are organized in the periodic table by their chemical properties. A5. An element's properties depend on the structure of its atoms.
Lesson Objective	**Even though atoms and molecules are too small to be seen they are always moving.**
5 mins	**Engage**: (Whole class) *Setting the Question*: Position students standing around the classroom. Ask if they think smell travels? Light the scented candle and ask them to sit down if and when they smell it. **Elicit**: Ask them why they can smell at different times, how does the scent travel? ***How does scent travel?***
10-15 mins	**Explore**: (Table Groups) *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* phase; individual students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: The scent travels like wind through the air.* ***Possible visual elements***: *Association*- perfume molecules escape into air (air molecules), *Movement*- without movement particles will not travel, *Proximity*- why when you are nearer the scent is stronger than when you're further away, the more scent molecules the stronger the smell, Distance, *Microscopic* to show particles. Remind students of different *view* to draw particles colliding- use a (top view/ slide view) projected view (small region)
20-30 mins	**Explain**: students (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps. **Elaborate**: Students return to groups and share their ideas. Student groups create a visual explanation of the phenomenon. Teacher prompt students during discussion of science concepts and visual elements.
5 mins	**Evaluate**: Students present in groups there reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:** Optional individual research

3.3.2 Lesson 2

Matter	**Lesson 2**
Curriculum Objectives this Week	B1. When two or more different substances are mixed, a new substance with different properties may be formed. B2. A physical change is when the substance keeps its chemical composition and properties: mixing, dissolving, melting, freezing, tearing, sawing. C1. Regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter does not change.
Lesson Objective	**Mixing substances can cause physical changes.**
5 mins	**Engage**: (Whole class) *Setting the Question*: Two beakers of water. Mark the water level. Ask students to add salt to one and sand to the other, spoon by spoon and watch what happens to the water level. **Elicit**: Student discussion and first thoughts. ***Why does sugar dissolve in water but sand does not?***
15 mins	**Explore**: (Table Groups) *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* step; individual students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconceptions: the sugar disappears.* ***Possible visual elements***: *Proximity*, relative size, microscopic. *Association,* made up of water molecules. *Exhaustive,* fill up the entire container (partial and exhaustive- inclusive association). *Microscopic,* water molecules are water. If you move the water molecules there is still water "contains" "made up of". Temporal sequence but connective is better, e.g. before and after. Comparative diagram between sugar and sand.
10 mins	**Explain**: students (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps. **Elaborate**: Students return to groups and share their ideas. Student groups create a visual explanation of the phenomenon. Teacher prompt students during discussion of science concepts and visual elements.
5 mins	**Evaluate**: Students present in groups there reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:** Optional individual research

3.3.3 Lesson 3

Matter	**Lesson 3**
Curriculum Objectives this Week	B1. When two or more different substances are mixed, a new substance with different properties may be formed. B2. A physical change is when the substance keeps its chemical composition and properties: mixing, dissolving, melting, freezing, tearing, sawing. B3. A chemical change is when the atoms in the substance rearrange themselves to form new substances with different physical and chemical properties: burning, rusting, cooking, exploding, baking. B4. Signs can be observed to find out if a chemical change has taken place, including: change in color, production of heat, foaming, fizzing, or release of gas bubbles, sound is produced, light is given off. C1. Regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter does not change.
Lesson Objective:	**Thermal energy is passed on during physical changes**
5 mins	**Engage**: (Whole class) *Setting the Question*: Put Ice on 2 surfaces, foam and a ceramic tile. Watch it melt to see which ice cube melts fastest. **Elicit**: Short discussion of student first responses ***Why does the ice on the ceramic tile melt faster?***
10-15 mins	**Explore**: (Table Groups) *Brainwave* step: Remind students to think about what science models might be involved in their explanation. Students use the science models (placemats) to help them explain what is happening. *See* step; individual students think about how they can represent what they think happened visually, what should they draw in the to show what is happening. Teacher support is important in this part to support understandings through questioning and prevent misunderstandings from beginning. *Misconception: what feels warmer is hotter. When something is cold it makes other things cold.* ***Possible visual elements***: Side view, Micro and macro, Temporal-series, Proximity- move away from each other (spacing), Distribution-Ice- way it is melting, point to where it is melting.
20-30 mins	**Explain**: students (given individual worksheet) attempt to explain in words through the *Sequence* and *Paragraph* steps. **Elaborate**: Students return to groups and share their ideas. Student groups create a visual explanation of the phenomenon. Teacher prompt students during discussion of science concepts and visual elements.
5 mins	**Evaluate**: Students present in groups there reasons why and defend their positions with scientific reasoning and argument.
Homework	**Extend:** Optional individual research

Appendix 4 Manuscript 5

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STEM: What's in it for English Language Learners? Extension lessons help ELLs define STEM problems

4.1 How can STEM support ELLs?

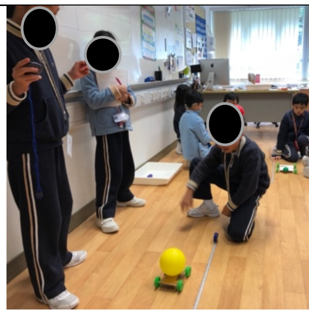
Fortunately for ELLs, STEM lessons include communication forms other than just English language. In fact, communicating in science involves multiple communication forms such as; drawings (mental or conceptual models), diagrams, model manipulation, graphics, mathematics and gestures (Lemke, 1998). These alternate communication forms provide ELLs with a variety of ways in which to learn (or extend) concepts and demonstrate learning (Lee et al. 2016). Furthermore, STEM lessons that are inclusive of an engineering cycle, allow students to *do* science and *be* engineers, including building solutions to problems, thereby, providing an authentic environment as well as multiple ways to learn and communicate through. This means STEM is an appropriate platform for ELLs to develop deeper conceptual understandings and skills. And, since the issues facing my ELLs centred around their English language abilities, STEM opportunities combined with extension lessons provided an opportunity for my ELLs to shine.

