Science Literacy for English Language Learners: A Qualitative Study of Teacher Practices in European Private International Schools

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Abstract

Worldwide, an influx of immigration, has increased the heterogeneity of our classrooms. In light of today's heightened teacher accountability, standards and high-stakes assessment, traditional ways of teaching need to change in order to effectively serve the needs of our culturally and linguistically diverse students. Therefore, a qualitative-interpretive study was conducted with ten science teachers working in six private, international schools based in Portugal, Spain, Switzerland, and Belgium with a focus on teacher perceptions, beliefs, teaching practices, and instructional resources used to teach science to English Language Learners (ELLs).

Emphasis was placed on the specific teaching modalities and resources that science teachers use to support ELLs in their classrooms. It also addressed the needs of teachers to effectively teach science to ELLs. In response to the research questions, the thematic analysis revealed that the teachers working in these schools had a good awareness of ELL needs in science and wanted to make a difference for these learners. They perceived ELLs as quiet, but hardworking and motivated students. To some degree, the teachers used all seven modalities of teaching: reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, and considered multimodality to be the most effective way to make science accessible to ELLs.

Though not exhaustive, this research offers a set of pedagogical tools and resources for *pre-service* and *in-service* teachers to meet the needs of their ELLs in science. Furthermore, based on the teacher responses, the research identifies five key areas which are necessary for science literacy development of culturally and linguistically diverse students. These include: (i) teachers' positive mindset and awareness towards ELLs in science; (ii) school leadership and administrative support for ELLs; (iii) time, multimodality, and specialized professional development (PD) to scaffold science for ELLs; (iv) the provision of realistic opportunities to collaborate with the ELL or English Language Development (ELD) teacher; and (v) co-teaching science with an ELL/ELD teacher. I would hereby like to share the findings of this thesis and make these accessible to fellow science teachers in the hope that they will refer and/or utilize the proposed strategies and resources in their daily practice.

Keywords: science literacy, English Language Learners and science education, multimodality, multiple representations, scaffolding, professional development, collaboration, co-teaching

Preface

This research is not intended to be neither a theoretical nor a philosophical piece on how to teach science to English Language Learners (ELLs), but rather, is designed and presented as a pedagogical tool for future *pre-service* or *in-service* science teachers worldwide. This dissertation offers a myriad of instructional resources and materials that science teachers can use to make science content more accessible to their ELLs, which explains the extensive use of "figures". Although, far from exhaustive, these instructional resources (inclusive of online resources) have been collated and recommended from the extensive repertoire of ten highly experienced science/science support teachers working in six private international schools based in Portugal (6 teachers), Switzerland (2 teachers), Spain (1 teacher) and Belgium (1 teacher). Given this small sample size, it may be viewed only as a "drop in the ocean". However, as with all research, every "drop" can make a small improvement, generally, in our shared knowledge of educational practices, and specifically, in supporting ELLs in science. It is also intended to provide more confidence and inspiration for ELLs to pursue a future career in science.

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List of Abbreviations

AAAS	American Association for the Advancement of Science
AP	Advanced Placement
BICS	Basic Interpersonal Communicative Skills
CALP	Cognitive Academic Language Proficiency
CBLT	Content-Based Language Teaching
CIPP	Cambridge International Primary Programme
CLD	Culturally and Linguistically Diverse
ComPADRE	Communities for Physics and Astronomy Digital Resources in Education
CORI	Concept-Oriented Reading Instruction
CP	Career-related Programme
CREDE	Center for Research on Education Diversity and Excellence
DP	Diploma Programme
EAL	English as an Additional Language
EL	English Learner
ELD	English Language Development
ELLs	English Language Learners
ESL	English as a Second Language
ESOL	English for Speakers of Other Languages
ESS	Environmental Systems and Societies
IB	International Baccalaureate
IDEAS	In-Depth Expanded Applications of Science
IGCSE	International General Certificate of Secondary Education

IPC	International Primary Curriculum
LASERS	Language Acquisition through Science Education in Rural Schools
LEP	Limited English Proficient
LLO	Learning and Linguistic Objectives
LRT	Linguistically Responsive Teaching
ML	Multilingual
MRs	Multiple Representations
MYP	Middle Years Programme
NGSS	Next Generation Science Standards
NSES	National Science Education Standards
NSF	National Science Foundation
PBL	Problem-Based Learning
PGCE	Postgraduate Certificate in Education
PhET	Physics Education Technology
PLCs	Professional Learning Communities
POGIL	Process-Oriented Guided Inquiry Learning
P-SELL	Promoting Science among English Language Learners
PYP	Primary Years Programme
RQ	Research Question
SDAIE	Specifically Designed Academic Instruction in English
SIFA	Science Instruction For All
SIOP	Sheltered Instruction Observation Protocol
SL	Science Literacy

SLIFE	Students with Limited, Interrupted, or Inconsistent Formal Education
STEAM	Science Technology Engineering Arts and Mathematics
STEM	Science Technology Engineering and Mathematics
VIPS	Valle Imperial Projects in Science
WIDA	World-Class Instructional Design and Assessment

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Science Literacy for English Language Learners: A Qualitative Study of Teacher Practices in European Private International Schools

In a changing world, heightened teacher accountability, standards and high-stakes assessment, traditional ways of teaching need to change given the increase in cultural and linguistic diversity in today's classrooms. Worldwide, an influx of immigration has increased the heterogeneity of our classrooms, affecting the process of teaching and learning. In the United States, for example, both the absolute size and percentage of English Language Learners (ELLs) is increasing (National Academies of Sciences, Engineering, and Medicine, 2018). Similarly, in Canada, the 2016 Annual Report to Parliament on Immigration, stated that Canada admitted over 271,000 new permanent residents, the highest number since 2010 (Government of Canada, 2016). It is estimated that 72.5% do not speak English or French (Statistics Canada, 2016). Likewise, in the United Kingdom, other European states, Australia, and New Zealand, the situation is no different. To date, English is spoken by approximately 1.75 billion people worldwide – this is equivalent to one in every four people. The British Council estimated that in 2020, two billion people would use English or would learn to use it (Beare, 2018).

With these global figures in mind, this research aims to explore, identify, and characterize teacher practices in science literacy integration for ELLs with the perspective to better understand ways to make science equally accessible to "All" students. This research also explores the perceptions, beliefs, and needs of science teachers to effectively integrate science literacy for ELLs. Although science literacy is a 21st century goal for all students, greater attention needs to be devoted to instructional practices and resources needed to help ELLs become more scientifically literate.

This research is based in the context of private, international schools in Europe, to better understand teachers' practices for ELLs in the science classroom with a lens on the challenges teachers now face to teach science to ELLs. It is important to mention that although private international schools represent "privileged" contexts, unlike the more challenging realities of public schools, there is still scope to learn from teachers' instructional practices with ELLs in science.

Thesis Overview

This thesis is organized in six chapters. In Chapter 1, the literature review addresses the working definition of science literacy, which is used in the context of this research, as well as the need for science literacy integration, especially for ELLs. It also describes current approaches and programmes to support ELLs and addresses the current challenges and opportunities for teaching science to ELLs – advocating for the use of multimodality and multiple representations (MRs) to support ELLs in the science classroom. The chapter ends with a comprehensive description of the seven modalities of teaching (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology) and contemplates on a more *holistic approach* for ELLs in science.

Chapter 2 addresses my conceptual framework as well as presenting the research questions. These questions intend to globally focus on: (i) teachers' perceptions and beliefs regarding science literacy for ELLs; (ii) teaching strategies or resources to support ELLs in science using different modalities; and (iii) teacher needs to effectively integrate science literacy for ELLs.

Chapter 3 presents my methodology with a focus on my research background, epistemology, and research design, the research context, the recruitment process, the research methods, data collection, and data sources. It also provides an in-depth explanation of my data analysis and its process, and justifies the approaches used to ensure the trustworthiness of my data. The chapter concludes with the ethical considerations taken and addresses the limitations of the study.

Chapter 4 presents the findings on teachers' perceptions and beliefs regarding science literacy for ELLs. It unveils the teaching modalities and/or instructional resources used by teachers to support ELLs in their learning of science. Finally, it addresses the need of science teachers to strategically and positively integrate science literacy for ELLs. These findings are the fruit of many interactions with ten participating teachers and are supported by the evidence gained during the analysis of diverse sources of data.

A discussion of the findings is addressed in Chapter 5. In this chapter, the findings I gathered from the teacher-participants are in most part supported by the existing literature and empirical studies relevant to this research domain. Finally, Chapter 6 provides some concluding remarks on the future of ELLs in science and addresses the contributions of this research to the field and practice of science education for ELLs.

Chapter 1: Literature Review

This literature review addresses the complexity of finding a common definition for science literacy. Hundreds of definitions and interpretations have been proposed since as early as the 1960s, and many programmes have been developed to promote science literacy in schools throughout the world. However, despite all the efforts for science literacy development, the ELL community remains underserved in this domain. This is largely due to: (i) teacher perspectives and views towards ELLs; (ii) the increasing demands, time constraints and lack of institutional structures to support effective collaboration between the science and ELL/ELD teacher(s); (iii) the paucity of effective scaffolding in science for ELLs due to a variety of reasons which will be discussed; and (iv) finally, the need for multimodality complemented by the use of multiple representations in science.

The Need for Greater Science Literacy Integration in Education

Ever since Paul DeHart Hurd's coining of the term "science literacy" as early as 1958, there have been hundreds of definitions of science literacy (Hurd, 1958). In fact, Layton, Jenkins and Donnelly (1994) found 270 meanings and rationales for science and technological literacy. This has resulted in the lack of a shared or common understanding of the mantra "Science Literacy for All." To date, there is no "universally" accepted definition of science literacy (Roberts, 2007), and it has often been referred to synonymously with *scientific literacy*. For the purpose of this research, the term "science literacy" has been used, as this is indeed the term and viewpoint adopted by most science teachers (*practitioners*). Yore et al., (2003) define science literacy as:

> abilities and habits-of-mind required to construct understandings of science, to apply these big ideas to realistic problems and issues involving science, technology, society, and the environment, and to inform and persuade other people to take action based on these science ideas. (p. 690)

Norris and Phillips (2003) emphasize the relationship between two components in science literacy: the *fundamental sense* of science literacy and the *derived sense* of science literacy. Literacy skills such as reading, writing, speaking, listening, etc. represent the fundamental skills needed to learn science content, whereas being knowledgeable and/or scientifically educated in order to make "real-life" decisions, constitutes the derived sense of science literacy. Both the fundamental and derived sense of science literacy work hand-in-hand (Norris & Philips, 2003; Ritchie et al., 2011). Since this research project focuses on teacher practices to support ELLs in the science classroom, it adopts the fundamental sense of science literacy.

To date, there are several programmes aimed at promoting science literacy worldwide. Both Anthony et al. (2010) in North America, and Vieira and Tenreiro-Vieira (2016) in Europe, provide a comprehensive summary of these programmes focusing on pedagogical approaches to encourage reading, writing, speaking, or inquiry, etc. in science. In North America, two renown integrated science and literacy studies include: *Concept-Oriented Reading Instruction* (CORI) and the *In-Depth Expanded Applications of Science* (IDEAS).

CORI was designed to support reading, reading motivation and comprehension strategies in science texts amongst third-graders from two schools in a small city located in a mid-Atlantic state (Cervetti & Pearson, 2012; Guthrie et al., 2004). Five motivational practices were integrated along with six cognitive strategies for reading comprehension. The motivational practices included: (i) using content goals for reading instruction; (ii) offering choices and autonomy to students; (iii) providing hands-on activities along with the texts; (iv) using interesting texts for instruction; and (v) organizing collaboration for learning from texts (Guthrie et al., 2004). Whereas the instruction on "strategy" was intended to support students' development of self-efficacy for reading comprehension. The results were that students in the CORI classrooms were higher than their comparative *Strategy Instruction* and *Traditional Instruction* students on measures of reading comprehension, reading motivation, and reading strategies (Guthrie et al., 2004). Overall, students in the CORI programme showed an increase in the understanding of science concepts, motivation, and text comprehension (Cervetti & Pearson, 2012; Tong et al., 2014).

Similarly, the Science IDEAS research initiative of integrated science and language instruction with a focus on science, reading comprehension and writing, included six main components (hands-on activities, reading, journaling/writing, propositional concept maps, application activities, and integration of prior knowledge/cumulative review) in Grades 3-5 (Romance & Vitale, 2012). This model has proven over the years, that students involved with the Science IDEAS programme have outperformed those students receiving separate language arts and science instruction on a range of reading and science texts, as well as in the areas of self-efficacy and attitudes towards science (Pearson et al., 2010; Romance & Vitale, 2012).

One commonality that these and other integrated science literacy programmes share is the explicit instruction of literacy embedded in science content. Research informs us of the importance of embedding literacy in science content, especially in middle and high school (Shanahan & Shanahan, 2008). This becomes even more relevant for ELLs, who are burdened by the double challenge of learning both language and science content simultaneously.

Embedding the Language and Content of Science

Language and content are interrelated; one cannot exist without the other. Language is the essence of any curriculum and hence cannot be separated from content (Barwell, 2005a, 2005b; Huang & Morgan, 2003). For example, a study by Tong et al. (2014) demonstrated that students receiving a literacy-embedded science instructional intervention, outperformed those who did not. The current dilemma is that many secondary school students are reading and writing at proficiency levels well below their required standard (Shanahan & Shanahan, 2008). Furthermore, Logan and Skamp (2008) as well as other researchers inform us that students' interest in science declines in middle school, especially as they transition from middle into secondary school.

Teaching both literacy and content may contribute to making science more accessible to "All" students, ensuring greater equity. Within the teaching profession, practitioners need to be mindful and recognize that given the changing landscape of their current classrooms, "every teacher is a language teacher" (Osborne, 2002, p. 207). By recognizing this dual role as language teachers, or as active collaborators with their language arts colleagues, science teachers now need to give more attention to the teaching of language structures and functions, key vocabulary, and to the conventions of academic discourse necessary to fully access the science curriculum.

Additionally, the teaching and inclusion of culturally and linguistically diverse students requires the understanding that ELLs can indeed be challenged with higher-level cognitive tasks and abstract curricular content, regardless of their stage of language acquisition (Verplaetse, 1998). This calls for the implementation of a *culturally responsive pedagogy* - one that can recognize and celebrate student diversity and draw upon prior knowledge and language abilities (Lee, 2003; Settlage & Southerland, 2012).

Who are ELLs? Instructional Approaches to Support ELLs in the Science Classroom

Many acronyms have been used to refer to ELLs. These include *English Learners* (ELs), students of *English as a Second Language* (ESL), students of *English as an Additional Language* (EAL), *Culturally and Linguistically Diverse* (CLD) students, and now, the *World-*

Class Instructional Design and Assessment's (WIDA) widely used term, *multilinguals* (MLs). Since this research was conceived several years ago and has been ongoing, the term ELL will be utilized in this dissertation. ELLs are defined as "students who are learning the language of instruction at the same time as they are learning the curriculum and developing a full range of literacy skills" (Ontario Ministry of Education, 2008, p. 5). Cummins (2000), a global expert on ELLs, as well as other researchers on second-language acquisition, inform us that the *basic interpersonal communicative skills* (BICS), everyday oral skills that students use to talk about concrete things, takes approximately two to three years to achieve; however, *cognitive academic language proficiency* (CALP), otherwise known as academic proficiency, requires a minimum of five years to achieve (Collier, 1989; Hakuta et al., 2000). Essentially, CALP requires the ability to read textbooks, to understand what is spoken or read, and to write and/or to argue content-related issues. Therefore, ELLs who may not have developed CALP, may be at a disadvantage in content classrooms such as science (Torres & Zeidler, 2002). In fact, based on my experience as a science teacher, many of these ELLs often "slip through the cracks" and go unnoticed.

A great deal of research has been conducted on bilingual education and immersion over the last three decades; these include Baker (2011), Bialystok (2007), Cummins (2000), Genesee (1994), Johnson and Swain (1997), and Snow et al. (1989), just to name a few. Hence, rather than restate what reputable experts in the field have already presented about bilingual education and immersion, I will briefly summarize the key lessons learned about immersion programmes in North America, as they can assist in the design and development of content-based instruction for ELLs.

There are three main lessons to be gained from immersion programmes conducted in both Canada and in the United States. When applied to science, the recommendations for teaching science to ELLs would look something like this: (i) science and language development need to be "integrated" because language taught in isolation has proven to be ineffective; (ii) active discourse and argumentation is an important component of second language acquisition and needs to be promoted whenever possible in the science classroom; and (iii) language development should be systematically embedded within all areas of science (inquiry, reading, writing, interpreting, etc.) in order to enhance language learning (Genesee, 1994). With these broad goals in mind, it is important to critically review some of the existing programmes and/or models that have been used to teach ELLs in science. These include: *Cognitive Academic Language Learning Approach* (CALLA), *Content and Language Integrated Learning* (CLIL), *Sheltered Instruction Observation Protocol* (SIOP), as well as multiple empirical studies relating to the teaching of science for ELLs. The affordances and limitations of these programmes and/or models will now be analyzed with the perspective of suggesting effective practices for teaching ELLs in science.

Cognitive Academic Language Learning Approach

One interesting approach for teaching ELLs is the *Cognitive Academic Language Learning Approach* (CALLA), originally proposed by Chamot and O'Malley in 1986. CALLA is based on cognitive learning theory and has shown positive results in both math and science as well as in other disciplines, to a smaller extent. CALLA operates on the premise that learners are "mentally active" participants who engage in metacognitive, cognitive, and social/affective strategies (Chamot et al., 1992). Essentially, by engaging in CALLA approaches, teachers create opportunities for their students to reflect on their own learning, to develop strategic approaches towards content material, and to engage in active problem-solving (Chamot, 1995). Enabling students to become more aware of their mental processes, helps them to reclaim any prior knowledge, to revisit any misconceptions, and to incorporate new concepts and theories in science. Students can do this independently, in small groups, and/or in pairs.

In principle, this sounds very promising. However, it presupposes that the student must demonstrate enough proficiency with the English language in order to perform in science. Intermediate or advanced ELLs are likely to benefit from such an approach; whilst beginner ELLs will be at a disadvantage. In addition, age, developmental appropriateness, and cognitive ability, seem to be important considerations for CALLA. Younger children and students with *exceptionalities* do not seem to meet the CALLA requirements.

Although not every approach is perfect for all, new ways are indeed necessary to integrate metacognition into the learning process. In a science classroom, teachers need to identify students' misconceptions, monitor, and evaluate them, as well as ensure that these are adequately juxtaposed with informed scientific knowledge (Yore & Treagust, 2006). Science education in the 21st century extends beyond reading, writing, speaking, and listening; it encompasses reading, writing, speaking, listening, as well as doing, interpreting, and representing (with or without the use of technology). Hence, the objectives of CALLA would need to be expanded further in order to integrate these skills.

Content and Language Integrated Learning

Content and Language Integrated Learning (CLIL) has been used extensively in thirty European countries, as well as in Asia and South America, since its launching in 1996 (Dalton-Puffer, 2011). CLIL uses a foreign language to teach a disciplinary subject such as science, math, social studies, geography, etc., or is alternatively used in pilot studies. In this programme, the content and language objectives are merged (Nikula, 2015). CLIL aims to incorporate regional and/or minority languages, as a means to fulfill the European Union policy requirements for developing multilingual citizens. To date, however, English is the most common language used in CLIL (Dalton-Puffer & Smit, 2013; Jäppinen, 2005).

Although it is claimed that many CLIL students outperform non-CLIL students in reading, writing, speaking, and listening (Merino & Lasagabaster, 2018), thus far, the effects of this approach on the mother tongue (L1) as well as on content acquisition, remains uncertain. This is largely because CLIL still lacks a "robust contextualized framework with clear aims and projected outcomes" (Coyle, 2007, p. 546). In addition, given the complex interrelationships between language, learning, and content acquisition (or competence) (Evnitskaya & Morton, 2011), the evaluation of CLIL programmes remains questionable. The vast diversity and widescale flexibility of CLIL programmes, and more specifically, how it is implemented; at what age; which curricular disciplines it is integrated in; which types of materials/resources it uses; and/or, for which duration, also make any generalizations about CLIL very difficult.