4.2 The STEM Unit

Grade 5 ELLs in a Hong Kong bilingual school, were introduced to the needs of engineers in this rapidly changing world, through four challenges (Table 1). The engineering challenges were chosen for three reasons, first their ability to link to local society (Hong Kong), second, for their ability to show how new or improved technologies are required due to societal needs and environmental issues (3-5-ETS1-1 & 2), and, third for their level of safety (see Table 1). Safety is paramount in

STEM since one of the advantages of STEM is the ability for students to take ownership of their learning.

Table 1 STEM unit

Engineering Problems linked to local area (Hong Kong)			
The Star ferry must change for the growing population of Hong Kong, design a boat with maximum passengers possible (Science Buddies, 2013)	China's astronauts need a way to come home safely, that allows for the chance to land on concrete roof (Pasco, 1996)	The air pollution in Hong Kong has reached detrimental levels, we need to design an environmentally friendly car (Science Buddies, 2017)	A typhoon caused Hong Kong island, to be stranded from the mainland, design a way to send food across the harbour (4-H, 2014)
Engineering Constraints			
1 piece of Foil 40 cm x 30cm, 2 x straws	Use any recyclable materials, raw egg	Recyclable cardboard, balloons, straws	Cardboard, plasticine, launcher blueberries
Criteria for Success			
It must remain afloat after 3 consecutive attempts holding the same amount of marbles to be successful.	6-meter drop eggs must be intact with no cracks for success.	Car must carry 10g or 20g weight over 2 meters for success	Rocket must travel 5-6 meters and land inside target for success
			
Stay Safe!			
*	***	**	***
The serrated edge of foil is sharp, allow teacher to hand out foil. Keep water tubs shallow and on the floor. Floor can become slippery, keep a mop/cloth handy.	Recyclable items need to be washed out prior to arriving. Only teacher uses knife to cut irregular shapes. Mark a designated drop site and keep it clear when students drop. Have an adult on stairs where students drop them If landers are to be kept, wrap eggs prior to dropping.	Use a corkscrew at home to make holes in caps prior to lesson. Bamboo skewers are sharp and can be assembled by teacher. Teacher only use knife to cut irregular shapes. Check for balloon/ latex rubber allergies. Wash before re-using balloon. Do not share. Designate a blower to avoid cross contamination.	Check for allergies to blueberries or raisins. Careful management in launching area. Eye-wear (ANSI Z87.1 glasses with side-shields) and sashes may be worn when launching. Check direction of launch and consider possible obstructions or hazards, including people walking past.

4.3 Assessment

Once the challenges were decided it was necessary to develop an assessment rubric (Figure 1) for students and teachers, that included elements of the NGSS expectations for Defining Problems (3-5-ETS1-1) and Designing Solutions (3-5-ETS1-2). Altogether, it included six objectives that linked to the overall performance expectations for the unit and was referred to by the teacher throughout each challenge. In the summative assessment students used it and the engineering cycle as a guide, when they re-designed a challenge of their choosing, independently, after being given a new set of criteria and constraints.

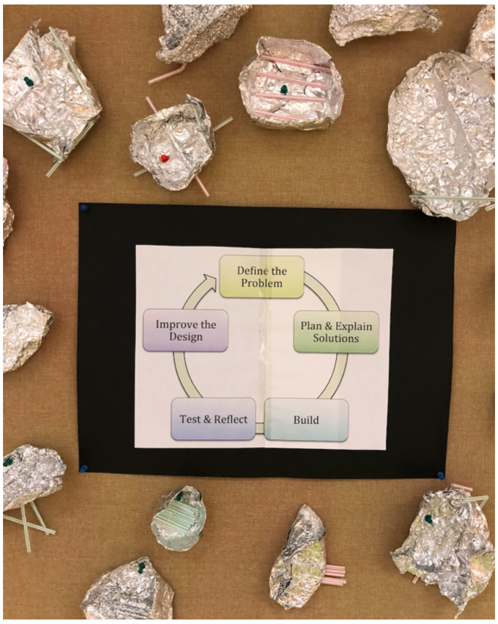
	STEM Unit Assessment Rubric	SUPPORT REQUIRED	ACHIEVING	COMPETENT
	DEFINING PROBLEMS			
1	Use prior knowledge to describe problems that can be solved			
2	Define a design problem which includes criteria for success and constraints on materials			
	CONSTRUCTING SOLUTIONS			
3	Use evidence (measurements, observations, patterns) to design a solution to a problem.			
4	Identify the evidence that supports particular points in an explanation.			
5	Apply scientific ideas to solve design problems.			
6	Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.			

Figure 1 Assessment rubric for STEM unit

4.4 Time necessary

Adequate time is needed for students to progress through the engineering cycle (Photo 1) for each challenge. I found approximately four 45-minute lessons appropriate. Directly following, an extension lesson that focused on the science within each challenge was provided and usually required an additional 45-minute lesson.

Photo 1



4.6 Engineering challenge example

4.6.1 Engage: In the following engineering challenge students became instantly engaged as they were read, "A super typhoon has hit Hong Kong and caused massive waves preventing boats from travelling across the harbour and power outages are preventing the MTR from running. Hong Kong Island has become stranded from the mainland. As an Aeronautical engineer you must design a new way to send food across the harbour but be careful of the strong winds" (4-H, 2014).

As with every challenge, the students began by first defining the design problem (3-5-ETS1-1). "Define the problem is very important before creating a plan or you won't know what to do to get success or know all the problems that need solving…" commented a Grade 5 ELL. She was right and to help, students were asked to list the materials and constraints in their science notebooks (Figure 2).

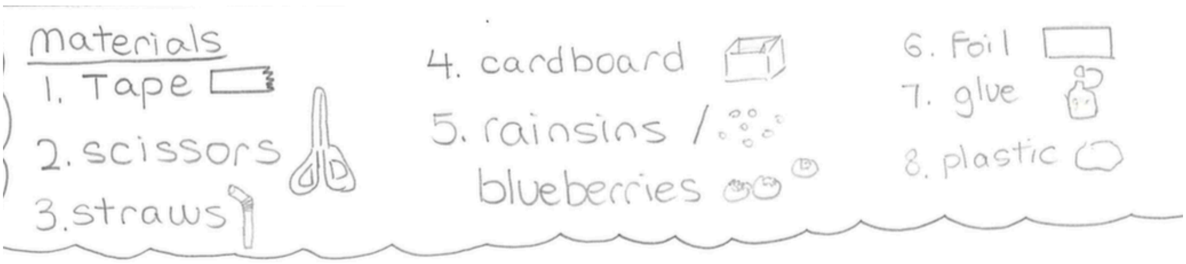


Figure 2 List of materials

To promote the consideration of necessary science concepts (which linked with later extension lessons) students were then asked, "What science words or ideas might be important to consider when thinking about this problem?" To answer this, ideas were first shared verbally, gesturally or by students drawing on the board. Once the class agreed, the teacher listed them on the board and ELLs copied the written ideas and vocabulary into their notebooks (Figure 3).

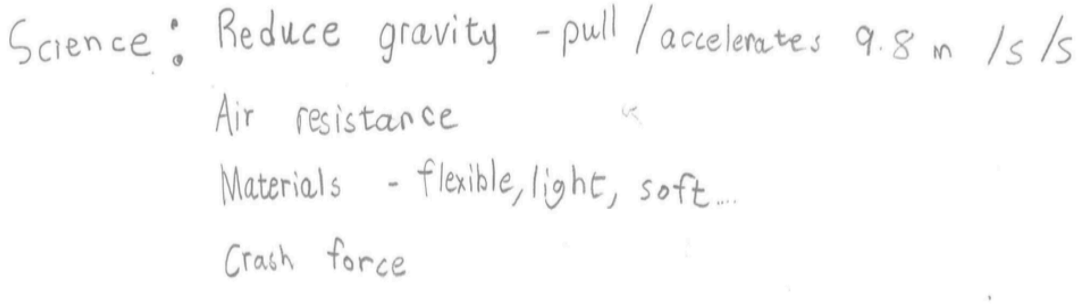


Figure 3 Science ideas

The extension lessons, ensured these ideas became more purposeful for students, who began reasoning their design choices with related scientific concepts. This connection supported the designing of more creative and successful solutions (Figure 4).

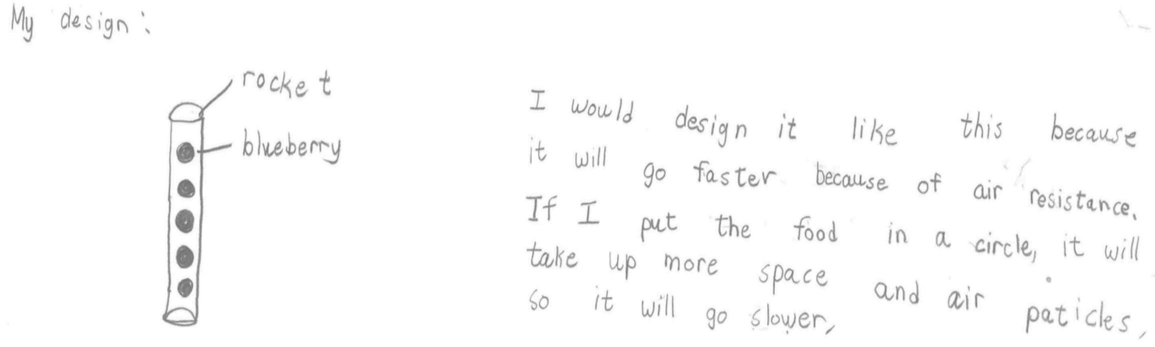


Figure 4 Student solution

4.6.2 Explore: The construction of drawings (conceptual models) was essential when students developed solutions to problems (NRC, 2012 p.54). Students were expected to produce and compare two different solutions (3-5-ETS1-2), plan A (Figure 5) and plan B which stimulated higher-level thinking and peer-discussion. Self-assessment checklists guided students (Figure 6) and included four areas; accuracy, detail, science and creativity.