Pérez-Cañado (2012) suggests several concrete research areas for CLIL in the future. These include the need for: (i) research-based empirical studies; (ii) longitudinal studies to complement cross-sectional ones; (iii) assessment of both language and content; (iv) methodological analyses and teacher observations; (v) information on teacher language training, linguistic abilities, support systems, assessment methods, collaboration, coordination etc.; and (vi) the implementation of mixed methods research designs using *sound* variables and statistical methodologies.

Having worked with CLIL within a private international school context, my personal opinion suggests that the discourse in science is complex enough. The academic language of science includes hypotheses, investigations, data collection, interpretation, sharing of findings, and the drawing of conclusions (Chamot & O'Malley, 1986; Hart & Lee, 2003). Trying to teach science through a foreign language should ideally be taught by a mother tongue teacher. Unlike immersion programmes, in CLIL programmes (Lasagabaster & Sierra, 2010) this has not been the case. As such, both the language and content are likely to be affected. In addition, for CLIL to work effectively in science, there needs to be close collaboration between the science and ELL/ELD and/or bilingual teacher. Although this is a critical aspect of any bilingual programme, it has unfortunately not occurred (Brown & Bentley, 2004) and will be addressed later on.

Sheltered Instruction Observation Protocol

Sheltered Instruction Observation Protocol (SIOP) is an instructional framework which promotes both content (such as science) and language development. Sponsored by the United States national *Center for Research on Education, Diversity & Excellence* (CREDE) and funded by the US Department of Education (1996-2003), it was developed as an observation tool to assess *sheltered instruction* techniques (Echevarria & Vogt, 2010; Kareva & Echevarria, 2013). Overall, it provides several useful tools for teachers working with ELLs in the areas of reading, writing, speaking, and listening. These include clearly defined content and language objectives for each lesson, diversified materials such as special texts, adapted or bilingual books, audiotapes, visuals etc., as well as a host of meaningful activities, aimed at activating the prior knowledge of students. In addition, SIOP promotes cooperative learning opportunities for student engagement with the aim of maximizing the socialization process, which is so critical to learning.

There are multiple affordances associated with SIOP, and in schools where SIOP has been implemented to a high degree, the improvements in second language acquisition have been significant (Kareva & Echevarria, 2013). However, its systemic implementation across a widescale educational system warrants some caution. First, the lesson-by-lesson planning approach advocated by SIOP can be perceived as rather taxing for mainstream or content teachers, who may value a less prescriptive and more creative approach to teaching. Moreover, authentic or meaningful experiences in teaching often occur outside the confines of structured lesson plans. Having to adhere to the eight-tiered planning and delivery components of SIOP: (i) preparation; (ii) building background; (iii) comprehensible input; (iv) strategies; (v) interaction; (vi) practice and application; (vii) lesson delivery; and (viii) review and assessment (Echevarria, 2005; Echevarria et al., 2008) may be viewed as constraining and may cause some degree of frustrations among educators.

In addition, professional development on SIOP for both pre-service and in-service teachers would need to be ongoing and funded long-term to ensure its widescale implementation. Given current budgetary cuts in education, this seems problematic. SIOP would also have to become a systemic component of all teacher education programmes; which has not been the case to date. Finally, similarly to CALLA, the SIOP programme also focuses on reading, writing, speaking, and listening, and hence would need to be expanded to include doing, interpreting, and representing, with or without the use of technology.

Although, there is a great deal of literature on developing science literacy in classrooms (Hand et al., 2003), research on science teaching for ELLs is less exhaustive. In addition, most studies on science and ELLs are for elementary school, not for middle or secondary school (Amaral et al., 2002; Brown & Ryoo, 2008; Stoddart et al., 2000; Zweip & Straits, 2013). This welcomes the need for greater research in this area.

Current Challenges and Opportunities for Teaching Science to ELLs

A science programme which aims at supporting its ELLs should not be an over-simplified programme, but rather one which has been adequately differentiated for linguistic purposes. Today, several challenges persist in the teaching of science to ELLs. These include: (i) conflicting teaching perspectives and views of ELLs in content courses such as science; (ii) the need for collaboration between the content and ELL/ELD teacher; (iii) difficulties with scaffolding for linguistic purposes as a result of time constraints, curricular demands, increasing administrative tasks, and/or lack of training; and (iv) the recognition that ELLs have a greater need for multimodality and multiple representations in science, and as such, require pedagogical changes to the traditional ways in which science is taught.

Teacher Perspectives and Views of ELLs in Science

The attitudes of content teachers, including science teachers and their observed lack of understanding regarding the linguistic needs of ELLs has promulgated a “deficit view”, which builds on the assumption that ELLs are likely to perform less well than non-ELLs (Fradd et al., 2001; Meltzer & Hamann, 2005). In addition, given the rising number of ELLs worldwide, common sentiments of mainstream teachers who work with them have been ones of frustration, lack of time, lack of training, and unpreparedness (Verplaetse, 1998; Youngs & Youngs, 2001). Unfortunately, teacher-training to date, has not addressed this issue satisfactorily. Research informs us that 75% of ELLs are placed into classrooms with teachers who have had no specialized training in second language acquisition and/or bilingual education (Wei et al., 2009).

Teachers are accustomed to standardized norms of classroom participation and mainstream expectations, which are often incompatible with the different knowledge-base inherent in their students' culturally diverse learning experiences (Ghosh & Galczynski, 2014). In addition, Arkoudis (2003) states that "teachers' views of language and teaching are embedded with their subject and disciplinary prejudices and biases" (p. 171). Science teachers may also have different disciplinary epistemologies, which creates a gap between themselves and their ELL/ELD teacher colleagues (Janzen, 2008).

Chamot and O'Malley (1986) mention that junior-high and secondary science teachers have gone so far as to request that their ELLs not be allowed in their science classes until they have reached an adequate level of linguistic and academic proficiency (August & Hakuta, 1997; Chamot & O'Malley, 1986). This is because most content teachers view themselves as subject teachers rather than language teachers (Baker & Saul, 1994). As a result, teacher identities and views of language and teaching have been at odds with each other. In addition, cooperation between science and ELL/ELD teachers has not always been easy (Brown & Bentley, 2004; Creese, 2005). As such, teachers need to evaluate their own identities, as well as their influences on student learning (Lee, 2003). One way of doing so is to realize that a content teacher is not an island; he/she needs to partner with the ELL/ELD teacher.

Collaboration Between Content and ELL/ELD Teachers

Content-teachers are indeed specialist teachers (especially at secondary school levels); whilst ELL and/or bilingual teachers are language specialists with expertise in language acquisition. Since many science teachers may not be trained nor certified to teach ELLs, collaboration between content-teachers and ELL/ELD and/or bilingual teachers is likely to open up new possibilities in science education (Janzen, 2008).

In the case of teaching ELLs, not only is it important to break down any deficit attitudes and views of ELLs which create barriers, but it is recommended to engage in constructive collaboration with ELL/ELD and/or bilingual teachers (Snow et al., 1989). This implies a process of negotiating understandings of pedagogy, which Arkoudis (2003) refers to as *epistemological reconstruction* (p. 171). In tandem, the collaboration between content and language teachers can create an instructional environment which is more *culturally congruent* with the diversity and realities of the classroom (Lee, 2004, 2005; Lee & Avalos, 2002; Slater & Mohan, 2010).

Scaffolding for Linguistic Purposes

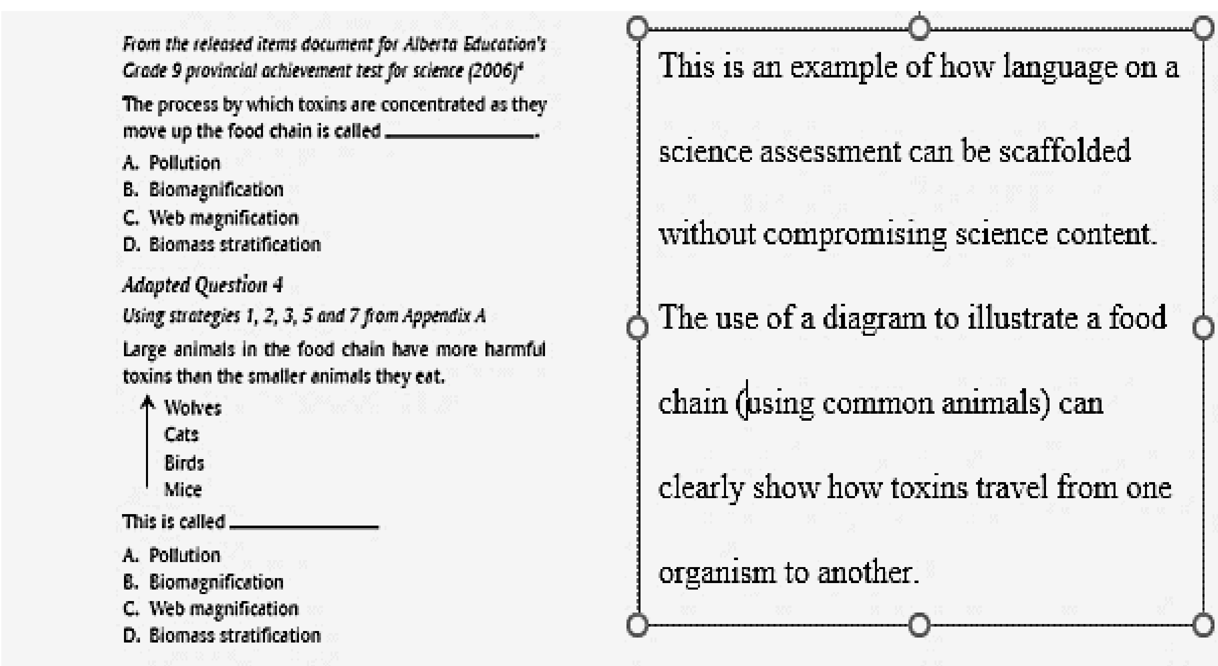
Scaffolding is important for content mastery (Zhang, 2016). However, scaffolding science for ELLs is not second nature to all teachers. Zhang (2016) mentions that several school districts have assigned to ELLs a similar list of accommodations provided to students with *exceptionalities* (or special needs), even though their challenges are purely linguistic and not cognitive in nature. Hence, a role exists for intervention programmes which promote collaboration with ELL/ELD specialists. Specialized PD is also important to assist teachers in preparing lessons which skillfully scaffold the teaching of science, alongside an acquired understanding of the needs of ELLs. What does this process of scaffolding really entail?

Lyster and Ballinger (2011), define *scaffolding* as “questions and feedback designed to support language learning while fostering students’ cognitive engagement with content in a language they know only partially” (p. 283). Fortunately to date, given the push for SIOP, CLIL, and other content-based language teaching (CBLT) programmes, research has shown that some content teachers do try to scaffold science without compromising content (Lyster & Ballinger, 2011).

Several teaching strategies can indeed aid and support ELLs in the science classroom. These include: (i) cooperative learning groups; (ii) extra "wait time" following a teacher's question; (iii) heterogeneous pairing or grouping (i.e., a non-ELL student with an ELL student); (iv) purposeful grouping (i.e., keeping ELLs together); (v) using supports such as study guides, sentence frames, as well as the explicit teaching of texts; (vi) frequent repetition; (vii) the use of a "working" word wall; (viii) complementing visual supports for texts; (ix) the use of technology; (x) alternative formative and summative assessments; (xi) tiered questions, and so on (Lucas & Villegas, 2013; Munro et al., 2013; Olson et al., 2009). Here are some concrete examples of scaffolding used in science.

Figure 1

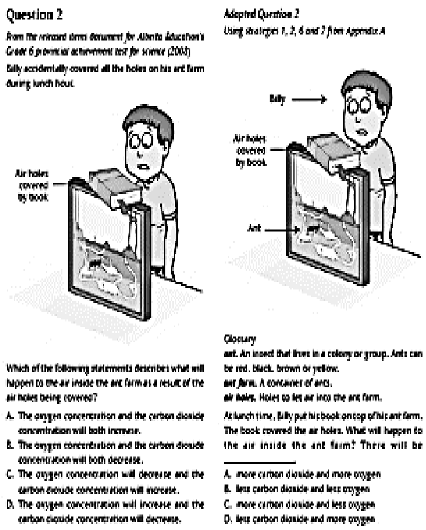
Scaffolding of a Science Question Using a Diagram as an Example



Munro et al., (2013), p. 41.

Figure 2

Scaffolding of a Science Question Using Labelling, a Glossary, and Reduced Text



Question 2

From the released items document for Alberta Education's Grade 6 provincial achievement test for science (2003)

Billy accidentally covered all the holes on his ant farm during lunch hour.

Which of the following statements describes what will happen to the air inside the ant farm as a result of the air holes being covered?

A. The oxygen concentration and the carbon dioxide concentration will both increase.
B. The oxygen concentration and the carbon dioxide concentration will both decrease.
C. The oxygen concentration will decrease and the carbon dioxide concentration will increase.
D. The oxygen concentration will increase and the carbon dioxide concentration will decrease.

Adapted Question 2

Using strategies 1, 2, 6 and 7 from Appendix A

Glossary

ant. An insect that lives in a colony or group. Ants can be red, black, brown or yellow.
ant farm. A container of ants.
air holes. Holes to let air into the ant farm.

At lunch time, Billy put his book on top of his ant farm. The book covered the air holes. What will happen to the air inside the ant farm? There will be ________

A. more carbon dioxide and more oxygen
B. less carbon dioxide and less oxygen
C. more carbon dioxide and less oxygen
D. less carbon dioxide and more oxygen

This example of scaffolding uses additional labelling, a simple glossary, as well as reduced text as strategies. Once again, the science context is not compromised in any way.

Munro et al., (2013), p. 39.

Figure 3

Scaffolding of a Science Test Question Using Sentence Frames

From the released items document for Alberta Education's Grade 9 provincial achievement test for science (2005)[5]

Joe watches television for 6.00 hours (21,600 seconds). The input power rating of his television is 200 W. The electrical energy consumed by any electrical device can be calculated using the following formula.

$E = P \cdot t$
E = energy (in joules)
P = power (in watts)
t = time (in seconds)

The total electrical energy consumed by Joe's television is ________.

A. 33.3 J
B. 108 J
C. 1.20 kJ
D. 4.32 MJ

Adapted Question 5

Using strategies 1, 2, 7 and 8 in Appendix A

- Joe watches ______ hours of TV, which is ______ seconds of TV.
- His TV uses ______ watts of power.
- Complete the equation using the information above:
  $E = P \times t$
  ______ = ______ × ______
- Joe's TV uses ____________ of energy.

A. 33.3 J
B. 108 J
C. 1.20 kJ
D. 4.32 MJ

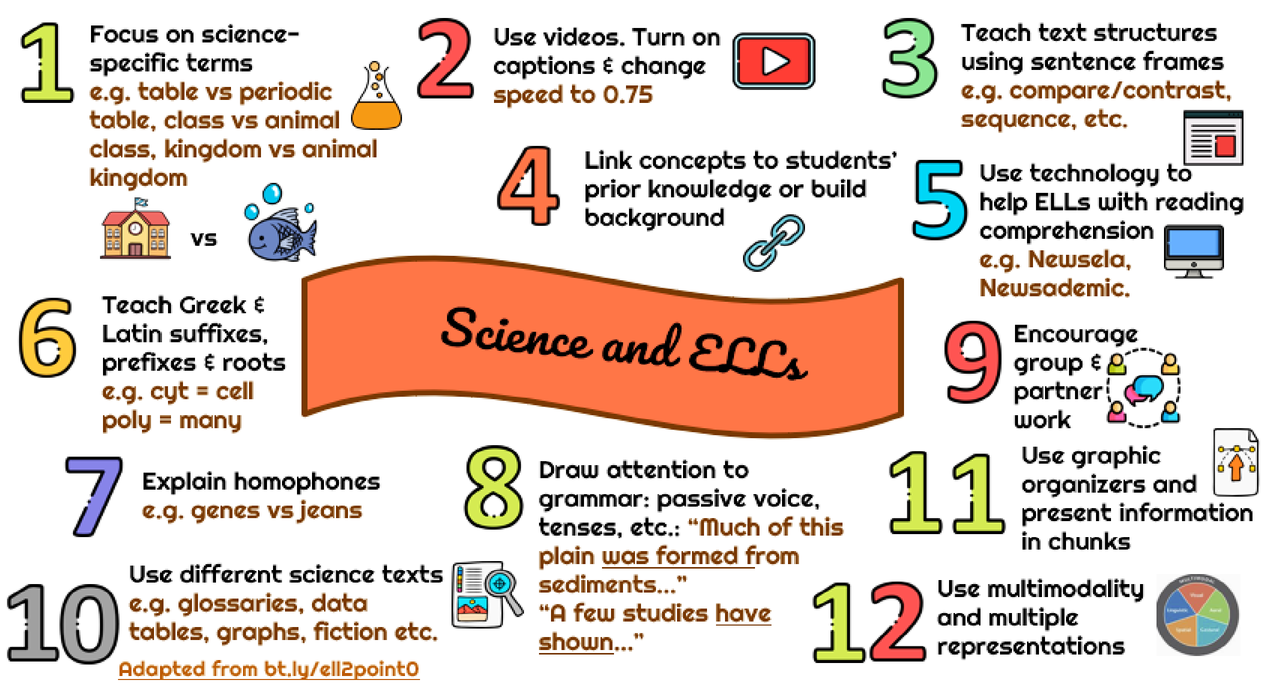
Sentence frames and bullet points are used to scaffold a word problem which is language intensive. Once again, this is a quick and simple way to make this test question more accessible to ELLs.

Munro et al., (2013), p. 41.

Regretfully, these scaffolds are exemplary, and are not the norm in today's science classes. ELLs remain at a disadvantage in the science classroom compared to their native English-speaking peers. The working hypothesis of this research posits that given the rapid rate of globalisation and the existing diversity of classrooms, teacher scaffolding using multimodalities such as reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, when combined with the use of multiple representations, is an effective way to support ELLs in science. The adaptability of teachers, if they are provided with adequate training to meet such needs, is hence critical. Figure 4 is a useful tool on how to scaffold for ELLs in science.

Figure 4

Simple Ways to Scaffold for ELLs in Science



Adapted with permission from Dr. Irina McGrath. ELL2.0 https://sites.google.com/view/ell20

Use of Multimodality and Multiple Representations to Teach Science to ELLs

Gillies and Baffour (2017) state that for ELLs, expressing their understanding or knowledge using diverse representations is highly desirable. They claim that "scientific literacy involves students being able to interpret and use different representations including language, text, diagrams, tables, models, drawings, portfolios, artefacts, and embodied forms such as gesture, role play and exhibitions of performance" (p. 493). Researchers advocate that this can be accomplished through multimodality and multiple representations.

Multimodality is the process of teaching for meaning-making using several kinds of modes (Klein & Kirkpatrick, 2010). Overall, multimodality research examines how students make sense of representations which are expressed and socially negotiated using diverse modes (Tang et al., 2014). Beneficially, multimodality instruction complements Lev Vygotsky's *social constructivist theory* which focuses on the social component of meaning-making. Knowledge acquisition cannot occur in a vacuum because we are surrounded by the animate and inanimate objects of a material world, as well as cultures, social structures, norms, and human interactions. Knowledge acquisition is social in nature. A student is not an isolated body or entity that is free of stimuli; on the contrary, he/she is continuously interacting socially, culturally, and historically. Hence, when concepts are acted upon or communicated within a social-cultural context, that knowledge can more effectively be constructed (Bächtold, 2013; Cummins, 2007; Kruckeberg, 2006).

Whereas *multiple representations* consist of asking students to represent the same concept using different representational forms, including verbal, graphic, numerical formats or by simply questioning students about their own productions (Berthold & Renkl, 2009; Tang et al., 2014). Essentially, it extends beyond the standard representation of a single artefact, to a process of *re-representation*. This may involve reading, writing, giving an oral presentation, drawing etc. to demonstrate scientific meaning (Cazden et al., 1996). Yore and Hand (2010) state "Give a learner a representation and he/she may learn the concept; but encourage a learner to develop insights into creating representations of mental images/ideas, and she/he will learn forever" (pp. 94-95).