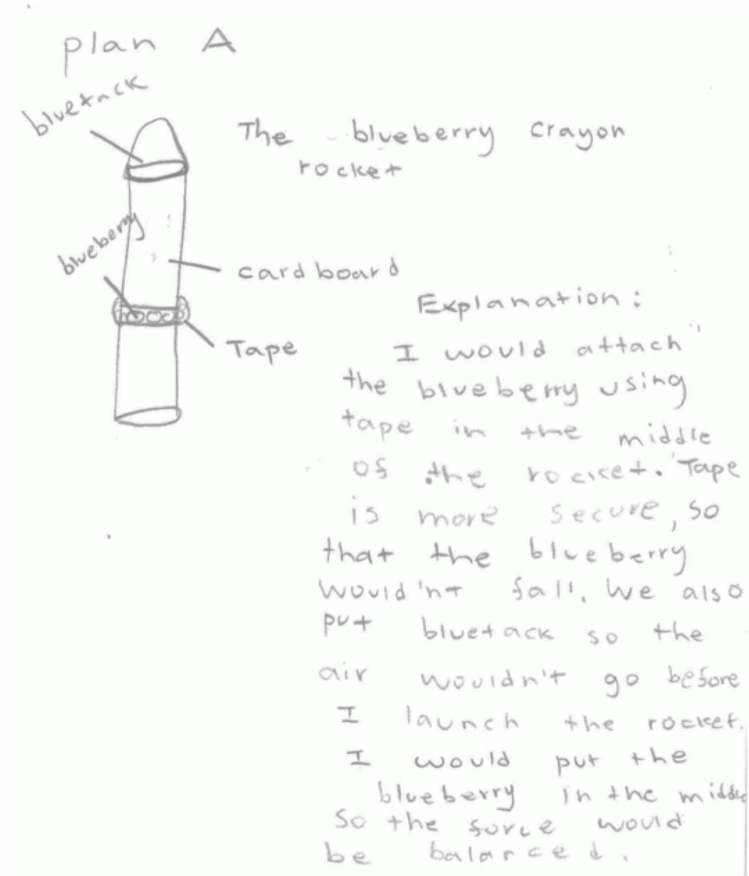


Figure 5 Plan A

Self-Assessment- Constructing Your Solution	No	Some	Yes
Accuracy			
Are measurements recorded?			
Are the measurements accurate?			
Detail			
Is there enough detail?			
Did your friend have any questions?			
Science			
Was a link made to the related scientific concepts?			
If so, are there any missing?			
Creativity			
Are the ideas my own?			
Did I copy from others?			

Figure 6 Self-assessment checklist for designing a solution

Next, students were put into mixed English ability groups, where they discussed how well their designs met the criteria and constraints (3-5-ETS1-2) and decided on a final design in which to build (Figure 7). These groupings offered support to the newest ELLs and strengthened student's verbal arguments.

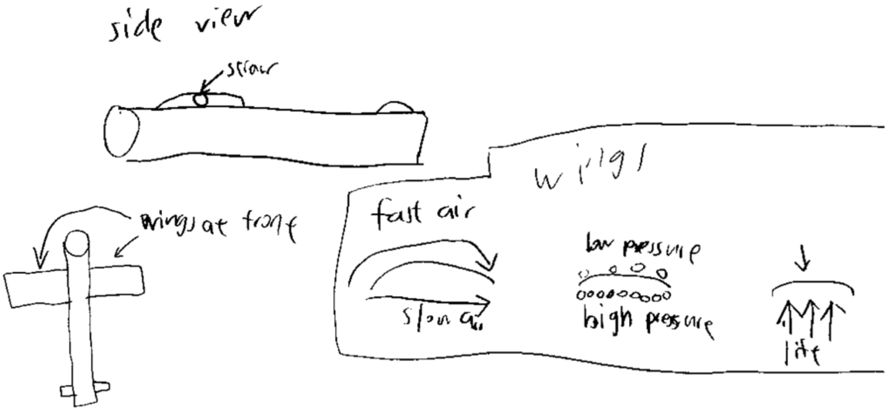


Figure 7 Group solution

To support cooperative learning, students were reminded to listen to everyone's explanations before deciding what to scribe or draw. Using a talking object, may help promote student engagement, since only those holding it can speak while others listen. Rotation of the object allows everyone's ideas to be shared.

5.6.3 Explain: Next, they were required to present, explain and justify their solution to the class (Figure 8). Sentence frames were given to support ELLs to defend their points of view.