The sequential process of representation and re-representation suggested by Hubber et al. (2010) suggests that students are involved in co-constructing knowledge and in sharing meaning with their peers, their teacher (facilitator), and/or independently. One of the roles of the teacher may consist in providing their students with access to these multimodal and social opportunities for concept-building in the classroom setting (Yore & Hand, 2010). In addition, teachers can teach their students how to interact and make constructive uses of the different modes of representation. Students should be able to identify the benefits and/or shortcomings of these diverse modes of representation, so that they can better discern the contexts which they work with in their everyday science classes.

Actively engaging students with multimodal teaching and multiple representations not only maximizes ownership of their learning, but it can also increase social interaction and develop the critical thinking skills of students (Alvermann, 2004). However, it is important to use caution, as specific representations may serve some students better than others. Prain and Waldrip (2006) state that "these modes of representation have different strengths and weaknesses in terms of precision, clarity, and associative meaning, and … students need to understand these … representations, as well as their integrated use to represent scientific concepts, especially in upper secondary" (p. 1844). In the same vein, Ainsworth (2008) alerts educational software designers about the excessive load of representational information used in science animations, simulations etc. It is the responsibility of the students, and not only the teacher, to become better judges of the affordances and the limitations of diverse modes of representation. But how do teachers "really" teach science in their everyday classrooms?

Teaching Modalities Used in Science

Norris and Phillips (2003) identify seven modalities of teaching and learning in science. These include: reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology. These modalities have been used as the backbone of this research and will be addressed individually. It is important to mention however, that these modalities complement each other. For example, modalities such as reading and writing; listening and speaking etc., go hand-in-hand. The holistic combination of all these seven modalities will be discussed further on.

Reading

Reading in science, as well as in other disciplines, promotes collaboration, discussion, metacognitive conversations between students, as well as vocabulary acquisition and comprehension, especially when it adopts different genres of science texts (i.e., lab reports, journals, popular magazines, science trade books, etc.). In this regard, Cervetti and Pearson (2012) place a great deal of emphasis on reading in the science classroom. Students are not only exposed to science texts, but also to interpreting data such as tables, graphs, diagrams, figures, etc. That said, the complexity and specificity of science terminology cannot be underestimated, especially as they pose challenges for ELLs.

Some teachers also assume that ELLs can easily use dictionaries, and/or rely on their first language, but this is not the case for "all" students who may have been educated elsewhere, and/or for refugees or immigrants who may have experienced education or literacy gaps given their life situations (Miller, 2009). As such, the teaching of vocabulary, use of picture dictionaries, and/or word walls, provision of unit glossaries, etc. are all tangible ways to scaffold reading for ELLs (Case, 2002; Goldenberg, 2008).

To date, time constraints, overloaded curricula and schedules, dense texts, as well as the fact that science teachers do not view themselves as literacy teachers, are all reasons which prevent content teachers from implementing effective reading practices in their science courses (Fang & Wei, 2010; Rivard et al., 2012). In fact, several studies in Canada, the United States, the United Kingdom, and Australia confirm that negligible time is devoted to reading in content classes. This is further exacerbated by the fact that the intrinsic motivation of students to read is reduced in middle school (Guthrie & Wigfield, 2000).

Despite this, research does inform us of the multiple affordances of reading in content-based classes. A few examples include: a National Science Foundation (NSF) funded project called, *Seeds of Science, Roots of Reading,* designed by both science and literacy educators, which implemented the explicit reading of instructional texts, reading routines and levels, vocabulary development skills, and reading comprehension tasks into the science inquiry activities of twenty, second- and third-grade classes, against twenty-four comparison classrooms in California. Using pre- and post-testing procedures, as a result of the embedded reading texts, researchers found significant gains in science knowledge, literacy, and vocabulary development (Stoddart et al., 2010).

Likewise, the *Science Instruction for All (SIFA),* also funded by the NSF, was a three-year study and curricular intervention with six schools and twenty-one, third- and fourth-grade teachers, in the San Francisco Bay area. This programme focused on science and literacy-integrated instruction, resulting in positive achievement in science (Stoddart et al., 2010), especially in children of Asian and Spanish backgrounds.

Promoting Science among English Language Learners (P-SELL) represents a large-scale integrated science and literacy development project aimed at third-grade ELLs in seven urban elementary schools in Florida. Once more, pre-, and post-instruction assessment showed significant gains in science understanding compared to the control groups (Stoddart et al., 2010). Many more studies have been conducted on science embedded English language and literacy development (Carrejo & Reinhartz, 2014; Dong, 2002; Tong et al., 2014). Whereas, Hapgood and Palinscar (2006) focused on the benefits of inquiry-based science for the development of literacy. The observed benefits of inquiry-based science included greater critical thinking and vocabulary development during science discourse; direct participation in inquiry; the use of multiple representations; and more in-context reading using a diversity of texts.

Regarding the importance of reading in science, while remaining cognizant of the difficulties inherent in reading science, Patterson et al. (2018) discuss the relevance of science teachers to learn a repertoire of reading strategies in order to effectively tackle science texts with ELLs in their classrooms. Students will not only benefit from their understanding of expository texts which they read in science, but they will learn even better when accessing their prior knowledge to make inferences about scientific texts, charts, tables, diagrams etc. This implies, for the students, the ability to decode both texts and visualizations.

One way to encourage reading practices in the science classroom, is to provide students with authentic and diverse science texts from which they can choose. Guthrie et al. (2004), corroborate with this idea. They state: “When students are interested in what they read, they process material more deeply" (p. 416). Most studies on integrated reading in science show that meaningful texts and engaged reading activities are critical to knowledge-building, and hence, learning. "[S]cience learning entails and benefits from embedded literacy activities and literacy learning entails and benefits from being embedded within science inquiry" (Pearson et al., 2010, p. 462). Hence, when teachers offer their students choice which links to their interests, this motivates them to read science and provides them with a diversification of texts, which also takes into account their reading abilities. This is often not the case when students, especially ELLs, are asked to use their dense, science textbooks.

The *lexical density* (or content words per clause) in science is very high. Moreover, the language of science is enriched with specific vocabulary, *nominalizations* (complex noun phrases), passive voice, technical words, and multiple semantic forms (Bruna et al., 2007; Shanahan & Shanahan, 2008; Swanson et al., 2014). This complexity may affect both the reading and writing of science. Therefore, by scaffolding strategies for reading such as teaching students Latin and Greek *prefixes* and *suffixes*; identifying *cognates* (a word that has the same origin in another language); explicitly teaching sentence or grammar frames and so on - these are all ways which are likely to build students' abilities with various genres of science texts (Parkinson et al., 2007). Such methods of scaffolding, benefit the reading skills of all students, especially ELLs.

Although several of the above-mentioned studies have shown gains in science understanding for ELLs, all of them have been implemented at the elementary school level. Middle and high school students are not reflected in these science literacy development projects, in spite of the fact that ELLs in middle and high school are the ones with the greatest needs for specialized language (Janzen, 2008; Tong et al., 2014). This opens up a niche for further research in this area and is one reason which validated the need for this dissertation.

The reality is that the language and vocabulary in secondary school sciences becomes more complex, often making it inaccessible to ELLs who often struggle to master science concepts and skills through limited and/or no proficiency in English (August & Hakuta, 1997; Lyster & Ballinger, 2011).

Reading comprehension, defined as the "ability to extract meaning from written text" (Patterson et al., 2018, p. 291) is essential for science and as such, proper scaffolding is a measure used by science teachers to ensure students' understanding of science concepts and theories. As such, teachers require specialized PD courses to be equipped to support reading in science. To make matters worse, as with reading, writing in science also poses several additional challenges for ELLs who need to familiarize themselves with the conventions of technical and scientific writing.

Writing

Writing plays an important role in science learning. The significance of this role suggests that, for the sake of student success, teachers should scaffold these writing tasks at many levels, depending on the cultures and languages of the students in the class. For absolute beginners, this may mean building word walls to develop scientific vocabulary, making picture dictionaries, engaging in basic journal writing activities etc. (Case, 2002). Regarding the modality of writing, Merino and Hammond (2001) conducted several interdisciplinary science inquiry projects using narrative texts. These texts were thought to improve writing, as well as offer a better understanding of science. Immersing students in meaningful writing practices can promote the knowledge of science, as well as develop academic writing skills for all students, especially ELLs (Carlsen, 2007; Huang, 2004).

Teaching structured writing has also shown benefits for ELLs (Goldenberg, 2008; Lyster, 2007). Teachers can model writing activities in the class and/or alternatively share exemplary student writing samples. In addition, diversifying writing tasks in science, not only improves the understanding of science for all students, ELL inclusive, but it may also activate their metacognitive processes. As students go through the writing process, they are constructing knowledge (Hand et al., 2002). Sampson et al. (2013) also address the importance of teaching argumentative writing skills to middle and high school students in science.

To date, more research is needed on writing-to-learn strategies in science for ELLs. Huang and Morgan's (2003) study of 35 ESL students is very interesting. It focusses on knowledge structure analysis in student written discourse, more specifically, classification – to address the current difficulties that teachers face in linking language and content in evaluation/assessment. Foulger & Jimenez-Silva (2007) instead explore the use of technology to aid the writing process of ELLs. Hopefully, future studies on writing will shed greater light on how to improve writing practices in science. Alternating genres of writing in science (i.e., narratives, expository writing, persuasive writing, technical report writing, journal writing etc.) is another strategy that may increase student interest in writing in science.

Speaking and Listening

Speaking is an important modality in language acquisition and one which promotes socialization with both the teacher and amongst a peer-group (Huerta & Jackson, 2010). Lemke (1990) reminds us that teaching students to use the specialised language of science is critical in science education (p. 167). One way of doing so is by modelling it. Teachers can do so with the use of synonyms, paraphrasing, repetition, and rephrasing of questions posed in class, as well as elaborating on students' responses (Lee & Buxton, 2012).

Given the disparities between scientific discourse, social language (language used with peers), and home language (language used at home), students are continuously faced with crossing language borders or discourses (Baker, 2011). Teachers need to provide students with opportunities to speak as well as to question science. In doing so, students are more likely to access and use their prior knowledge during argumentation and to co-construct new knowledge with their peers. Lemke (1990) stresses the importance of language to express ideas and build conceptual understanding in mainstream science classes. Likewise, the study of Simon et al. (2006) stresses the importance of explicitly teaching argumentation, especially in secondary school science classes. Students should be provided with opportunities to develop their scientific responses while using supporting evidence to enrich their arguments.

Creating discussion opportunities in the science classroom becomes particularly relevant for ELLs to develop both their oral and content skills. Speaking about science means "learning through authentic and meaningful communication" (Dong, 2002, p. 47). Allowing students to discuss or argue how data and/or evidence supports or does not support scientific theories, may create ownership of science content, and engage ELLs in a discourse-intensive activity (Swanson et al., 2014). New vocabulary is learned, ideas are exchanged, different perspectives can be heard, partial misunderstandings can be clarified, and new meaning can be constructed (Dawes, 2004). This becomes especially relevant during the use and interpretation of multimodal representations in science inquiry, which are superb opportunities for social interaction amongst students and teachers (Gilles & Baffour, 2017).

Hakuta et al. (2000) argue that the oral fluency of ELLs can often be misleading to content-teachers. They equate it with academic proficiency, whilst this is not the case. Teachers should develop an awareness and understanding of the diversity in their classes. Depending on the cultural and linguistic backgrounds, allowing students to discuss science in their native language, in pairs, or in small groups, should be encouraged as much as possible because it validates the culture of ELLs. Alternatively, ELLs may be paired with native English speakers, as this may improve their oral use of academic English. Long's (1983) *Interaction Hypothesis* in fact claims that when ELLs interact with native speakers, they maximise their comprehension. Teachers should try to encourage both speaking and listening skills whenever possible, as students work together to construct knowledge (Kim & Hand, 2015). Fisher and Frey (2014) state that: "Technology offers teachers new ways to engage students in speaking and listening tasks" (p.69). Note the several ways to creatively encourage listening skills for ELLs as well as mainstream students, via the use of technology, illustrated in Table 1 (Fisher & Frey, 2014).

Table 1

Creative Ways to Promote Listening Skills Using Technology

E-Listening Gallery Walk	- Students create a visual image, record themselves talking about the image, and then code it with a symbol that will allow others to access the digital file. One way to do this is with QR codes.
Digital storytelling	- Students create original digital narratives and informational pieces. - The *Storybird* app provides access to thousands of illustrations and photographs to illustrate original pieces of writing. - The *Voicethread* website offers two-way communication between writers and readers.

	- Students dictate the text for each page. Subsequent listeners can either listen to the writer's own voice or read the dictated script. - Readers can then pose questions and offer connections that are in turn viewed by other readers.
E-Photo narratives	- Students collect images on the web and then record a digital narrative to accompany the images.
E-Listening stations	- Students listen to digital recordings of their teacher reading a complex informational text aloud. - Students then discuss the questions the teacher poses at the end of the recording (Skouge et al., 2007).

Adapted with permission from Fisher & Frey, 2014, pp. 67-69.

Although listening is now greatly facilitated using technology, there are other creative ways to promote listening skills without the use of technology. Once again, these are suggested by Fisher and Frey (2014) and are summarized in Table 2. Two separate tables have purposely been created with the aim of differentiating how listening skills can be promoted in the science classroom.

Table 2

Creative Ways to Promote Listening Skills Without Technology

Readers' Theatre	- Student's practice reading and rereading a script, either one that was prepared for them or one they developed collaboratively (Young & Rasinski, 2009). - Students present that text to the rest of the class while others listen. - To ensure students are listening, the teacher asks them to take notes, write down questions, or retell the information presented to a partner.
Presentations	- Students research a topic and then share their findings with their peers, either in a small group or a large group (Fisher et al., 2013). - Students are asked to provide their peers with feedback about their presentation skills.
Reciprocal Teaching	- Students read chunks of a given text and then take turns with various comprehension strategies such as predicting, questioning, clarifying,

	and summarizing (Palincsar & Brown, 1986). - To ensure that students actually listen to one another, teachers create note-taking tools that require students to maintain a written record of the conversation.

Adapted with permission from Fisher & Frey, 2014, pp. 67-69.

Doing (Science Inquiry)

As with science literacy, researchers have proposed a myriad of definitions for the term science or scientific inquiry. The *National Science Education Standards* (NSES) defines scientific inquiry as:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 23)

Minner et al. (2010) who conducted a research synthesis of 138 inquiry-based science studies between the years 1984-2002, conclude that when students engage in active thinking during an investigation cycle, by generating questions, designing experiments, collecting data, drawing conclusions, and communicating findings, the result is a positive one, contributing to a greater understanding of scientific concepts. Similarly, the use of hands-on activities also results in an increased understanding of science. Stoddart et al. (2002) remind us that science inquiry is ideal for the development of scientific language because it is linked to hands-on tasks; it is concrete; and it is contextualized (p. 665). However, given the multiple definitions of science inquiry, both teachers and students have interpreted scientific inquiry very differently (Cuevas et al., 2005). In fact, Minner et al. (2010) call for the need to operationalize the term "science inquiry" more clearly.

Doing science or engaging in science inquiry "occurs when students generate questions, plan procedures, design and carry out investigations, analyze data, draw conclusions, and report findings" (Cuevas et al., 2005, p. 341; NRC, 1996, 2000). It is an effective method for teachers to engage ELLs in both content and language development. Science inquiry is a combination of hands-on activities, thinking (minds-on), discourse, argumentation, and social interaction (Dionne et al., 2019; Stoddart et al., 2002). Inquiry-based science can "provide a rich environment for simultaneous cognitive and linguistic development" (Kessler & Quinn, 1995, p. 97). It is an ideal context for language exchange and the building of scientific understanding. The *American Association for the Advancement of Science* (AAAS) *Project 2061* in the US focuses on science inquiry, and the *National Science Education Standards* (NSES) claims that inquiry science is at the core of teaching science for all students (NRC, 1996).

Science inquiry supports ELLs in many ways: (i) it gives them time to build knowledge and understanding; (ii) it reduces the amount of text; (iii) it develops thinking skills; (iv) it engages them in social interactions as well as in science discourse; (v) it provides them with a safe, non-judgemental, and comfortable classroom setting; and (vi) it fosters positive attitudes towards learning (Amaral et al., 2002).

The *Valle Imperial Projects in Science* (VIPS) is one programme which aimed at developing science, reading, writing and maths skills for a large population of Latino/a students in southern California. It adopted a kit-and-inquiry-based science instruction, alongside the use of science notebooks (Klentschy, 2006; Klentschy & Molina-De La Torre, 2004). Students were able to develop their science literacy and numeracy skills within a hands-on, inquiry setting.

Similarly, the *Language Acquisition through Science Education in Rural Schools* (LASERS) project funded by the NSF, implemented a systemic project of seven districts in central California focusing on the integration of science inquiry and discourse. This project combined scientific talk alongside hands-on science activities. The results demonstrated significant gains in the understanding of science concepts and the academic language of science (Stoddart et al., 2010). Inquiry has a great potential in science education, and it is rendered even more effective when there is a real link between science content and everyday life. Moreover, students benefit from both time and opportunities to engage with data collected during their inquiry projects (Banilower et al., 2010). This entails interpreting and/or representing their data with or without the use of technology and hopefully, leads to further discussions in science.

Interpreting and Representing

Science is data- and evidence-based and includes several types of interpretations and representations. For teachers, these may include using print formats such as data tables, graphs, charts, numeric equations; or other non-print formats such as demonstrations, videos, simulations, animated-diagrams, gestures, photographs, 3-D models, etc. (Cazden et al., 1996; Wilson, 2008). In either type of format, all science students are asked to assess, evaluate and/or make sense of data.

Technology, when used strategically, has the power to help students sort through the management of data and thus, tackle the processes of interpretation and analysis more readily. In this regard, the *Next Generation Science Standards (NGSS)* states the following:

Scientific investigations produce data that must be analyzed to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools — including tabulation, graphical interpretation, visualization, and statistical analysis to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis (Retrieved on August 7, 2020 from https://ngss.nsta.org/Practices.aspx?id=4) page 1).

The role of technology for interpreting data is well established. Not only can technology assist in data management and statistical analysis, but it enables a person to make more knowledgeable decisions about science, technology, society, and environmental issues. This is one of the fundamental goals of science literacy (Yore et al., 2003).

Carrier (2005) states that ELLs need supplementary literacy and/or language-related assistance to "(a) locate information in science texts; (b) interpret and apply that information; and (c) ask, answer, describe, explain, and make predictions about science; all in a language which is still in its developmental stages" (p. 5). Providing students with a rich classroom environment to negotiate, design, refine, and/or possibly re-represent science concepts and theories is critical to creating meaning or knowledge in science.

> Scientific ideas cannot be separated from their representation, and the learning process entails harnessing students' representational resources to develop scientific ways to think about (i.e., represent) phenomena. Developing understanding of science topics involves learning to represent, refine, and re-represent ideas in different modes as part of learning science literacy, rather than viewing learning as

> a purely cognitive process of shedding naïve conceptions in favour of scientific ones (Hubber et al., 2010, p.7).

Interpreting and representing data with or without the use of technology are expectations in most science classes nowadays, and for ELLs, this is particularly challenging with limited language in English. Interpreting data and graphs is a complex skill for all students. However, if they are to make informed decisions about science-related matters, translating data between graphs and "real-life" problems becomes very important. Hence, explicit teaching of the language surrounding trends, patterns, and causal relations becomes important in science (Hipkins, 2011).

Teaching Science to ELLs: Modalities, Multimodalities or More?