We decided to … because …

We predict … will impact … because of …

We predict that if we … then…

Constructing … allowed us to …

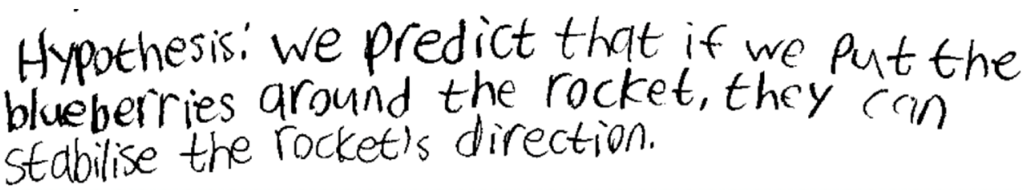
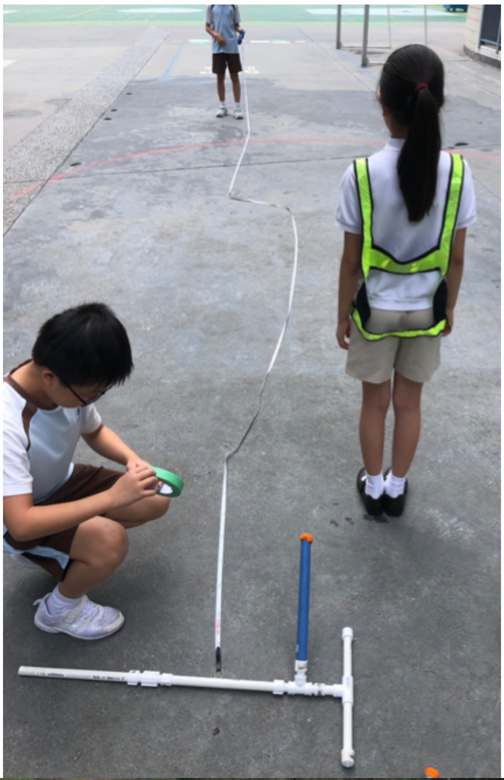


Figure 8 Student explanation

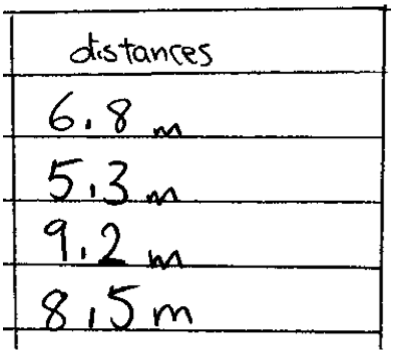
During presentations, each group was permitted to ask other groups one question only, represented by a popsicle stick. This was to ensure careful listening occurred, as well as thoughtful discussion between group members about their concerns or interests of other group's solutions. Collecting the sticks, will keep groups accountable and help you keep track of discussions.

To further support ELLs scientific learning during group discussions; clarifications, translations, questions, and discussions of concepts were allowed to occur in any language. This was because engaging in learning through their mother tongue when discussing concepts ensured they had better access to the curriculum (Lee et al. 2016). Better access means deeper understanding.

4.6.4 Elaborate: Finally, it was time for students to build, test and reflect on their solutions. Rockets were built using card and tape. Blueberries were secured with foil, clingwrap or tape. Before testing secure measuring tape to the ground and mark each meter with coloured tape. During the build and test phases safety was key (see Table 1). The use of multiple launchers (such as three) increases the chance for students to conduct multiple tests in the given time period. Having students line up behind launchers and participate in the countdown for each launch will safeguard that all students are aware and remain at a respectable distance. Eye-wear (ANSI Z87.1 glasses with side-shields) were utilised when launching and safety sashes worn when collecting rockets. We found the force from stepping on the bottle with one foot only was enough.

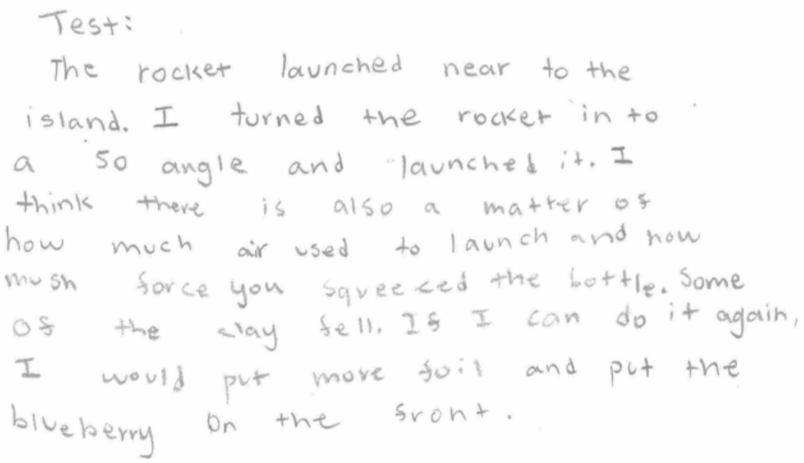


4.6.5 Evaluate: Reflect phase. Students recorded all tests (Figure 9) and reflections (Figure 10, 11 & 12) in their science notebooks. To support reflections questions were provided such as; What did you observe when your group's rocket was launched? How close were you to success? If you could change one thing in the build phase what would it be? Why? When marking their notebooks, I used the rubric and assessed if they were making correct links to scientific concepts in their reflections and looked for areas that still contained misconceptions, which I hoped to address in the extension lessons.



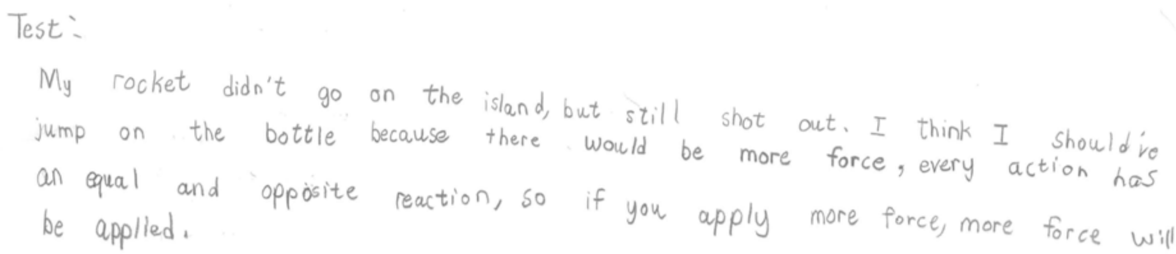
distances
6.8 m
5.3 m
9.2 m
8.5 m

Figure 9 Student data collection of the distances the rocket travelled



Test:
The rocket launched near to the island. I turned the rocket in to a 50 angle and launched it. I think there is also a matter of how much air used to launch and how mush force you squeeced the bottle. Some of the clay fell. If I can do it again, I would put more foil and put the blueberry on the front.

Figure 10 Student reflection after testing



Test:
My rocket didn't go on the island, but still shot out. I think I should've jump on the bottle because there would be more force, every action has an equal and opposite reaction, so if you apply more force, more force will be applied.

Figure 11 Student reflection after testing

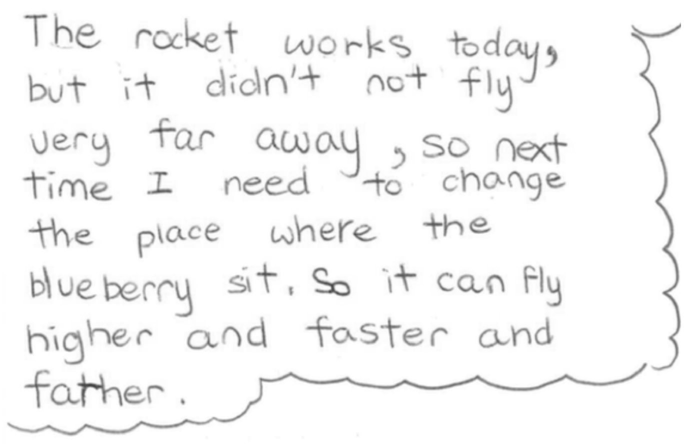


Figure 12 Student reflection after testing

4.7 Extension lessons

Each engineering challenge was followed by a corresponding extension lesson (Table 2). The aim was to extend Grade 5 ELLs' scientific knowledge and develop further communication forms. To do this, several scientific practices of the Next Generation Science Standards (NGSS Lead States 2013) were adopted, since each practice promoted communication in science. Actually, the act of communicating in science is equivalent to learning science. This is because the ability to create, alternate between, or translate from one communication form into another is considered learning (Lemke, 2000). This was the premise behind the extension lessons, during which, collaborative student groups journeyed through a multimodal sequence in order to construct an explanation to a problem question. Each part of the sequence required a particular communication form (listed in bold in Figure 13), nevertheless like good scientists, students were seen utilizing many other forms to support their learning.

Table 2 Extension lessons

STEM Challenge	Extend Lesson	Extension Question	How questions were presented
Ferry	1	Why do the coins stay when the note is pulled?	Demonstration- pulling a paper note out from a stack of coins on a bottle. The coins stay.
Landing Astronaut	2	Why did you receive those results?	Demonstration- use Newton's G-ball to record the time of 1m, 2m, 3m & 4m drops
Green Car	3	Why does the car move?	Model- balloon car
Rocket Travel	4	How does the rocket launcher work?	Model- rocket launcher

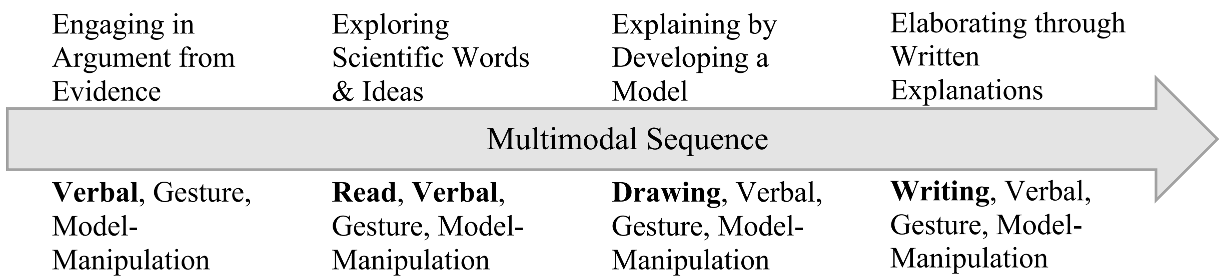


Figure 13 Multimodal sequence

4.8 Engaging in argument from evidence

The question is delivered to the children with: a demonstration, model or experiment, since relia is considered an asset when teaching ELLs (Lee et al. 2016). In lesson 4, How does the rocket launcher work? a model was used. It provoked instant verbal and gestural discourse among students, regarding their beliefs about how the launcher worked. The skills of making a claim came naturally, "that's because the rocket is hit by a force", and "I think the squashing of the bottle pushes the rocket". Students co-constructed by building on the ideas of others. They also naturally debated ideas: "No it doesn't!", "Yes it does, cause…" Which lead them to defend their ideas with evidence for each claim, "No it won't", "Yes it will, cause…that's when the rocket blasts off". The students drew from evidence they had collected in previous STEM lessons as well as, manipulated, pointed to, and used models or demonstrations in front of them. This helped strengthen their claims and reasoning.

For example, one student in each group immediately began assembling the launcher, while discussing what was happening. During the lessons, their passion to explain the question, meant restrictions in English vocabulary did not prevent the ELLs from communicating their ideas through the models, gestures, or other languages. It was great to see students guiding another student's vocabulary. In the exert Billy and Jane are pseudonyms for two of my ELLs.