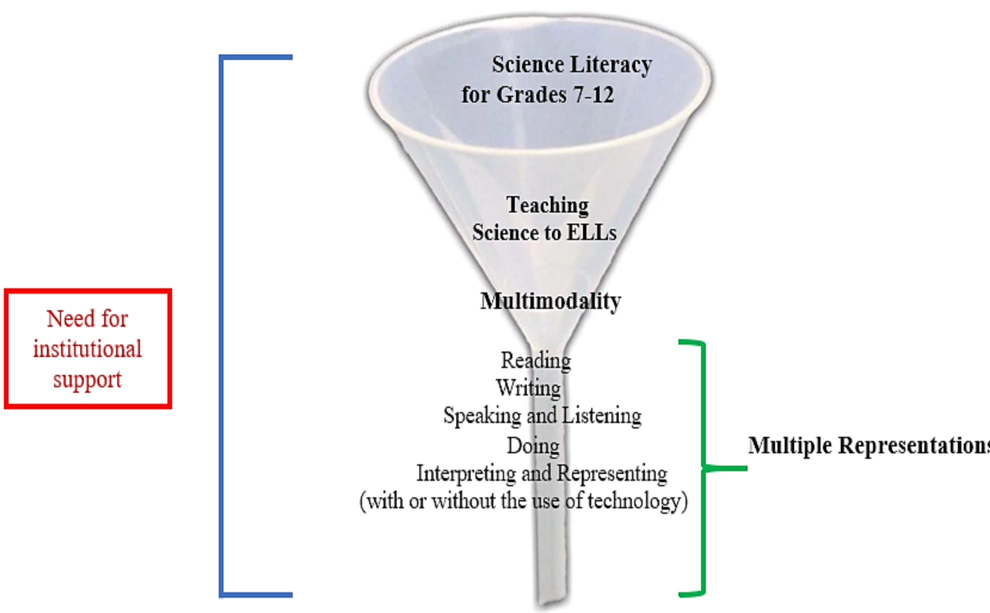
To date, several empirical studies have been conducted on how teachers can use a specific modality to teach science, such as reading in science (Tong et al., 2014); writing activities in science (Huang, 2004; Huang & Morgan, 2003); talking in science (Lemke, 1990; Swanson at al., 2014); doing science/science inquiry (Amaral et al., 2002; Stoddart et al., 2002) etc. However, two additional teaching modalities – interpreting, and representing (with or without the use of technology) also need to be addressed, since these skills are essential for science literacy development (Norris & Philips, 2003). Research on interpreting and representing in science with a special focus on ELLs has not been conducted on a large scale and hence deserves attention.

Whereas, other empirical studies have focussed on a "combination" of different modalities such as talking and writing in science for ELLs (Chen, 2019); reading and writing; reading, writing and speaking; reading, writing, speaking and listening; reading, writing, and science inquiry (Fisher & Frey, 2014; Lemke, 1990; Roth & Welzel, 2001).

While the concept of science literacy is commonplace, the teaching strategies and approaches used to help students develop their scientific literacy varies considerably, particularly in school contexts where learners are differentiated by their levels of English proficiency. This begs the following questions: How can we adopt a more holistic approach regarding the use of teaching modalities for ELLs in science? Can the use of multimodality and multiple representations by both teachers and students result in a greater understanding of science? What are teachers' needs? How can these needs be met in schools? With these set of questions in mind, I used the image of a funnel as a conduit to guide my thoughts and ideas for this research. This was useful in helping me conceive my research questions which will be presented in the next chapter.

Figure 5

Funnel as a Conduit of Ideas



Chapter 2: Conceptual Framework and Research Questions

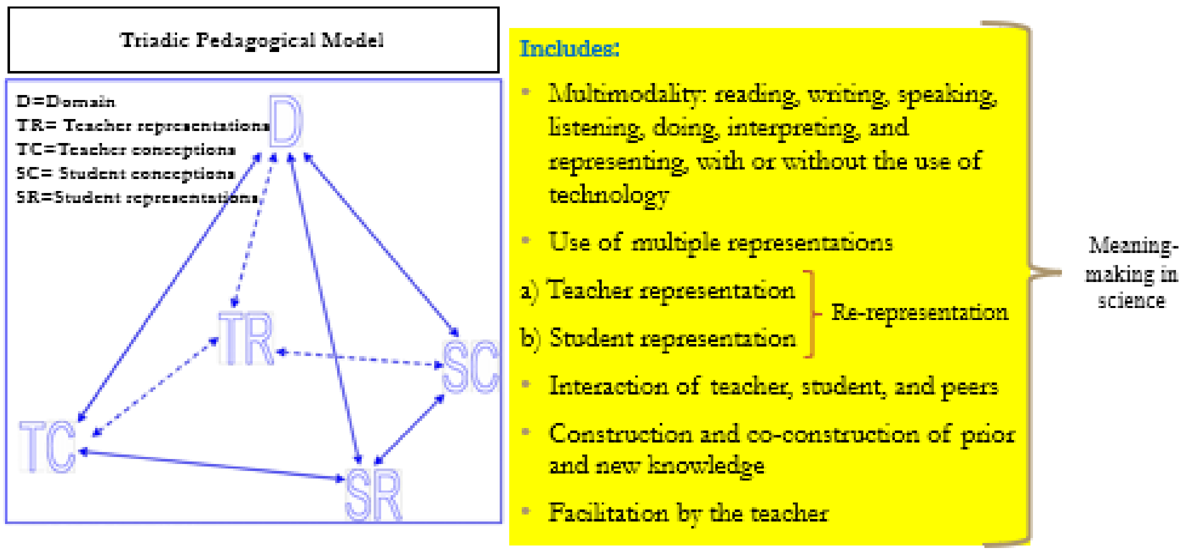
This chapter presents the conceptual framework of this research inspired by the *Triadic Pedagogical Model* of Waldrip, Prain and Carolan (2010). It also addresses the influence of teacher epistemologies in their practice of science, most specifically, with a lens on modalities of teaching, advocating for a more holistic use of teaching modalities to make science more accessible to ELLs. Finally, it addresses the need for greater institutional support for ELLs and concludes with the research questions employed in this study. Miles and Huberman (1994) define a *conceptual framework* as a visual or written product, that "explains, either graphically or in narrative form, the key concepts to be studied and the presumed relationships among them" (p. 18).

Inspiration for My Conceptual Framework

In order to situate the conceptual framework, I have added (see section on the right side) the need for multimodality, multiple representations, and re-representations to meet the needs of ELLs in science onto the Triadic Pedagogical Model of Waldrip, Prain and Carolan (2010) which visually illustrates the interconnectedness between the domain of science, teacher conceptions and representations, and those of student conceptions and representations. I posit that teachers' use of scaffolding in all seven *modalities* of their teaching practices (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology), combined with the use of *multiple representations* is an effective way to support ELLs in science. This is the broad assumption which was explored in this study in an effort to embrace Zhang's (2016) concern that, "Little to no studies have been conducted to examine ELLs' conceptual learning from a multimodal perspective" (p. 7).

Figure 6

Inspiration for the Conceptual Framework of this Study



Adapted from Waldrip, B., Prain, V., & Carolan, J. (2010). Using multi-modal representations to improve learning in junior secondary science. *Research in Science Education*, *40*(1), 65-80. https://doi.org/10.1007/s11165-009-9157-6

Epistemology and Its Relevance on Teaching Practices in Science

Atwater (1996) informs us that no single epistemology can fully determine what happens in science teaching and learning, however, several researchers inclusive of myself, contend that "[t]eacher's beliefs play a major role in teacher decision-making about curriculum and instructional tasks" (Savasci & Berlin, 2012, p. 66). Not all science teachers may have a constructivist approach to teaching, although, Dewey's constructivist theories have certainly affected the practices of many science educators, myself included.

Constructivism is a cognitive approach to learning that is based on several constituents. These include active participation, problem-solving, critical thinking and the creation of new knowledge, all based on prior knowledge and experiences. Constructivism is an active, hands-on and minds-on form of learning. It is student-centered, and as such, the teacher acts as a facilitator, guiding the process of active engagement in the science classroom. The constructivist teacher is ideally one who adopts different modalities of teaching and who is proficient in both verbal and non-verbal communication. In accordance with Krashen's second language acquisition theory, a constructivist approach to science teaching implies vocabulary development, alongside gestures, graphics, objects, *realia* etc. It is indeed this type of teacher who can most effectively integrate ELLs in science (Gibbons, 2003).

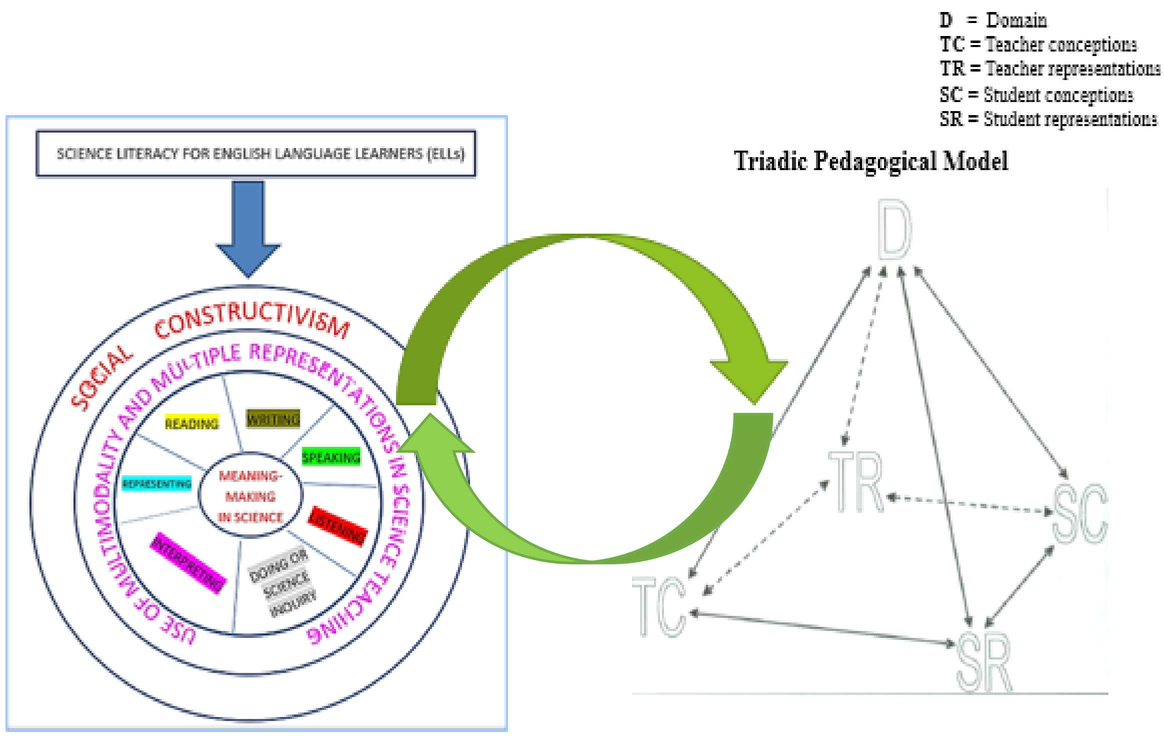
Carrejo and Reinhartz (2014) also remind us of the importance of co-developing language and science literacy in the classroom through contextualized instruction. It is through this social process of co-developing language that meaning-making can occur and content literacy can be developed. This process embraces the constructivist approaches of science inquiry.

Using a Holistic Model of Teaching Modalities in Science

Using an adapted form of Waldrip, Prain and Carolan's (2010) Triadic Pedagogical Model which illustrates the exchanges between teacher conceptions and representations with students, and that of students' conceptions and representations with both their teacher and peers in the science classroom, the following conceptual framework has been designed (see Figure 7). In order to teach ELLs more effectively in science, this framework calls for a holistic approach of teaching modalities – using all seven modalities of reading, writing, listening, speaking, doing, interpreting, and representing, with or without the use of technology. I posit that it is via this social exchange of representational understanding, discourse, negotiation, and re-representation, along with the use of different modalities, that teachers, students, and peers can create knowledge in science.

Figure 7

Holistic Multimodal and Multi-Representational Conceptual Framework



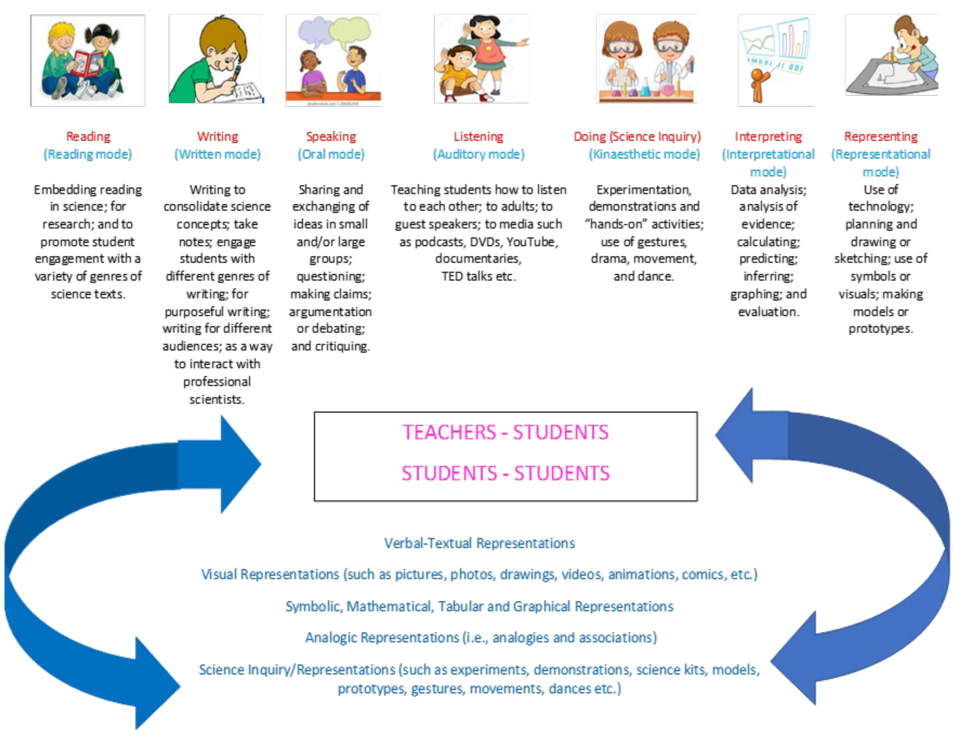
Waldrip, B., Prain, V., & Carolan, J. (2010). Using multi-modal representations to improve learning in junior secondary science. *Research in Science Education*, *40*(1), 65-80. https://doi.org/10.1007/s11165-009-9157-6

This emerging conceptual framework is embedded in a *social constructivist* epistemology and intends to show that science literacy in the 21st century should adopt a more holistic multimodal instructional approach inclusive of: (i) *reading* (textbooks, internet, newspapers, science journals, case studies etc.); (ii) *writing* (lab write-ups, research papers, articles, reflections etc.); (iii) *speaking* (scientific discourse or argumentation); (iv) *listening* (teacher, peers, TV, video, TED talk, etc.); (v) *doing* (science inquiry or experimentation); (vi) *interpreting* (extrapolating, predicting, inferencing, making or drawing conclusions etc.); and (vii) *representing* (graphs, diagrams, concept-maps, equations, etc.) with or without the use of technology, in the science classroom. In light of this, I explored the modalities that science teachers use and/or prefer to use in order to support their ELLs in the science classroom. Observational focus was placed on both the modalities as well as multiple representations used by teachers to teach science to ELLs.

Several empirical studies have been conducted on a combination of these modalities for non-ELLs such as reading and writing; reading, writing, and speaking; reading and interpreting etc., (Fisher & Frey, 2014; Lemke, 1990; Roth & Welzel, 2001). Regarding ELLs, I posit that the two most effective ways to teach science to ELLs is: (i) to plan or co-plan science units using all seven teaching modalities of reading, writing, speaking, listening, doing, interpreting, and representing (with or without the use of technology) via an active process of social interaction, teacher-student, and peer-engagement; and (ii) to use multimodality, along with teachers' and students' multiple representations (Figure 8).

Figure 8

Multimodality and Multiple Representations to Teach Science to ELLs



Research Questions

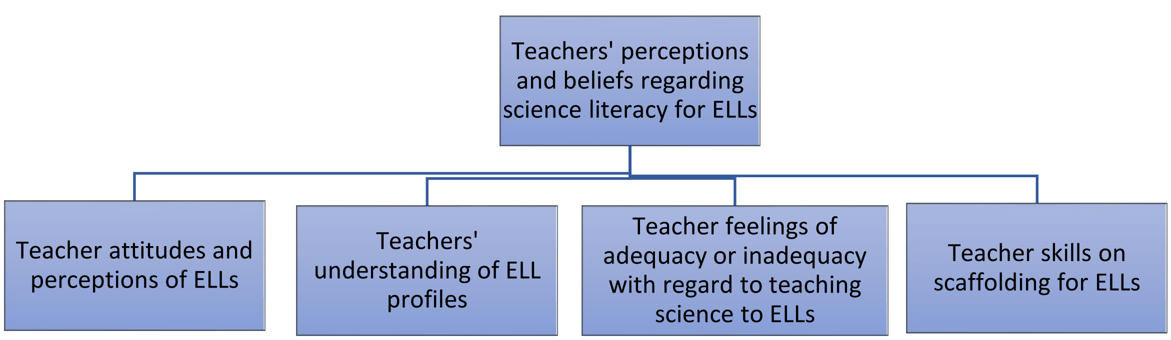
In order to better understand the teaching strategies that teachers used to teach science to their ELLs, it was important to explore and understand teacher perceptions towards ELLs. As mentioned earlier, we know that teacher practices are influenced by their epistemology. Hence teachers will exhibit stronger reflexivity and will be more open to new practices if their epistemology is a constructivist or social-constructivist one. Given the space and opportunity to discuss, engage and reflect on their practice, they are more likely to revisit what they do and/or try new strategies or instructional resources.

Research Question One

What are teachers' perceptions and beliefs regarding science literacy for English Language Learners (ELLs) in the classroom? Based on this research question, herewith is a schematic diagram of the first research objective and its sub-objectives:

Figure 9

Schematic Diagram of Research Question One



Research Question Two

What teaching strategies and/or instructional resources do teacher-participants use to teach science to ELLs?

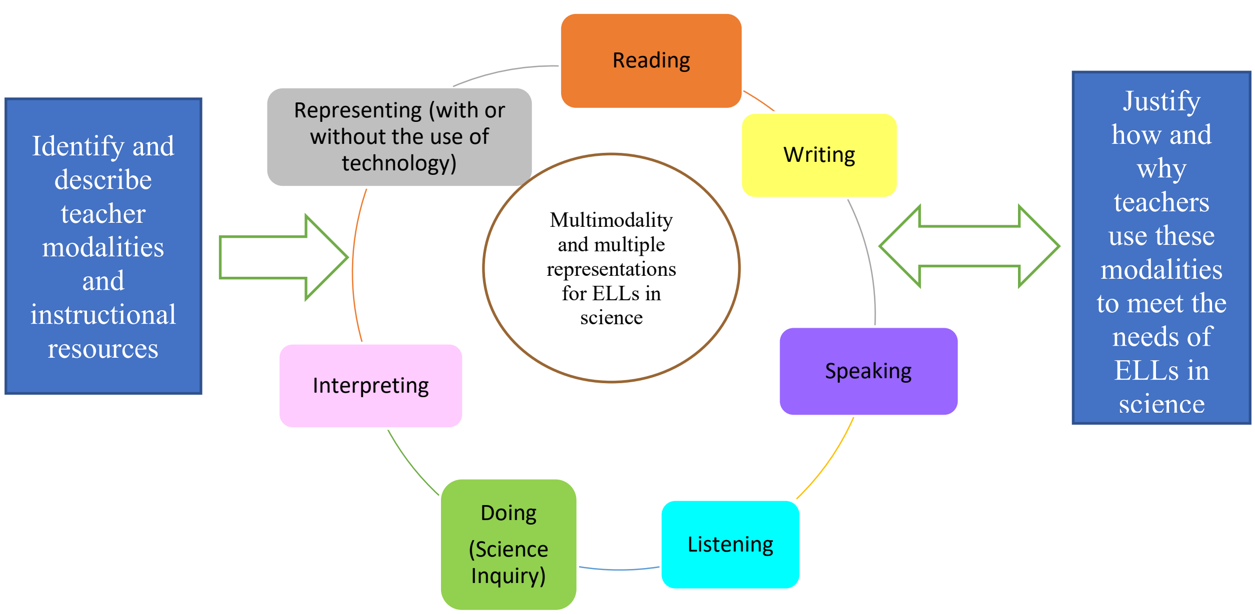
a) What teaching modalities (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology) and/or instructional resources do they use?

b) How and why do they use these modalities to meet the needs of ELLs?