Billy	"OK so when you smash (smashes hand down on bottle) this, the air comes out"
Jane	"You don't smash it, you step"
Billy	"Step on it"
Jane	"The air comes in"
Billy	"and if this is there"
Jane	"No"
Billy	"I mean I mean I mean, if these two thingies" (points to the parts on the launcher)

These initial discussions provided an opportunity to assess my ELL's understandings and check for lingering misconceptions. I suggest keeping a clipboard and student list handy to record your anecdotal notes on as you move from group to group. As I visited each group my role became about making sure, in their excitement, they were careful not to leave anything out of their explanations. I found myself continually using probing questions to advance their explanations, including;

Teacher	"Now when the rocket gets launched why does it stop?"
Billy	"Huh?"
Jane	"Because there's no more force"
Billy	"Beca beca because air … is get less"
Teacher	"Why would it fall to the ground?"
Billy & Jane	"Gravity!"
Billy	"and, and, it will stop because of air friction"

4.9 Exploring scientific words and ideas

The extension lessons also presented opportunities for ELLs to think outside the box.

They were asked to identify keywords and ideas from four science placemats (Newberry & Gilbert, 2016). Each contained a different scientific model: forces, particles, life, and energy. Using these, they choose words important to each explanation. It was important to check they understood the words they chose, to prevent misconceptions forming later.

This step further elicited discussions from students and required more explanations, as the ELLs defended their choices. "Why do we need (the word) force?" "Cause gravity is a force." Disagreements promoted discussion of concepts and theories, extending their scientific learning. However, it was necessary to make sure the students were focused on answering the question being asked. Sometimes, the exposure to multiple scientific words caused students to become distracted by unnecessary concepts. If this happens, I suggest redirecting by asking students to repeat the question, then ask if the word they chose helped answer their question. Once everyone agreed, it was added to the list. This list (Figure 14) was dynamic and could be modified throughout as their explanation solidified.

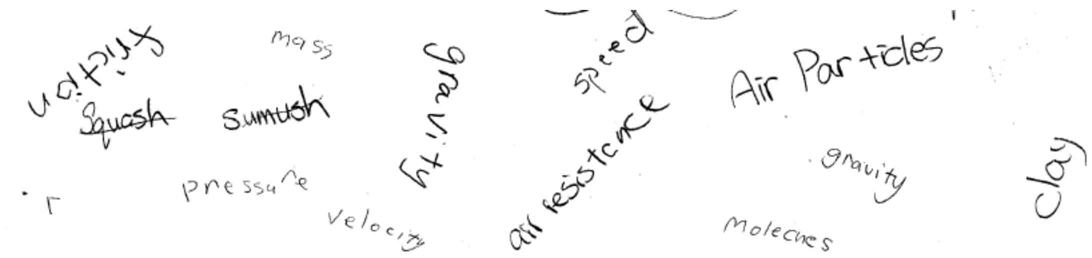


Figure 14 Keywords and ideas selected by ELLs

4.10 Explaining by developing a model

Developing a model to explain the question illuminated student's thoughts on intricate details within explanations. When my students constructed a 2D model (drawing) together, they were confronted by the expectation of re-representing their current explanation into a tangible form. Particularly since the teaching of drawing in not yet prevalent in science. As a result, it encouraged the refining of ideas. Decisions were needed as to what subject matter was necessary and how to add movement or depict change within the model. I recommend teaching visual symbols related to science concepts, in this case, force arrows, before lessons. As it helps provide students with more visual communication capabilities (Lemke, 2000). After all, learning how to represent concepts is a part of learning science (Waldrip, Prain, & Carolan 2010) and thus a necessary teaching objective.

It was necessary to challenge my students to think about how to depict what they wanted to explain. Since, they usually wanted to reproduce an accurate picture of the relia used when the question was set, instead of thinking about what aspects were necessary in the depiction of their explanation. For example, in Figure 15, the unnecessary foot in the first picture, got replaced with the word ‘force’ and an arrow, instead.

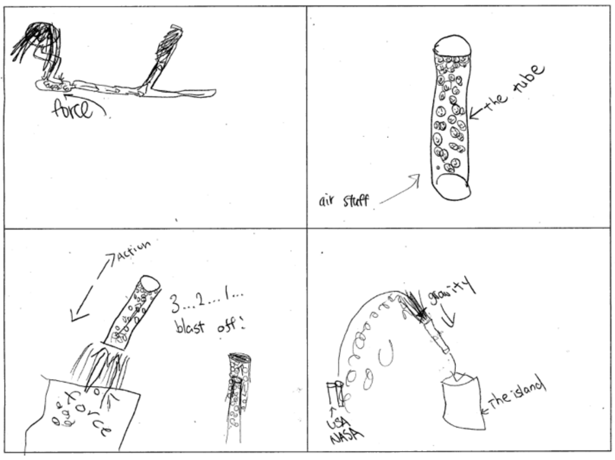


Figure 15 Pictorial explanation to the question: How does the rocket launcher work?

4.11 Elaborating through written explanations

Writing proved the most difficult representation for my ELL’s. So, a further scaffold was provided. Before progressing to a paragraph, students were required to break their explanation into single ideas or phrases (Figure 16). These could then be arranged in a sequential order. Usually, in doing so, my ELLs returned to dialogue to co-construct the phrases. I used this time to assess and correct misunderstandings.