Based on this research question, herewith follows a schematic diagram of the second research objective and its sub-objectives:

Figure 10

Schematic Diagram of Research Question Two

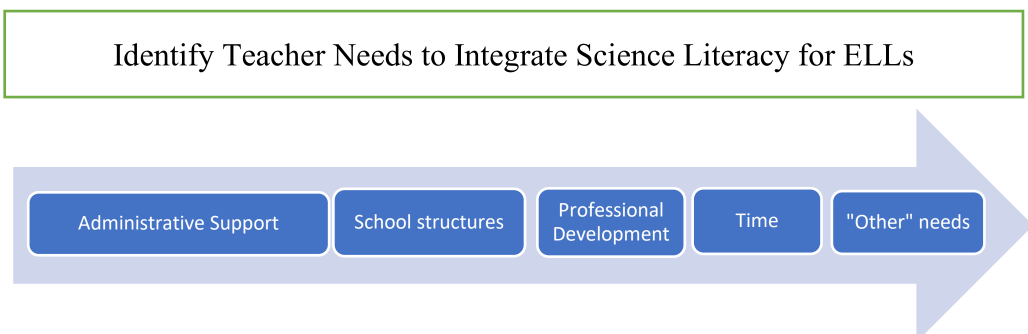


Research Question Three

What do science teachers need to effectively integrate science literacy for ELLs (e.g., structures, resources, administrative support, types of professional development, other needs etc.)? Based on this research question, herewith follows a schematic diagram of the third research objective and its sub-objectives:

Figure 11

Schematic Diagram of Research Question Three



Chapter 3: Methodology

This chapter begins by presenting my background and epistemology as a science teacher and researcher, as well as the research design. It also presents the research context, the process of recruitment of ten teacher-participants (inclusive of their profiles), and the research methods. Data collection in tandem with the process of data analysis are explained at length, concluding with the ways used to ensure the trustworthiness of my data, as well as the ethical considerations taken while conducting this research. Lastly, the chapter ends by addressing the limitations of the study.

Researcher's Background, Epistemology, and Research Design

The broad epistemology in which this research project is embedded is *constructivism* and it also includes several important aspects of *social constructivism*. I have been a middle and secondary school science teacher for twenty-three years and have worked in private international school contexts and with ELLs for over two decades. I have chosen constructivism/social constructivism as the lenses for this research because constructivism relies on meaning-making based on prior knowledge and diverse experiences, with which ELLs are greatly endowed.

Constructivism is a way of creating knowledge using one's own subjective and intersubjective realities through specific contexts or experiences and then reflecting on those experiences to make sense of phenomena. It involves accessing prior knowledge by looking deeply into oneself, to explore what one knows or does not know (Davis, 2004; Hershberg, 2014; Spender, 2008). Human understandings of reality are continuously evolving and being revised; past and present experiences are re-called and re-evaluated, during the process of new meaning-making (Jones & Brader-Araje, 2002). "Furthermore, there is an inevitable historical and sociocultural dimension to this construction. We do not construct our interpretations in isolation, but rather, against a backdrop of shared understandings, language…" (Schwandt, 2007, p. 38).

Unlike the beliefs of Piaget, who also believed in the importance of a dynamic learning process, the social nature of language and learning as a collaborative process played a very important role for social constructivists. In addition, social constructivists believed that the construction and co-construction of knowledge are the product of social interaction, collaboration, interpretation, and understanding (Vygotsky, 1962). Social constructivism envisions learning as an active mental process which incorporates social and cultural exchanges between the teacher and other learners. It is through these two lenses and with my baggage of science teaching experience that I will explore the teaching practices of my ten participants.

This research was a *qualitative-interpretive study* which aimed at understanding the subjective meanings and experiences of science teachers with their ELLs (Creswell, 2013). Meaning was inductively developed via in-depth interactions with ten teacher-participants. This research explored both the professional challenges and opportunities associated with teaching science to ELLs, given its specialized domain, language, and skills. Via this qualitative-interpretive study, as a researcher, I managed to build a professional, respectful, and trusting relationship with ten science and science-support teachers (Savoie-Zajc et al., 2018). The data and findings generated were emergent throughout the research process. This research was a reflexive experience for all those involved. The research methods and data sources collected will be discussed in later sections. Let us take a brief look at the research contexts of this study.

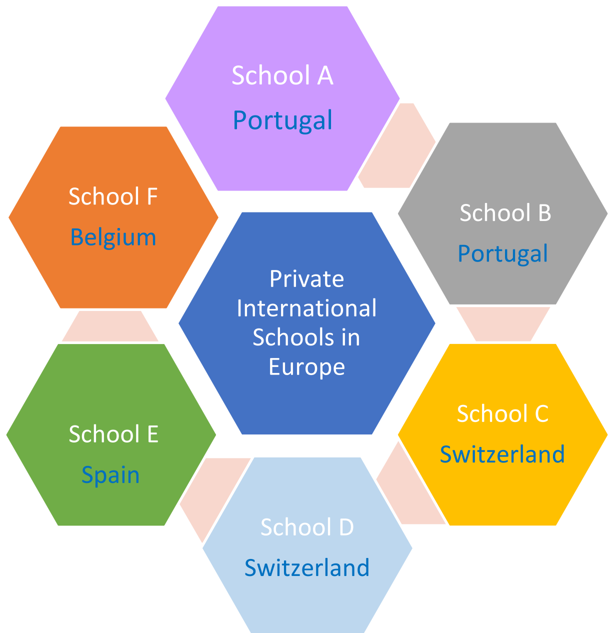
Research Contexts

During this research, I collaborated with ten, Grade 7-12, science and science-support teachers working in the context of six private, international schools based in Europe. These included schools in Portugal (2), Switzerland (2), Spain (1) and Belgium (1). The six schools were not compared to each other. Due to Covid-19, school closures, and the fact that I was unable to visit all six schools in person; only two of them (Schools A and B), the school contexts cannot be compared. In addition, Hayden and Thompson (2008) would also concur with me that making comparisons of international schools is not recommended given their considerable diversity. Having said this, the main commonalities gleaned from all six schools in which my teacher-participants were recruited from, can be summarized as follows.

All six schools: (i) are private, international schools based in Europe; (ii) use English as the medium of instruction; (iii) share (to some degree) in their mission statement, an interest in fostering “international-mindedness”, world peace, tolerance and inclusion, as well as a respect for diversity, environmental and social responsibility; (iv) offer one or more programmes of the International Baccalaureate (IB), whether it be the Primary Years Program (PYP), the Middle Years Programme (MYP), the Diploma Programme (DP), the Career-related Programme (CP), or a combination of these; and (v) charge tuition fees and as such serve a more socio-economic advantaged community of families, resulting in somewhat of a “privileged” and/or “elitist” student population.

Figure 12a

Schematic Diagram of the Teachers Recruited by Country



School A was based in the mid-west of Portugal, a Pre-K to 12 international school with a great deal of student diversity. Its student body consisted of approximately 700 students with 53 nationalities represented. Of these, 28% of the students were from Portugal; 28% from other non-English speaking countries; 20% from the United States; 10% from Brazil; 9% from China; and 5% from English-speaking countries. The school offered an IB programme in Grades 11-12 and had an ESL programme to provide support for English as well as support its ESLs in content areas.

School B was also located in the mid-west of Portugal, with a student body of 600 students and over 50 nationalities represented in the school. It offered all three academic programmes of the IB (i.e., PYP, MYP and DP). This school did not publish the linguistic data of its student-body; however, it did offer English-as-an-Additional Language (EAL) support to those students who were new to English. It also offered EAL support on an "as needed" basis.

School C was located in the south-western, French-speaking side of Switzerland. It had 1800 students from Pre-K to 12, comprising 88 nationalities and 57 mother tongues. It offered an IB programme in secondary school as well as ELL support. It also offered a voluntary after-school "Mother Tongue Programme" to maintain the language and culture of its international students.

School D was located in central Switzerland, in the Swiss-German part of the country. It was also an accredited IB school, had 1250 students with over 50 nationalities, and four IB programmes (PYP, MYP, DP and CP). During the academic year 2018-2019, approximately 44% of the students spoke English; 10% German; 6% Spanish; 5% Dutch, Russian and French; 3% Danish and Swedish; 1.5% Greek, Italian and Portuguese; and the remaining students 30.5 % spoke other languages. In addition, the school offered EAL support as well as a "First Language Programme" to develop students' first language within the curriculum and after school.

School E was located in north eastern Spain. It had approximately 700 students with over 50 nationalities. Of these, 55% spoke English; 38% spoke Spanish; and 7%, spoke other languages. The school offered the DP in Grades 11-12 and adopted an inclusion model of teaching English through science content in the regular classroom. In the higher grades, for those students experiencing difficulties in English, the science teacher could also work with small groups in an EAL classroom.

Finally, **School F** was located in central Belgium, and had a student population of approximately 1400 students. Of these, 785 European students came from 28 different countries; 291 North American students came from three different countries; 269 Asian students came from 21 different countries; 24 South American students came from four different countries; 17 African students came from four different countries; and 15 Oceanian students came from two different countries. Of the 62 nationalities represented in School F, this can be broken down as follows: 55% European students; 25% North American; 16% Asian; 2% South American; 1% African; and 1% Oceanian.

Each year, when new students with little or no English enroll in School F, they join the ELD programme. The school also offered an after-school “Home Language Programme” to assist students in maintaining their home language and culture. This school offered four programmes: (i) an Individualized Diploma programme; (ii) a US High School diploma; (iii) a Diploma Programme; and (iv) the Career-related Programme (CP), as an alternative option.

All six schools catered largely towards children of expatriates, as well as local residents who sought an alternative to their national education system. The diversity of the students, teachers and administrators was extraordinary. For practicality, Table 3 provides “fast-facts” on these six schools, although it is important to reiterate that it is the teachers and their instructional strategies and practices with ELLs, that are the main focus of this research.

Table 3

“Fast-Facts” on the Six Schools of the Participating Teachers

School and Teachers	Country Where the School is Based	School Size	Student Language and Cultural Diversity	Curricula	Language Support Programs
School A	Portugal	700 students	53 nationalities 28% from Portugal	Grade 11+12 Diploma Programme (DP)	ESL programme

			28% from other non-English speaking countries 20% from the United States 10% from Brazil 9% from China 5% from English-speaking countries		
School B	Portugal	600 students	50 nationalities	Three academic programmes of the IB (PYP, MYP and DP).	English-as-an-Additional Language (EAL) programme EAL support on an "as needed" basis
School C	Switzerland	1800 students	88 nationalities 57 mother tongues	IB programme	Mother tongue after-school programme
School D	Switzerland	1250 students	50 nationalities 44% English-speaking 10% German 6% Spanish 5% Dutch, Russian and French 3% Danish and Swedish 1.5% Greek, Italian and Portuguese 30.5 % other languages	Four IB programmes (PYP, MYP, DP and CP).	"First Language Programme" to develop students' first language within the curriculum and after school.
School E	Spain	700 students	50 nationalities 55% English speaking 38% Spanish	Grades 11-12 Diploma Programme	English through science content in the regular classroom

			7% other languages		
School F	Belgium	1400 students	62 nationalities 55% European 25% N. American 16% Asian 2% S. American 1% African 1% Oceanian	Individualized Diploma US High school diploma Gr 11 +12 DP Gr 11 + 12 CP	ELD programme Home Language after-school Programme

The rationale behind choosing European international IB schools for this research was based on the fact that I had been a science teacher in two international schools based in Europe for over two decades and was familiar with the multicultural/multilinguistic contexts of these such schools. These were school contexts that I knew well and professional environments that I felt comfortable with, to conduct my research. The fact that all the schools were IB schools was also reassuring because the IB science curriculum (which I am very familiar with) is rather prescriptive and hence was a common factor in all six international schools.

Recruitment of the Participants

The recruitment process to select teacher-participants consisted in contacting the school principals directly and asking them whether they had any science teachers with a special interest in ELLs, who might be interested in this research. Since the main goal of this research was to explore the teaching strategies, instructional resources, and/or scaffolding methods that Grade 7-12 science teachers use to meet the literacy needs of their ELLs, it was of great relevance to observe the strategies used by the science teachers directly in their international school contexts. Unfortunately, due to Covid-19 and school closures, this was not possible for all schools. I was able to be physically present in two schools (Schools A and B), prior to the Covid-19 lockdowns.

In order to recruit a select group of teachers (*n=10*), I utilized *purposeful sampling* (Creswell, 2013). Science teachers were initially recruited by emailing and sending a letter to the secondary school principals of private international schools based in Portugal and then to other private international schools throughout Europe. The initial aim was to recruit Grade 7-12 science teachers sharing a special interest in ELLs. In Portugal, an IB Physics teacher was initially recruited. This teacher then assisted me in contacting other science colleagues within the school's science department, who willingly and graciously volunteered to participate in this research.

Teachers in the other international schools were recruited in the same way. Although balance and variety are important while recruiting participants for a qualitative research study, there can be differences among teachers based on their age, gender, educational backgrounds, years of teaching experience, cultural, and socioeconomic backgrounds. In this case, however, several of the teachers recruited shared similar backgrounds. Most of the teacher-participants recruited were European nationals: British (4), Portuguese (3), American (2), and Irish (1). Three of the ten teachers were non-native English speakers, while the rest were anglophones. In addition, eight of the teachers were science teachers and two were ELL teachers who supported the science curriculum in both a "pull-out" and "push-in" classroom setting.

The science teachers had an average of eighteen years of teaching experience and the ELL science-support teachers both had twenty-three years of teaching experience in international schools. Together, the average number of teaching years for all ten teachers was nineteen years. As a result, the experiences they shared were very enriching. The ten teachers who were recruited for my research, worked in these schools (see Figure 12b).

In an effort to protect the identity of my participants, whilst honouring the context in which they work, each teacher has been given a *pseudonym* starting with the letter of their designated school (School A, B, C, D, E and F). Their gender was not concealed. It should also be noted that all the teachers voluntarily agreed to participate in my research and signed an official consent form to confirm their participation. They were of course given the liberty to withdraw from the research at any time. At the end of the research, I offered each teacher a small gift voucher as a token of appreciation for their time, dedication, and collaboration in my research.

Figure 12b

Schematic Diagram of the Geographical Location of the Schools and Teachers

A collated and brief, self-reported summary of all teacher backgrounds is included in Table 4. Purposefully omitted are personal details in order to maintain and protect their confidentiality. All ten teachers (Adam, Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy, Eva and Frank) shared a genuine interest in ELLs, however, the instructional strategies they used to support ELLs in science varied from teacher to teacher. Additionally, some strategies were more commonly used than others and will be discussed in greater detail in subsequent chapters. Of course, many other instructional strategies and resources to meet the needs of ELLs in science do exist. However, this dissertation will focus on the extensive repertoires of the ten teacher-participants involved in this research.

Table 4

Profiles of the Recruited Teachers

Teacher	Educational Background	Number of Years of Teaching	Subjects Taught in 2019-2020
Adam	Degree in Biology and PE Master's in Environmental Science/ Ecology	21 years	Biology and ESS
Adele	BSc. in Biology Master's in Marine Biology/Management of Marine Resources	16 years	Biology and ESS
Aisha	BA in Chemistry US Teacher Certification Online master's degree in Chemistry	6 years	Chemistry and Biology
Amelie	Bachelor's degree Master's in Education K-12 Certification in ELL	23 years	ELL Coordinator and ELL Science-Support
Anna	Major in Biochemistry Master's in Physics Doctorate in Physics	22 years	Physics

Brooke	BSc. Honors in Biological Sciences Master's in Education PGCE Teacher Certification	7 years	Science and Biology
Clara	BA in Modern Languages M. Phil in Applied Linguistics Higher Diploma in Education	23 years	English, ELL and Science-Support
Daisy	BSc. in Applied Biology PGCE Teacher Certification Master of Science	22 years	Science and Design & Technology
Eva	BSc. in Applied Chemistry PGCE Teacher Certification Master's degree	24 years	Chemistry
Frank	Bachelor's degree in Animal Physiology PGCE Teacher Certification	26 years	Science and Chemistry

Research Methods

It is through a qualitative-interpretive design and with my baggage of science teaching experience that I explored the teaching practices of my ten participants. The methods involved in this research included: semi-structured interviews, classroom observations (approximately 10 hours per teacher), online observations during Covid-19 (whenever possible), document collection, analysis of instructional resources and/or artefacts shared by the participating teachers, memos, and a researcher journal which I used to jot down my observational notes and personal reflections.

More specifically, three 1.5-hour interviews were conducted with each teacher who signed a consent form to officially participate in this research (see Appendix A). During the first interview, the teachers shared their personal backgrounds as well as their views on science literacy; their perceptions on ELLs in science; as well as their personal opinions on what constituted an "effective" practice for teaching science to ELLs (Appendix B). Teachers were not only asked to respond to a series of interview questions, but also asked to provide specific feedback (written and/or oral) on a teacher modality grid and to prioritize, justify, and provide pedagogical materials and/or resources during the second interview (see Appendix C for specific details).

Savoie-Zajc (2000) claims that the interview method is an effective way to understand a specific phenomenon which affects a person or a specific group of people. It allows participants to convey attitudes and perceptions about their everyday lives and situations. The interview process was indeed an effective way to gather a great deal of qualitative data regarding teachers' perceptions and beliefs on science literacy for ELLs; their teaching strategies; as well as their instructional resources to meet the needs of ELLs in the science classroom. A specific focus was placed on the teaching modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology. I also explored teacher "needs" to integrate science literacy for ELLs.

The ten teacher-participants involved in this research not only relied on their prior knowledge about teaching science to ELLs, but they expanded their knowledge, based on their experiences and the reflective space and opportunities provided by this research (Creswell, 2013). By agreeing to be a part of this research, these teachers were able to reflect on their practice, discuss it with me, and revisit both their perspectives and instructional strategies for ELLs in their science classes. This was a "win-win" opportunity for both of us (teacher participant and myself, the researcher).

Data Collection

As the research methodology was a qualitative-interpretive study, data collection was completed using a theoretical literature review, several empirical studies, and using three semi-structured interviews (1.5 hours each x 3 = 4.5 hours in total) with eight (Gr. 7-12) science teachers and two ELL science-support teachers, face-to-face, as well as via *Zoom* and *WhatsApp*. It also included: (i) classroom observations; (ii) analysis of teacher materials and resources; (iii) lesson plans and artefacts; (iv) online observations; (v) a detailed researcher journal inclusive of my own interpretations, reflections and questions; (vi) an analysis of documents and the school website in order to attain statistics on school size, school diversity, nationalities, languages spoken, and get a feeling for the school's mission and its commitment to ELLs; (vii) thematic analysis; and (viii) coding (Elliot & Timulak, 2005; Nowell et al., 2017).

Three semi-structured interviews were conducted with each teacher participant. The first one was an introductory interview, focusing on the teacher's background, beliefs, and perceptions about teaching science to ELLs. In this first interview, I explored: (i) teacher attitudes and perceptions of ELLs; (ii) the extent to which the teachers understood the profiles and backgrounds of their ELLs; (iii) how comfortable or confident the teachers felt about teaching science to ELLs; and (iv) the range of skills and/or experiences the teachers had regarding scaffolding for ELLs in science.

The second interview focused on teacher practices and instructional resources, and as such, some questions included: "How does science literacy play a role in your classroom? How do you integrate science literacy in your classroom? Please focus on the ELLs in your classroom as you answer this question." A more targeted/specific question included: "How do you teach, encourage and monitor the listening skills of your student's vis-a-vis yourself, their peers, and other adults?" After the second interview, the teachers were also asked to provide written and/or oral feedback on a "teaching modalities grid" and to prioritize, justify, and/or provide pedagogical resources on how they taught science to their ELLs (see Appendix C).

The third interview involved teacher reflections, instructional strategies, and resources for ELLs in science (see Appendix D). However, a lion-share of the time was devoted to understanding teacher "needs" to teach science to ELLs in an effective way — one which could improve their performance in science. An interesting aspect of the third interview (for teachers working in Schools B, C, D and E) was that they discussed the needs for collaboration, scheduling, and specialized PD. Teachers from Schools A and F seemed to mention this less; this was because their schools placed a higher priority on PD and training, and also because School F had a very good co-teaching programme in place.

Several of the interviews and interactions with the teachers occurred on campus in a quiet and neutral environment. This was the case for Adam, Adele, Aisha, Amelie, Anna, and Brooke. Unfortunately, since my field work was interrupted by Covid-19 and school closures, the observations of the science teachers changed rather abruptly from in-person to virtual observations. Online interviews were conducted via *Zoom* or *WhatsApp* for Clara, Daisy, Eva and Frank.

During the interviews, consent to audiotaping was requested at the start of the interview, and if no consent was granted, then I planned to take extensive hand-written notes. This was not necessary because in fact, all teachers granted permission to be recorded. During my Interview #1 for Adam, I encountered some technological issues, so I took laborious notes instead. As this pandemic was beyond anyone's control, thanks are due to the participants for their openness and willingness to continue virtual collaboration throughout the research period. The teachers were explicit in mentioning, that because of school closures, their teaching strategies for ELLs had also changed accordingly. Despite this, the richness of their online tools and resources was commendable and of significant value, nonetheless.

Data Analysis

Data analysis took place throughout the fieldwork period (January 6, 2020 - June 30, 2020) and beyond. In accordance with Braun and Clarke (2006), *thematic analysis* was used to code and analyze the qualitative data. “Through its theoretical freedom, thematic analysis provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex account of data” (Braun & Clarke, 2006, p. 78). I used, as guidance, the seven coding recommendations suggested by Saldaña (2009) which include: (i) organization; (ii) perseverance; (iii) the ability to deal with ambiguity; (iv) flexibility; (v) creativity; (vi) ethics/ honesty; and (vii) the use of extensive vocabulary.

As Saldaña (2009) mentions, the process of data analysis is not a linear one, but is rather recursive and cyclical. Hence, verbatims were read, reread, thematically coded and recoded many times. Collier-Reed and Ingerman (2014) argue the importance of reading and rereading transcripts in order to create “meaning units” (p. 252). The similarities and/or differences amongst the teachers’ beliefs and perspectives regarding teaching science to ELLs, were examined repeatedly, to help in identifying emergent themes which were observed and recorded (Miles & Huberman, 1994).

Once all verbatims were transcribed, I read the text several times in order to fully immerse myself with the teacher responses. Using Word, a six-cm margin on the right-hand side of each verbatim page was created, and as the text was read and reread, key themes and categories were identified (Paillé, 1994). These key themes and categories were noted using the Word.doc “Comments” function, and then those teacher responses which “best” reflected the initial themes identified, were underlined. This was used as a starting point since I expected that emerging and/or new themes would undoubtedly arise during the recursive process of my data analysis.

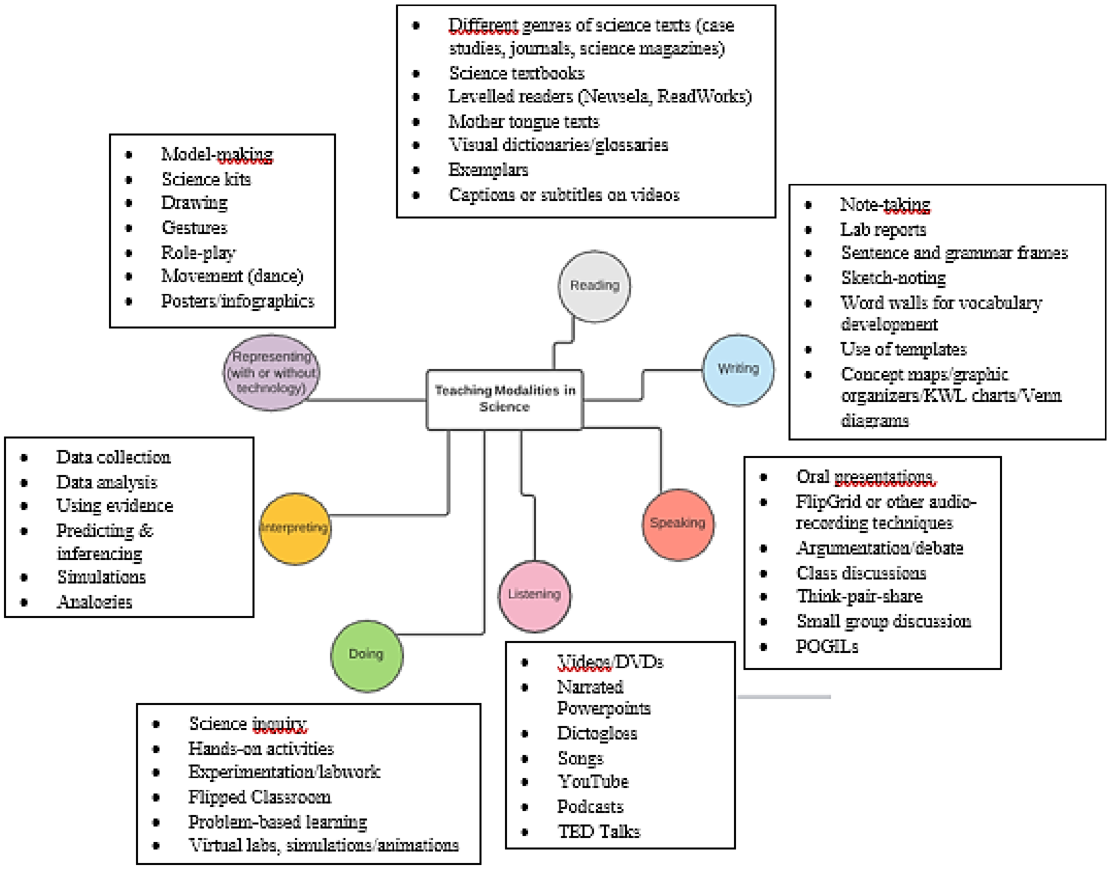
The recorded information was then used to create a weblike thematic network (Attride-Stirling, 2001). This was mostly done as a representational strategy to visualize my basic themes. Attride-Stirling (2001) reckons that weblike structures should consist of 4-15 themes and states that the weblike shape adds flow as well as a non-hierarchical structure to the themes being presented. The resultant weblike thematic network provided a spatial view of the data, and offered me the opportunity to probe the data further and to identify strategies that were most commonly used by the teachers to meet the needs of ELLs in science.

As evident from Figure 13, the weblike thematic network resembles a metro/subway map. It was useful in giving me a holistic picture of all the different strategies adopted for each teaching modality. Specific teaching strategies and tools were listed in bullet form for each modality and focus was placed on those strategies and tools which were mentioned most frequently by the different teachers. I counted the frequency of those strategies and tools mentioned.

On most occasions, I simply relied on the stories and experiences shared with me by the participating-teachers regarding the impact of their strategies on ELLs in science classroom. The use of the flipped-classroom as well as POGILs, which will be discussed later on, are examples of such strategies.

Figure 13

Initial Weblike Thematic Network



I later decided to collate a data table matrix for each interview (Interviews #1, 2 and 3). However, given the large amount of text that each verbatim generated, I decided it was best to make three separate data tables (i.e., one for each research question). All interview responses were collated under each research question (RQ#1, RQ#2 and RQ#3). Once all three data tables were completed, observable relationships between the responses of the interviewees (on each research question) were identified.

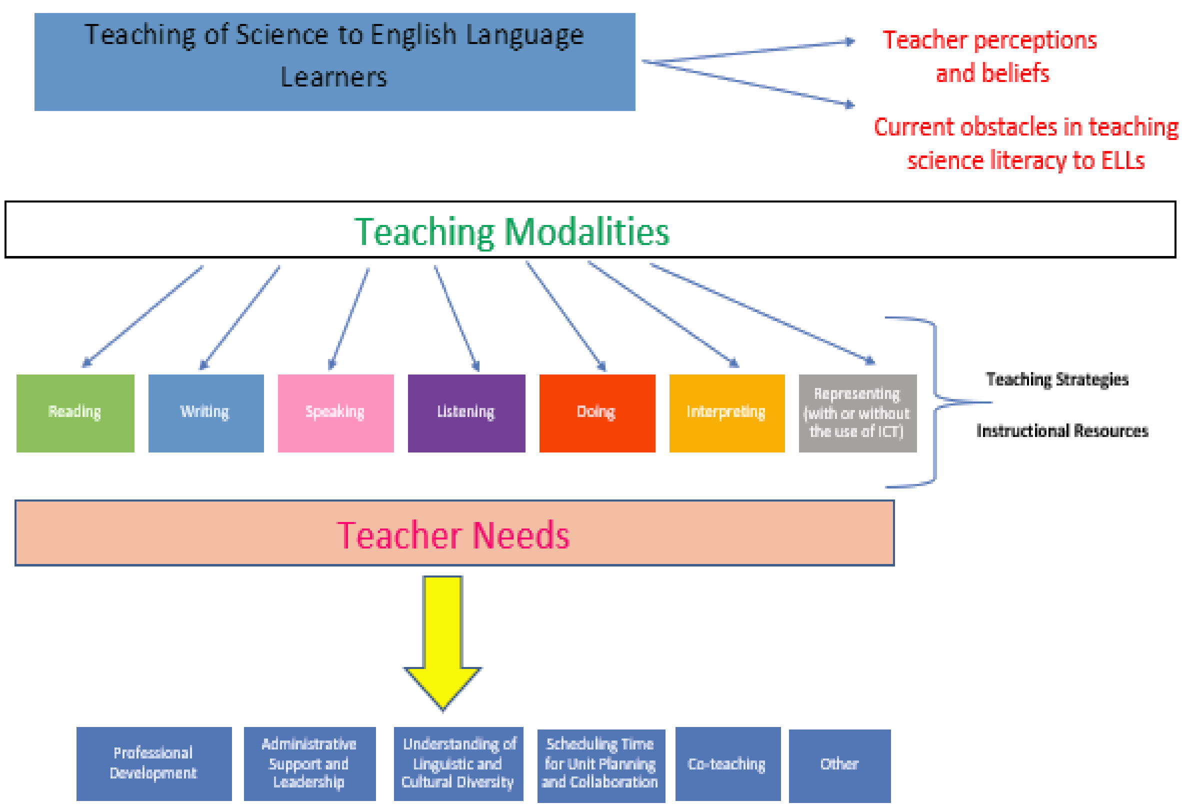
Next, the interview data was transferred onto a grid format, using the seven modalities for science teaching indicated on my conceptual framework: (i) reading; (ii) writing; (iii) speaking; (iv) listening; (v) doing; (vi) interpreting; and (vii) representing, with or without the use of technology. Each time a specific teaching modality was discussed, its details were noted, as well as the teachers' perceptions, views, prioritization, and justification for its use. Detailed notes of the resources and/or materials used were taken. The overall goal of this task was to confirm and/or alter any initial themes as well as to identify new emerging themes. The original conceptual framework was monitored throughout the process of data analysis to note whether it required changes. The goal was to avoid a rigid framework, and to create one which was flexible and evolving along the continuum of the research process.

Coding solo, which is what most new researchers experience, requires various forms of cross-checking procedures. These may include discussions, sharing of coded interview notes with fellow researchers in the field, confirmation of notes with teacher-participants, etc. I attempted to create new meaning or knowledge about science literacy integration for ELLs by making inductive interpretations of the data; extrapolating from observed experiences of the participants; talking at length with my teacher-participants; and using my personal experience as a science teacher for over two decades. Member checking was conducted by sharing the interview transcriptions with the participants on a voluntary basis. This was done purposely to ensure the accuracy of the data. It gave participants the opportunity to confirm and/or elaborate on any point they wished to provide comment on.

Given the many demands on teachers during Covid-19, providing feedback was made voluntary, so as not to add any additional stress for teachers. Most of the teachers ensured their trust in me as a researcher and were eager to read the findings gained in my final dissertation. Once the data analysis was complete, I summarized key points into a schematic diagram (Figure 14). This was a useful and reflexive tool, as it allowed for the generation of some preliminary conclusions.

Figure 14

Schematic Diagram for Data Analysis



The process of data analysis occurred as follows. Initially, folders for all ten teacher-participants were created on my hard-drive. All the relevant school documents, curricula, instructional resources shared, as well as the full interview transcriptions were inserted into each respective folder (i.e., ten folders in total were created). Each recorded interview was listened to several times, and I made a pragmatic decision to use the three research questions (RQ#1, RQ#2 and RQ#3) as a template to organize my data. Three data tables were created for each teacher-participant using the following headings (in bold for emphasis):

1. **Teacher perceptions** and **beliefs** regarding science literacy for ELLs.
2. **Teaching strategies** and/or **instructional resources** used for ELLs in science. The focus was on the seven teaching modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology.
3. **Teacher needs** to integrate science literacy for ELLs.

These main headings were chosen because they aligned with the research questions and my overall conceptual framework. A color-code was then assigned for each teacher (Adam=burgundy; Adele=orange; Aisha=red; Amelie=grey; Anna=pink; Brooke=blue; Clara=turquoise; Daisy=purple; Eva=black; and Frank=green). This color-coding strategy was useful to easily differentiate between the responses of each teacher. Once the transcription of all the text was completed for each teacher, a collated grid of all ten teacher responses was generated under each heading. The end-products were three collated data tables: (i) teacher perceptions and beliefs regarding science literacy for ELLs; (ii) teaching strategies and/or instructional resources used for ELLs in science; and (iii) teacher needs to integrate science literacy for ELLs. The collated data tables were read and re-read multiple times before proceeding to use Miles, Huberman and Saldaña's (2014) three-step process of data analysis: (i) data condensation; (ii) data display; and (iii) conclusion drawing/ verification.

Miles, Huberman and Saldaña (2014) define *data condensation* as the continuous "process of focusing, simplifying, abstracting, and/or transforming the data that appear in the full corpus (body) of written-up field notes, interview transcripts, documents, and other empirical materials" (p. 12). During the process of data condensation, after listening to the interviews again and again, as well as reading the collated data tables in depth several times, common themes which where iterated and reiterated by the teachers, were extracted. These themes were noted in a data analysis grid, using the same three headings mentioned earlier: (i) teacher perceptions and beliefs; (ii) teacher strategies and/or instructional resources; and (iii) teacher needs. Care was taken to record which of the ten teachers had mentioned each theme. This also revealed the frequency and importance of each theme. After this lengthy data condensation phase, a data display was consolidated.

Data display is defined by Miles, Huberman and Saldaña (2014) as “an organized, compressed assembly of information that allows conclusion drawing and action” (p. 13). Such a data display may include matrices, graphs, charts etc. Following the data condensation process of this research, the data display took the form of a data analysis grid. An enormous amount of qualitative data was condensed into a tabular format which was more user-friendly, was more visual, and which provided the possibility to glean through the main themes more effectively. The collective responses of all teachers were easily visible, the main themes under each teaching modality were identifiable, and the number of teachers who mentioned and/or elaborated on those themes, was easily noticeable.

The final step, known as *conclusion drawing/verification*, is defined by Miles, Huberman and Saldaña (2014) as interpreting “what things mean by noting patterns, explanations, causal flows, and propositions” (p. 13). Conclusions were drawn on all the data collected and then confirmed with the teacher-participants, finding direct quotes from the verbatims to serve as evidence, triangulating the findings with Prof. Liliane Dionne (my doctoral supervisor), as well as collaborating with a retired teacher and friend. This opened multiple perceptions which aided in creating meaning (Denzin & Lincoln, 2005). The data viewed through multiple eyes generated new and interesting angles which had not previously been considered.

Ensuring the Trustworthiness of My Data and Findings

As I was the sole researcher in this study, attention was given to ensuring the rigor and trustworthiness of my data and findings. First of all, I focussed on maintaining the *credibility*, *dependability*, *confirmability* and *transferability* of my data (Lincoln & Guba, 1985). Regarding credibility, I engaged with my teacher-participants extensively and collected a diverse set of data sources for the purpose of data triangulation. Using a combination of semi-structured interviews, classroom observations, teacher resources and artefacts, online informal discussions with the teachers, memos, and a research journal as sources of data, all helped to confirm the themes that emerged, as well as the findings and conclusions I reached.

I tried to maintain the dependability (or reliability) of my data sources by making my research process logical and well-documented. Schematic diagrams and matrices were used extensively to visualize, plan and/or re-plan, and guide my research along the way. Multiple drafts of my research were written, rewritten, and continuously tweaked, until I was satisfied with a final version. The aim was to make my research process as transparent as possible to the reader(s).

I also sought the confirmability of my data by clearly showing how my findings and interpretations were derived from the analysis. By using color coding of texts, I was easily able to view those themes which were most commonly iterated by the ten teachers. Once again, schematic diagrams and the identification of categories/themes were used. Nowell et al. (2017) remind us of the importance for a qualitative researcher to clearly demonstrate how conclusions are drawn from the findings.

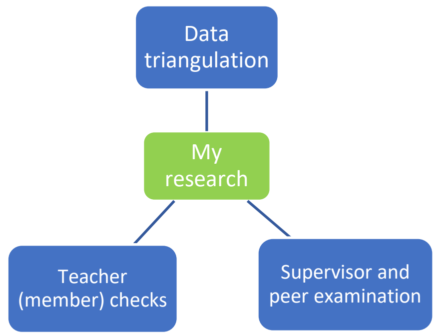
Given the specific context of private international schools based in Europe, the issue of transferability was dealt with very cautiously by openly discussing the limitations of the research contexts, its specificity, and its somewhat “elitist” milieu. Having said this, although the contexts do not represent the norm of science classes, there are certainly some benefits to be gained from the teacher practices and instructional resources used by these ten teachers for ELLs in science.

A second way to ensure the trustworthiness of my data and findings was through teacher (member) checks (Elliot & Timulak, 2005). Interview transcripts were shown to the teacher-participants on a voluntary basis. They were asked to confirm whether what had been gleaned and extrapolated from their interviews, was indeed accurate. Since the teachers were very stressed and overworked during the first Covid-19 lockdown, this member-checking process was made optional, so as not to burden the teachers with extra work during such unprecedented times. As mentioned earlier, none of the teachers chose to re-read their full verbatims, however, several informal conversations on *WhatsApp* helped me clarify certain points which required further explanation.

A third way in which the trustworthiness of my data and findings were tackled, included sharing the data and data analysis with my PhD supervisor, Prof Liliane Dionne, as well as with a retired teacher, for peer examination. This cross-checking procedure assisted in confirming the reliability of my data and assertions (Savoie-Zajc et al., 2018) and provided the opportunity to view new perspectives which had not yet been explored. It opened up new pathways for reflection. Viewing data through multiple eyes and discussing whether the assertions being made are coherent and/or make sense, is very useful to a novice researcher.

Figure 15

Ensuring the Trustworthiness of My Data and Findings



Adapted from Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd Ed.). SAGE.

Ethical Considerations

All research in education requires ethics clearance, and as such the uOttawa, *Office of Research Ethics and Integrity* had to approve this research prior to its implementation. The ethical considerations which I upheld included: (i) requesting consent at all times; (ii) being cognizant of my personal biases or preconceptions via the use of a researcher journal to observe any judgments or biases which may have developed regarding the different teacher-participants and/or strategies they had adopted in the classroom; (iii) maintaining the integrity of the results at all times; (iv) being mindful of possible power relationships and avoiding them in any interactions with the participants; (v) safeguarding utmost confidentiality; and (vi) allowing the participants the possibility to withdraw from the research process at any time.