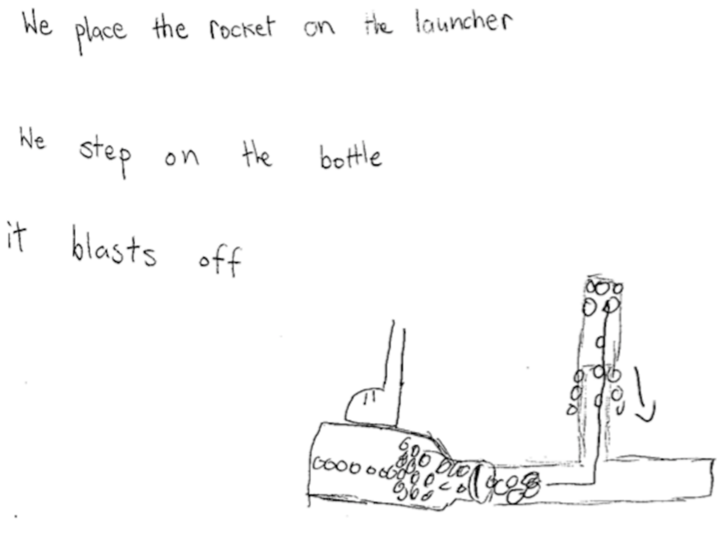


Figure 16 Jane’s sequenced explanation

During construction of the paragraph, another scaffold supported the connection of sentences. This was a list of connective words. At this time, it also helped to remind the students to use their previous representations (drawing, word list) as a support. Revisiting the prior steps, supported Jane in transforming her written sequence (seen in Figure 13) into her final paragraph:

> Firstly, we placed a rocket on the launcher and we step on the bottle, the rocket blasts off. As we step on the bottle the air molecules are pushing its way out the bottle, which creates the force. As it hits the clay the molecules don't have a way out so it pushes back out the side which causes the rocket to blast off. According to Newton's Law of motion for every action there is a reaction. Then, it falls back down because gravity is pulling it down, so it will stop.

4.12 Evaluating science learning

Although assessing all forms of communication would provide a more comprehensive view of the ELL's understandings, time factors did not allow. Nevertheless, assessment of written explanations demonstrated marked improvements in student's science knowledge and English writing. When marking I provided students with written feedback, focused on how accurate explanations of scientific concepts were, in particular the relationships found within (e.g., Cause and effect) and between scientific theories (e.g., forces, energy, matter and life).

4.13 Extension lesson application to STEM challenges

Overtime, student's explanations demonstrated deeper thinking when defining problems. They began to identify more science concepts within problems, often describing more than one scientific theory. Students even began to include drawings (2D models) to support their explanations. Likewise, discussions of engineering solutions, included more detailed spoken and written justifications. Overall, the extension lessons enhanced my ELL's scientific learning and communication skills, thereby, making the science within STEM problems become more genuine. I highly recommend you consider giving them a try.

4.14 Resources

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Science Buddies. (2013). Shipping Science: Building a Boat That Can Carry Cargo. [online] Scientific American. Available at: https://www.scientificamerican.com/article/bring-science-home-shipping-science/ [Accessed 11 Apr. 2018].

Science Buddies. (2017). Build a Balloon-Powered Car. [online] Scientific American. Available at: https://www.scientificamerican.com/article/build-a-balloon-powered-car/ [Accessed 11 Apr. 2018].

4.15 References

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Newberry, M., and J. Gilbert. 2016. Thinking frames approach. Retrieved at https://www.pstt-cpd.org.uk/ext/cpd/the-thinking-frames-approach/index.html

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4.16 Table of links to NGSS

3-5. Engineering Design Performance Expectations		Connection to Classroom *Students…*
3-5-ETS1-1.	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.	Explore the parameters of each problem by listing the constraints of each problem, simultaneously analysing how prior knowledge of scientific concepts might support explanations for their choices regarding solutions.
3-5-ETS1-2.	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.	Students drew two solutions for each problem and justified with reasoning which was more likely to achieve success based on their scientific knowledge and design constraints.
Science and Engineering Practices Defining Problems Constructing Solutions		As well as listing the constraints, students linked scientific knowledge to each problem when defining it in order to construct thoughtful solutions. Eg. Boat = upthrust, surface area, weight Lander = gravity, air-drag, impact force Car= force, speed, friction Rocket = force, air-drag, gravity
Extension lessons for defining problems Developing and Using Models Constructing Explanations		In the extension lessons students • sketched a model to depict their explanation for why the rocket launcher worked • think, verbalize, use gestures, draw, collaboratively to construct an explanation
Disciplinary Core Idea ETS1.A- Defining and Delimiting Engineering Problems: Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different		Students measured and explored the physical constraints as they designed their solution to the problems. Questions arose about materials and students were encouraged to consider all options and make choices based on their knowledge of science concepts, which

proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (3-5-ETS1-1)	were further investigated during extension lessons.
Cross Cutting Concepts	
Influence of Science, Engineering, and Technology on Society and the Natural World People's needs and wants change over time, as do their demands for new and improved technologies. (3-5-ETS1-1) Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. (3-5-ETS1-2)	Challenges chosen demonstrated the changing needs and issues within Hong Kong. **Ferry** -*need* to include more people due to population growth **Car** -*need* for improved technology to get around without adding to air pollution **Lander** -Nasa is always *improving* its designs, to find a better way of landing safely, so is China **Rocket** – Potential hazards of Earth's storms requires *new technologies* to be created