I also maintained professional conduct throughout the research journey and adopted all the necessary measures to ensure that the participants were never exposed, or judged in any way. The use of pseudonyms starting with the letter of the schools (School A, B, C, D, E, and F) was one of the measures I took to safeguard their anonymity.

Limitations of the Study

One limitation of this study includes its lack of quantitative data. As qualitative-interpretive research implies both subjective and interpretive forms of inquiry, triangulation (the process of using multiple perceptions) was used to converge data from different sources of evidence (i.e., interviews, document analysis, notes in my research journal, classroom observations, memos, discussions of teacher resources and lesson plans, and teacher artefacts). Background research and theories also seemed to be coherent with the conclusions drawn (Denzin & Lincoln, 2005), although the beauty of conducting research is that this may not always be the case.

Another limitation of this study was its sample size. This research included eight science teachers and two ELL science-support teachers – i.e., ten teachers in total. A sample-size of ten participants is rather small. Additionally, as this research focused on teaching practices specific to the ELL student population, it was important to avoid generalizations, as every teacher, in any school, always has a unique classroom setting and dynamic, and as such adapts his/her teaching methods to the needs of the students.

Most importantly, the narrow focus on private international schools based in Europe was a significant limitation of this study. This somewhat restricted both the school contexts and the profiles of the teacher-participants, although it did provide a highly multilingual and multicultural context for my study. The rationale for this choice was based on my personal experience, background, and familiarity with teaching in European private international schools. Hence, the need for vigilance over the possible influence of personal biases throughout this research study.

Purposeful sampling is generally a limitation in any research because it makes *generalization* even more cautionary. The findings of this research may indeed have been very different within a public-school context. The rather “elitist/privileged” nature of private international schools that charge tuition fees and which serve expatriate communities as well as local residents who are mostly from socio-economically advantaged backgrounds, are usually able to afford and hire qualified, multicultural, and linguistically diverse teachers. Depending on the priorities of the school leadership, such schools can also fund for professional development and specialized training.

The milieus of private international schools are not the norm; they are usually endowed with small class sizes (15-24 students), and have more freedom or agency with regards to their programmes and choices of curricula. These usually include the IB, Advanced Placement (AP), Key Stage 1, 2, or 3 (UK system), the International Primary Curriculum (IPC), the Cambridge International Primary Programme (CIPP), the International General Certificate of Secondary Education (IGCSE), or the French or European Baccalaureate (Hayden & Thompson, 2008). Although this was beyond the scope of my study, future research on science literacy development for ELLs could valuably compare the outcomes in the school settings of both private and public schools.

The focus of this research was placed deliberately on the teaching practices and pedagogical tools used in reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, in science (see RQ#2 in Appendix E). A timeline of the field work is available in Appendix F. This research focussed on “teaching modalities" rather than on "student learning". A lens on ELL student learning using multimodalities in science might indeed be an interesting research study for the future.

Lastly, another limitation of this research is that it adopts a rather Western view of science literacy and teacher practices in science. As mentioned earlier, the views and teacher practices in content areas, science inclusive, are greatly affected by culture and epistemology, hence this research does not take into account indigenous values, perspectives, epistemologies and contexts. Traditional educational knowledge has not been acknowledged in this research context, and certainly deserves attention in future studies. [For more information on indigenous knowledge in science, please refer to Kim, E. J. A. (2018)]. In light of these limitations, let us now take a look at the findings gained from this research.

Chapter 4: Findings

This chapter presents the findings regarding teachers' perceptions and beliefs in science literacy integration for ELLs; a focus on teaching modalities used to meet the literacy needs of ELLs; as well as the needs of science teachers to integrate science literacy for their ELLs. The findings presented are congruent with the three research questions and sub-questions, reiterated herewith.

Research Question #1: What are teachers' perceptions and beliefs regarding science literacy for English Language Learners (ELLs) in the classroom?

Research Question #2: What teaching strategies and/or instructional resources do teacher-participants use to teach science to ELLs?

a) What teaching modalities (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology) and/or instructional resources do they use?

b) How and why do they use these modalities to meet the needs of ELLs?

Research Question #3: What do science teachers need to integrate science literacy for ELLs (e.g., structures, resources, administrative support, types of professional development, "other" needs etc.)?

For purpose of clarity, the findings of this research will be presented under each research question heading, so as to demonstrate the relationship of the research questions to the findings gained, beginning with teachers' perceptions and beliefs regarding science literacy for ELLs. The remaining two research questions will be subsequently addressed.

Teachers' Perceptions and Beliefs Regarding Science Literacy for ELLs

The "deficit theory" of ELLs suggested by Cummins (2000) did not transpire during the interviews with the ten teacher-participants. None of teachers spoke about ELLs "negatively", nor perceived them as a "burden" to their science class. On the contrary, the ten teachers I interviewed had very positive attitudes and perceptions towards ELLs. They were invested in their ELLs and were committed to helping them as much as possible, despite the existing structures and time constraints under which they worked. Emotionally, they were compassionate and understanding towards ELLs in their classrooms. This was evident during the classroom and online observations. Table 5 summarizes some anecdotes shared by the teacher-participants, related to their beliefs and perceptions about ELLs and what ELLs need in order to learn science (see RQ#1 in Appendix E for more details).

Table 5

Teachers Perceptions and Beliefs about ELLs and ELL Needs

Teacher Perceptions and Beliefs about ELLs:	What ELLs Need:
- ELLs do try hard; are motivated to do well; are brave; do extra work. (All teachers)	- Need and thrive with a combination of both images and text. (All teachers)
- Feel they are members of the community, when given the right support. (Adele, Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank)	- Need gestures as well as verbal cues to better understand the topic. (Adele, Aisha, Clara, Daisy, Eva)
- Are humble; the quietest and sweetest in room. (All teachers)	- Need modified assessments for language; not content. (Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank)
- Cope well; they are incredibly resilient. (Clara)	- Need encouragement to communicate orally in class. (All teachers)

- Often "mask" what they do not understand. (Amelie, Clara)	- Need extra time to complete tasks. (All teachers)
- Work well with activities having reduced text (such as hands-on activities, interpretation and numeracy skills, data analysis etc.). (All teachers)	- Need consistency as well as repetition, paraphrasing, and rephrasing. (Aisha, Amelie, Clara, Daisy, Eva)
- Often use their primary language to make sense of science in English. (Adele, Amelie, Clara, Daisy, Eva)	- Need a combination of modalities. (Aisha, Amelie, Anna, Brooke, Clara, Daisy, Eva, Frank)

Furthermore, from the comments collated in Appendix E (for RQ #1), there were four major themes which transpired. These included: (i) ELLs are hardworking and motivated students; (ii) ELLs benefit from multimodality and scaffolding; (iii) ELLs should be encouraged to use their native language as much as possible; and (iv) ELLs need explicit language instruction in science.

As mentioned earlier, awareness of and sensitivity towards ELLs were strong in all the ten teachers interviewed. This may be due to the fact, that most of the teachers had many years of experience with ELLs from a wide array of international settings (refer back to Table 4 on "Teacher Profiles"). In fact, in addition to teaching in international schools in Portugal, Switzerland, Spain, and Belgium during the academic year 2019-2020, collectively, the teachers also had experiences in teaching in schools in the United Kingdom, Kenya, Dubai, Mexico, United States, Costa Rica, Brazil, South Korea, Columbia, Kuwait, New Zealand, Ethiopia, Hong Kong, Shanghai, and Italy. Their teaching experience with culturally and linguistically diverse students was extremely rich, which may explain their heightened sensitivity and openness towards the needs of ELLs in their classrooms.

The feedback of these teachers also needs to be seen in context. All these teachers worked in rather privileged private international school environments with class sizes ranging from 15-24 students. The students came from socio-economically advantaged backgrounds and were mostly bilingual or multilingual. Most of the students had attended their school for many years and/or had been exposed to the English language for at least five years. Although many students did speak English, all ten teachers mentioned that 20-25% of their students had low academic language development in science; while 5-10% of their students had low English proficiency (see Table 6).

Table 6

Teacher Self-Reported Numbers of Students Language Development in Science

Teacher Self-Reported Numbers of Students Language Development in Science		
School A	2 out of 15 students	10-15%
School B	4 out of 16 students	25%
School C	6 out of 24 students	25%
School D	6 out of 22 students	25-27%
School E	7 out of 22 students	30%
School F	3 out of 21 students	10-15%
Average		22%

In addition to asking about teachers' perceptions and beliefs about ELLs, all ten teachers were also asked to share their definition of science literacy. During Interview #1, when asked to share their definition of science literacy, the teacher-participants replied as follows. Science literacy (SL)…

Table 7

Teacher-Participants' Definitions of Science Literacy

Teacher	Definition of Science Literacy (SL)
Adam	SL is the same as lab reporting. Students need to be able to write a discussion, conclusion, and an evaluation. *(Reading, writing, and interpreting*)
Adele	Implies reading scientific data and text and speaking about it. *(Reading, speaking, and interpreting*)
Aisha	SL is the ability to gain meaning from scientific, academic texts. *(Reading and interpreting*)
Amelie	Exposure and understanding of scientific terminology, as well as the ability to read graphs. Be able to write a lab report. *(Reading, writing, and interpreting*)
Anna	To understand enough of science to be able to have an opinion and critical thinking and even making decisions. (*Reading, listening, speaking, and interpreting*)
Brooke	Is how proficient you are in expressing the concepts necessary to achieve an understanding in science. Science literacy includes concepts, collecting, analyzing, and evaluating data. Understanding that science is a "process" - a way of answering questions. *(Reading, writing, speaking, listening, and interpreting*)
Clara	Comprises the reading, writing and communication skills specific to and necessary for the expression and application of scientific content, concepts, and processes. It implies an understanding of the register and conventions specific to scientific text and discourse. It gives students a framework of academic language and skills through which they can access scientific content, frame their understanding, and communicate their knowledge of science. *(Reading, writing, listening, speaking, doing, and interpreting and representing*)
Daisy	Being able to do the scientific method and conduct research; cite sources in the correct format; being able to write in an analytical way; and having the ability to read scientific texts. *(Reading, writing, and interpreting*)
Eva	SL is the ability to read, understand, decipher (or decode) science writing, and respond to it using correct vocabulary in the right setting. *(Reading, writing, speaking, and interpreting*)
Frank	Using technical language; analyzing data; looking for patterns; asking questions and hypotheses; being able to describe data and connect data with theory. *(Reading, writing, listening, speaking, and interpreting*)

As evident from the text in italic in Table 7, most teachers reported that reading, writing, and interpreting were the most important modalities for the development of science literacy. Regarding the actual supports to meet the literacy needs of ELLs in science, several recommendations were proposed. These will be described here and will certainly have implications for science education in the future.

For pragmatic purposes, teaching strategies and resources have been organised under the specific modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology. Each modality will be presented individually, although several researchers, as well as myself, suggest that effective ways to teach science to ELLs implies using a combination of these modalities (Ajayi, 2009; Wu & Puntambekar, 2012). A teacher in School A (Anna) in fact states:

> What I learned from my ELL co-teacher is that two modalities work better than one, and three are better than two, and so forth. So, don't just speak, don't just read, don't just write, don't just talk. It's when you combine them that ELLs understand best. You need to combine images with words, combine sounds with words, hands-on activities with words and images etc. You must combine as much as possible.

Teaching Modalities: Strategies and Resources Used for ELLs in Science

Reading

Reading is a critical modality in any subject area, but is especially relevant in the field of science, given its complex lexical structure and specialist terminology. Science uses complex informational texts which are often difficult to decode, even for native English speakers. This makes vocabulary such a key factor in the domain of science.

During the interviews with the teachers, three main areas of intervention seemed to be flagged with regards to reading in science, especially for ELLs. These included the need for: (i) levelled reading or the levelling of existing science resources available (i.e., science textbook and/or other sources) to reduce students' lexical challenges; (ii) vocabulary development in science; and (iii) embedding explicit teaching of language in science. Each of these factors will be considered individually, as follows.

Levelled Reading. Seven teachers (Adam, Adele, Aisha, Anna, Brooke, Daisy, Eva) argued that given their current densely-packed curricula, there was little time and space to engage in as much reading as they would have liked to do in science. One teacher (Aisha) mentions, "I would like to read more science articles, but I need more time as well as a database of levelled articles to use." Eight teachers (Adam, Adele, Aisha, Anna, Brooke, Clara, Daisy, Eva) did integrate some reading of scientific issues within their units of science.

Levelled reading (i.e., science content presented with different linguistic or lexical scaffolds for their ELLs) was a priority for six teachers (Amelie, Brooke, Clara, Eva, Daisy, Frank). These included instructional tools such as the website *Newsela*, www.newsela.com, which enables teachers to use science articles with appropriate reading levels for their students. Although these levelled articles provide more simplified versions of the original text, they still preserve its integrity, including its vocabulary, scientific content, and length. The articles are also complemented with questions and writing prompts, which serve as comprehension checks.

Similar levelled resources used by some teachers include *Newsademic*, www.newsademic.com (Clara, Daisy), as well as *News in Levels*, www.newsinlevels.com (Eva). Both of these resources are scaffolded to meet the linguistic proficiency levels of ELLs in the classroom. They also meet the science literacy requirement for authentic reading in science. Providing ELLs with the opportunity to read about "real life" science at a level with which they feel comfortable, is one way to develop science literacy.

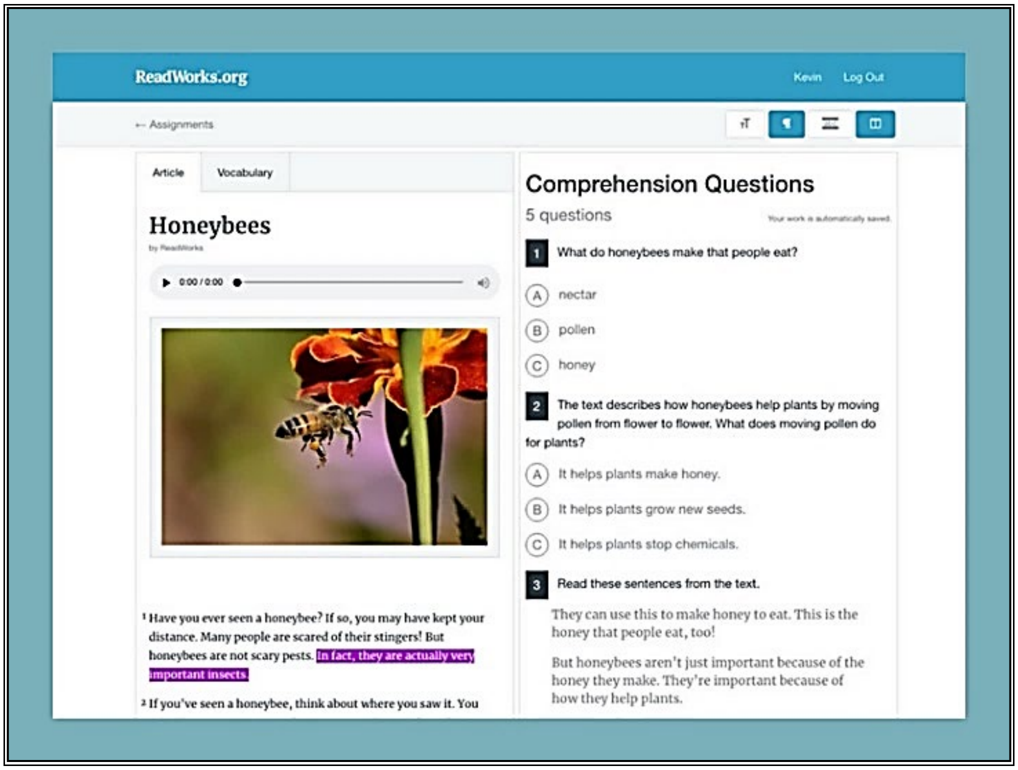
One of the teachers (Eva) mentioned two interesting instructional resources which are worth highlighting, due to their functionally adaptable nature for ELLs. The first one is a website known as *ReadWorks,* (www.readworks.org), which not only provides science texts with differing English reading levels, but also includes key vocabulary and questions with multiple choice answers that can either be read and/or listened to by the students. Additionally, ReadWorks is also supported in seven languages, which is a great asset for ELLs from different countries. One teacher (Eva) states, "This resource is easy to use and is great for homework before class discussions."

As evident from Figure 16, this website offers ELLs the opportunity to use audio versions of the reading content, thus engaging them in using both their listening and reading skills. It also offers ELLs the possibility to highlight and/or annotate notes, as well as follow a guided reading strip at their own pace.

With regards to teachers, ReadWorks, also offers free professional development via online webinars to those teachers who are new to this website. Although it is not the intention, or the role of this dissertation to promote educational websites, having investigated this resource in depth, it should be recognized for offering scaffolded content for the linguistic needs of ELLs in science. It is one of many recommended resources for developing science literacy.

Figure 16

Screenshot from ReadWorks



Similarly, *Britannica Online,* (www.Britannica.com) is an online encyclopedia which also offers step or levelled reading opportunities for students doing research on a science topic. This useful resource for ELLs engages them in research topics in science. It is used by six of the participating-teachers (Amelie, Brooke, Clara, Daisy, Eva, Frank). Clara has used this resource for research papers in science and has also designed a modified ELL scaffold on essay writing, which will be presented later.

Six teachers (Adam, Adele, Aisha, Anna, Daisy, Eva) also mentioned that they often use relevant science articles from this source linked to their curriculum and read them in small groups. If there are students who share similar native languages, the teacher groups them into smaller groups (by language) and has them read an online article in their mother tongue. They then discuss the article within their small language groups. Clara states, “When they have a resource in their own language, they have more self-confidence to then tackle it in English.” The next step is to read an article (on the same science topic), in English, with the aid of visual dictionaries or related videos, audio recordings etc.

Vocabulary Development in Science. In light of the findings gained from the analysis of the interviews with the participating teachers, another technique for understanding reading in science includes vocabulary development. Eight teachers (Adam, Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy) mentioned the importance of building glossaries and proposed diverse ways on how ELLs could make them. These included: (i) the conventional writing of definitions in their science notebook (Adam, Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy); (ii) digitally creating visual glossaries that combine text and image; (iii) collectively building a word wall of the key terms encountered in each chapter (Aisha, Amelie, Clara); (iv) using mother tongue visual dictionaries to create a glossary in their native tongue (Clara); and (v) making vocabulary cards (Clara).

Adele explicitly lists the “key words” that the students should learn and retain from a science chapter. For example, to learn the specifics of the hydrological cycle in the *Environmental Systems and Societies* (ESS) class, Adele assigns the following words for vocabulary development and then models them orally in class. Using repetition and paraphrasing, Adele ensures that these words are used in context and are reinforced throughout the teaching of the unit.

Figure 17

Example of Key Vocabulary on the Hydrological Cycle Flows

The Hydrological Cycle Flows

Read pages 214 to 216 of your textbook and fill in the table below:

Type of Flow	Description
Precipitation	
Interception	Interception loss
	Throughfall
	Stemflow
Evaporation	
Transpiration	
Infiltration	
Overland flow	
Condensation	
Sublimation	
Advection	
Freezing	
Melting	
Stream-flow	
Flooding	

Eight out of the ten teachers (all except of Eva and Frank), also give students key vocabulary words to be identified in the unit. Both teachers and students collectively define the terms and leave them on their wall (if they have their own classroom), and/or share them in a digital format for easy access at home. One of the teachers (Brooke) also uses an effective color-coding system of green, amber and red to emphasize important relationships of the "key words". For example, in the unit on the *Variety of Life*, words highlighted in "green" relate to the *environment*, words written in "amber" denote *interactions*, and words in "red" represent the *key words* present in the unit. The use of these colors is explicitly taught at the beginning of each unit, so that the students are acquainted with the color-coding system and its relevant associations (see Figure 18).

Figure 18

Using a Color-Coded System for Vocabulary Development

Topic 3: Variety of life

Key Concept: **Systems**
Related concepts: **Interaction** and **environment**
Global Context: **Globalization and sustainability**

Statement of inquiry:
……
……

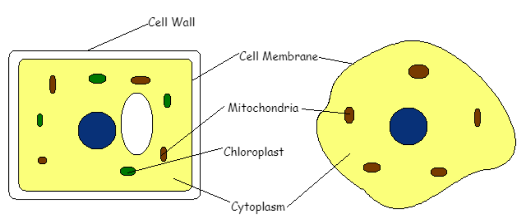
Learning Objectives

After studying this topic, students should:
Characteristics of life

- Know what "alive" means in science.
- Know about: cells, tissues, organs, systems of organs and the organism.
- Know that there are special cells for special jobs.

Plants and Animals

- Know that animals and plants are the most complex forms of life.
- Know the things that are the same and the things that are different about animals and plants.
- Be able to see some of the parts of a cell in a microscope.



- Draw and label the main parts of animal and plant cells.

Adaptation of plants and animals to the environment

- Know about physical and behavioral **adaptations** of plant and animals.

Interaction of different forms of life

- Know that living things interact.
- Draw food chains and food webs.
- Draw food chains and food webs including **producers** and **consumers**.

Conservation of different forms of life

- Give examples of endangered species.
- Know why extinction happens.

Key words:

Systems
Interaction
Environment

Cells
Tissues
Organ
Adaptation
Species

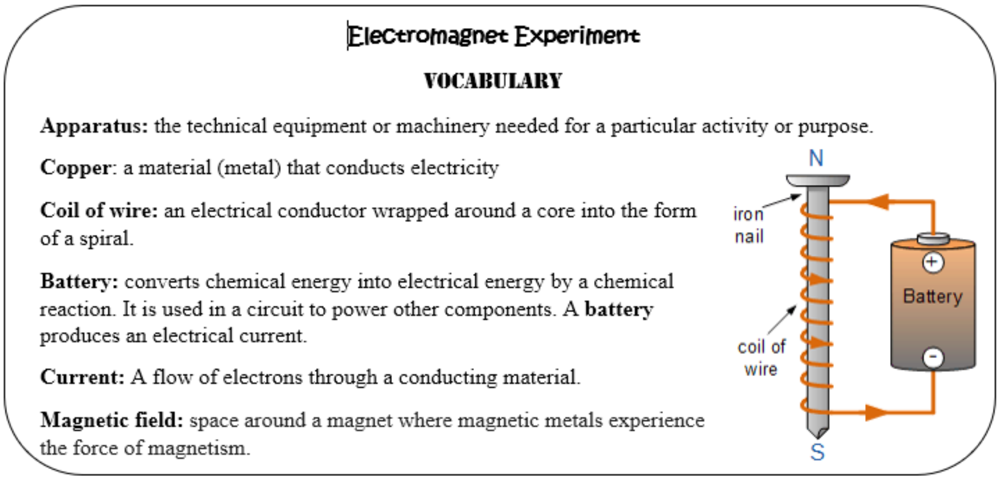
Nucleus
Cytoplasm
Cell wall
Food chain
Producer
Endangered

Cell membrane
Predation
Vacuoles
Chloroplast

Another teacher, Amelie, tackled vocabulary development of science concepts such as an electromagnet by providing students with the concise definitions of key terms, alongside a labelled image, so that the ELLs could then combine these sentences together, in a logical order, to better understand how an electromagnet works (Figure 19).

Figure 19

How to Scaffold an Electromagnet Experiment


Electromagnet Experiment

VOCABULARY

Apparatus: the technical equipment or machinery needed for a particular activity or purpose.

Copper: a material (metal) that conducts electricity

Coil of wire: an electrical conductor wrapped around a core into the form of a spiral.

Battery: converts chemical energy into electrical energy by a chemical reaction. It is used in a circuit to power other components. A **battery** produces an electrical current.

Current: A flow of electrons through a conducting material.

Magnetic field: space around a magnet where magnetic metals experience the force of magnetism.

Two teachers (Brooke, Daisy) mentioned the use of *Quizlet* and in particular, *Quizlet Live,* as effective and engaging instructional tools for vocabulary development in science. Quizlet Live is a team-based vocabulary learning game where students work together to correctly match a set of scientific terms and definitions. The team that matches 12 words in a row, wins. Quizlet Live adds a competitive and fun twist to the learning of scientific vocabulary. This is very similar to playing *Science BINGO*, which three of the teachers (Brooke, Clara, Daisy) also use in their classroom. The building of science vocabulary is fundamental to science literacy development, hence finding creative ways such as *Quizlet*, *Brainpop*, *Science Bingo*, *Kahoots*! and other games for use in the class is of significant value to ELLs. In addition, all ten teachers agreed that, key words are to be linked in context, and not taught merely as an isolated list of vocabulary words.

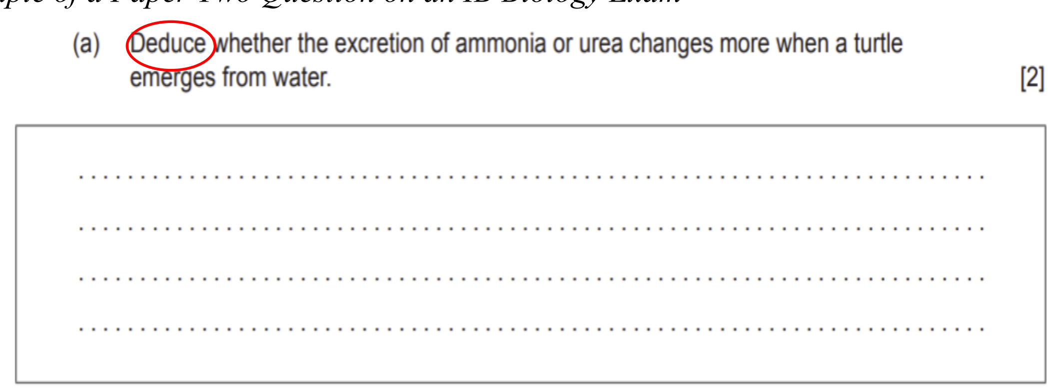
Explicit Teaching of Science Language. With the exception of Frank, all the teachers mentioned that ELLs require explicit teaching of the language of science, particularly when it involves the decoding of instructions and questions. This technique is useful especially on assessments such as their IB exams. Adele states:

> Especially when it comes to *command terms* like, what is the meaning of "explaining"? What is the meaning of "outlining"? They have a hard time understanding that. Most of the issue is in the understanding of the wordage because despite English being the mainstream language, not all students understand in between the lines or what they mean. And this is something that I, for example, have noticed. They also have a hard time chunking or breaking down longer questions, more complex questions in ESS.

Command terms such as "infer", "persuade", "outline", "evaluate", and "deduce" which appear in Paper Two of IB Biology exams, for example, remain unclear for many students, but especially for ELLs. These words should be explicitly taught and modelled by the science teacher so as to better prepare ELLs on their assessments.

Figure 20

Example of a Paper Two Question on an IB Biology Exam



(a) Deduce whether the excretion of ammonia or urea changes more when a turtle emerges from water. [2]

International Baccalaureate Organization (2017)

Writing

With regards to the modality of writing in science, the majority of the writing tasks demanded of students in the science classroom, as mentioned by the participating teachers, is on the writing up of labs/experiments. Notetaking and research papers (expository writing) come in second place. Unfortunately, for high school students (except for IB extended essay questions), more creative writing tasks such as narratives, journaling, reflections, persuasive writing, article writing etc., are less prevalent than for students in middle school.

As was the case with reading mentioned earlier, the paucity of writing tasks in science is also largely due to high school teachers' lack of time for additional genres of writing, as they strive to satisfy the curricular demands of preparing their secondary school students for their science exams. This is a notorious problem affecting science education, which is worthy of further research.

Three main techniques are used by science teachers to support writing for ELLs in science: (i) the use of sentence or grammar frames; (ii) the use of templates or exemplars (such as print copies of labs as models); and (iii) visual-to-text supports in the form of study guides or teacher PowerPoint notes (with reduced texts). These are equipped with writing space on the right side of each slide, to enable ELLs to annotate and/or translate the teacher notes into their mother tongue. Additionally, these supports are complemented with visuals, diagrams, and equations. Let us take a look at each of these separately.

Sentence and Grammar Frames. Writing up a science lab requires complex and technical language within a structured format. Unfortunately, some teachers assume that ELLs understand this structure by "osmosis". On the contrary, before ELLs can be expected to write up a lab report, teachers are required to explicitly teach students the steps, structure, sentence, and grammar framework required for a lab report. Seven out of the ten teacher-participants (Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank) stressed the importance of providing ELLs with such supports or scaffolds. Examples of sentence or grammar frames used by Daisy include the following.

Figure 21

Excerpt on Sentence and Grammar Frames for Labs

RESEARCH QUESTION: Does ________________ affect the time taken for the colour coating to come off an M&M?

1	**Aim**: The aim of this experiment is to see if ____________________ affects the time taken for the colour coating to come off an M&M
2	**Hypothesis/Prediction**: If the M&M is _____________ then the M&M with lose its colour faster/slower.
3 (a)	***Independent variable*** I am changing the amount of ____________
3 (b)	***Dependent variable*** I am measuring the _________
3 (c)	***Control variables*** I will keep the following things the same: 1. Amount of ______ 2. Temperature of ______ 3. Type of ______ 4. Colour of the ______

In addition to going over the steps of the scientific method, breaking it down into sentence frames, and teaching each step one-at-a-time, the use of templates and/or exemplars is also helpful for modelling labs. Aisha, Brooke, Clara, Daisy, Eva and Frank all use exemplars for their ELLs. Sentence frames such as the ones shared by Brooke provide ELLs with linguistic scaffolds, alternative sentence starters from which to choose, as well as exposure to the structure of a lab report.

Figure 22

Use of Sentence Starters for Lab Reports

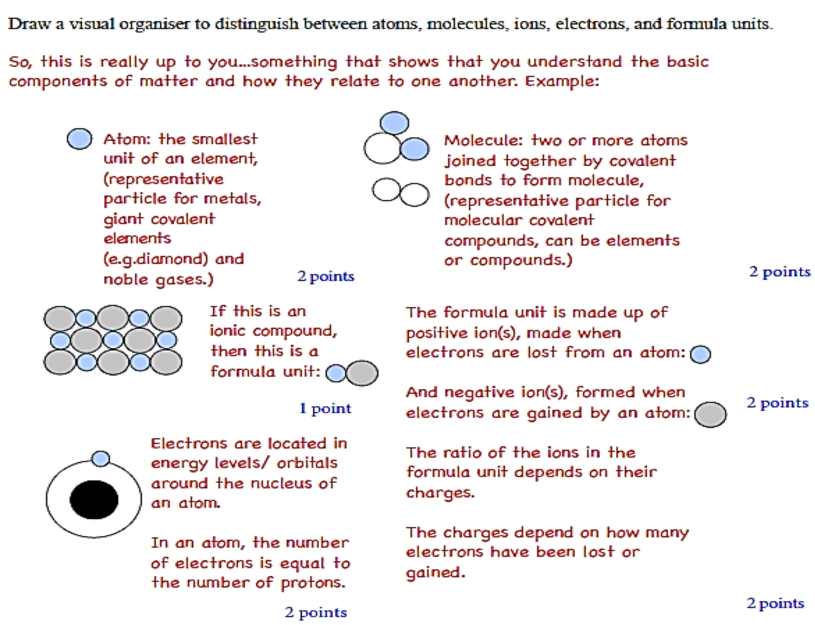
Hypothesis: Outline a *testable prediction* using *scientific reasoning* ❑ I predict that if I increase / decrease ... then ... will ... ❑ This is because... ❑ Other information that supports my hypothesis is.... ❑ My prediction is / is not testable. I know this because	My **hypothesis** is testable, and includes my **variables**, with my reasons as a 'because' statement.
Method & Materials: Design a safe, *logical* and *complete* method ❑ There are some / no risks in this investigation because... ❑ I will **stay safe** by ... ❑ I will **keep others safe** by ... ❑ I need to use these **materials** and **equipment** in my investigation... ❑ I need to **carry out these steps** in my investigation... ❑ This is a photo / diagram of my investigation	My **procedures** are safe, complete, and logical. Someone else would have no problem with my lab because I describe how to work with the variables and collect data. I have selected every **material** I will need, including quantities, and I won't need to ask for anything on the day of the lab.

Use of Templates and/or Exemplars. More than half of the teachers (i.e., six) used templates and/or exemplars especially for lab write ups (Aisha, Brooke, Clara, Daisy, Eva, Frank). Frank provided a step-by-step PowerPoint as a support for lab write-ups. The ELLs were asked to use this PowerPoint as a scaffold to write up their own labs. Whereas Aisha provided the students with a complete lab exemplar. The terminology of this exemplar was very complex for ELLs. Therefore, Aisha read the lab out loud in class and then addressed each step orally by asking the students for suggestions on how the language could be modified and/or be made more accessible. Sentence starters and sentence frames were co-created during each step and written on the board. At the end of all steps, which took a considerable amount of time, the students culminated the activity by conducting a relevant experiment related to their current topic in science and were then asked to write up their own lab independently, using the exemplar as a model.

In addition to composing successful lab write ups, understanding how teachers assess student work or performance on exams is also an important skill in science. As a way to prepare students for science assessments, Eva provided the Chemistry students with exemplars of IB Chemistry exams and their respective answers. The use of a teacher-designed "answer key" was distributed to model responses for the IB exam. In addition, students were able to see how many points each question was worth (1 point, 2 points etc.). Visuals, color-codes, as well as reduced text were used to support the ELLs in the class. Figure 23 is an excerpt of a review sheet used in Eva's Chemistry class. This was used as an exemplar which could then be modelled on the actual IB exam.

Figure 23

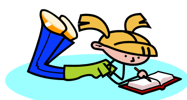
Review Sheet with Questions and Answers from a Chemistry Teacher



Beyond lab writing and assessments, during my discussions with the teachers, what transpired was that the writing of research papers in science was more commonplace in middle school versus secondary school. An ELL science-support teacher (Clara) was very effective at deconstructing the parts of a Gr. 7-8 essay writing task and making this accessible as well as less daunting for ELLs. This science-support teacher (Clara) provided the students with an outline and explicitly taught the students each step. This was in preparation for a research essay. Figure 24 is an example of how such an outline can be used to scaffold a five-paragraph research essay in science. Clara mentioned that although this process takes time, the benefits of investing such time for essay planning and writing are extraordinary for all students involved.

Figure 24

Template of a Research Essay Outline



Research Essay Outline

Introduction

Background Information

Definition:

Thesis – big idea – what will you PROVE?

Main Points (MP) – HOW will you prove it?
MP1
MP2
MP3

Main Point 1

Topic Sentence

Example 1
Explanation
Example 2
Explanation
Example 3
Explanation

Closing Sentence

Main Point 2

Topic Sentence

Example 1
Explanation

Example 2 Explanation **Example 3** Explanation
Closing Sentence
Main Point 3
Topic Sentence **Example 1** Explanation **Example 2** Explanation **Example 3** Explanation **Closing Sentence** **Conclusion**
Restate thesis and MP 1, 2 and 3 – what have you proven? Underline it. **Final, powerful statement – sum up AND convince us!**

Upon completion of the essay outline, this support teacher (Clara) subsequently provided the students with a template from which to develop their essay, step-by-step. Below is an example which Clara provided to all her ELLs. This template not only deconstructs an essay into simpler parts, but it is an effective tool which supports students in writing a five-paragraph research essay.

Figure 25

Template for Writing a Research Essay

Building a Research Essay

Part - Introduction:

Grab reader's attention and introduce topic.

____

____

Ask focus question:
____?

Introduce ALL of your main points (MP) in a paragraph.
MP1:
MP2:
MP3:

Part 2 - Heading About Main Point 1
Make sure your headings are capitalized and underlined!
- ◎ *Topic sentence to introduce Main Point One.*
- ◎ *Follow this with supporting details (facts and examples).*
- ◎ *REMEMBER TO USE THE LETTERS FROM YOUR BIBLIOGRAPHY TO SHOW WHERE YOUR INFORMATION CAME FROM!*

Part 3 - Heading About Main Point 2
- ◎ *Topic sentence to introduce Main Point Two.*
- ◎ *Follow this with supporting details (facts and examples).*
- ◎ *REMEMBER TO USE THE LETTERS FROM YOUR BIBLIOGRAPHY TO SHOW WHERE YOUR INFORMATION CAME FROM!*

Part 4: Heading About Main Point 3
Make sure your headings are capitalized and underlined!
- ◎ *Topic sentence to introduce Main Point Three.*
- ◎ *Follow this with supporting details (facts and examples).*
- ◎ *REMEMBER TO USE THE LETTERS FROM YOUR BIBLIOGRAPHY TO SHOW WHERE YOUR INFORMATION CAME FROM!*

Part 5: Conclusion- Answer the focus question here!
1. *Sum up main points.*
2. ***Answer your focus question*** *– and explain/support it. Answer that focus question with confidence and convince your reader.*
3. Plus, leave your reader with something to remember!

In conclusion,

Sum up main points 1-3

____

____

Ask focus question:

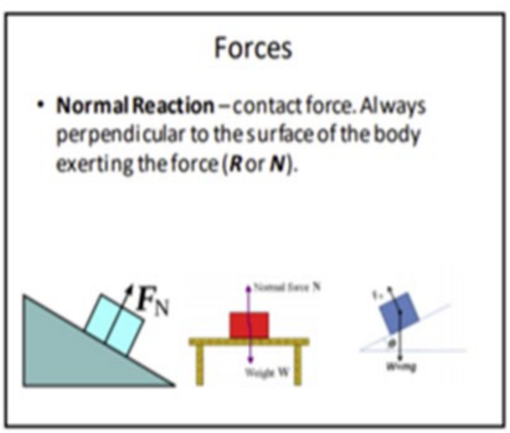
Answer focus question:

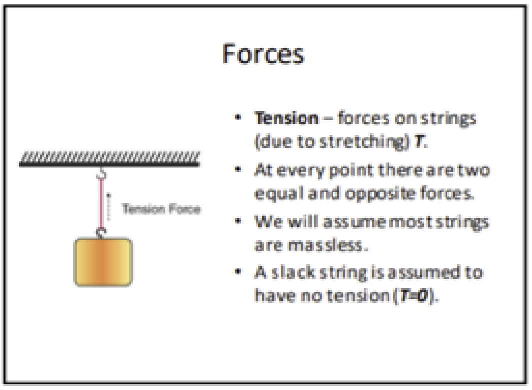
Explain why – and convince your reader (final statement):

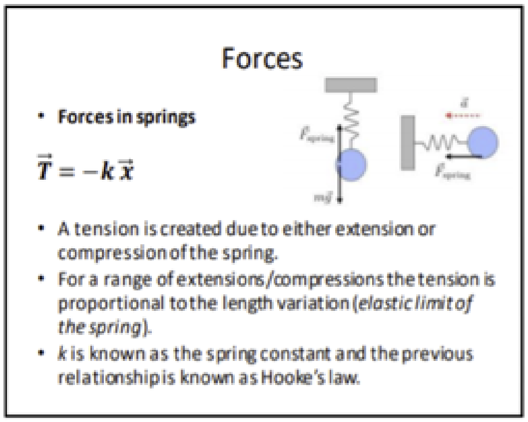
Visual-to-Text Supports for ELLs. One alternative to traditional notetaking while a teacher lectures, is a technique to provide both native speakers as well as ELLs with teacher-notes (containing reduced text, diagrams, equations etc.), and to supply them with adequate space to take their own notes and/or translate them into their native tongue. This process not only validates their own language, but it reduces the burden of English-only text. Six teachers (Adele, Aisha, Anna, Brooke, Clara, Frank) have used this type of support. Herewith are some screenshots that one of the teachers (Anna) uses in a unit in Physics.

Figure 26

Visual-to-Text Supports for ELLs







From these screenshots, one can see that the amount of text is reduced and is complemented by diagrams (visual representations of the units of "force") as well as mathematical equations. ELLs can attempt to infer the meanings of words such as "massless," "tension," "compression," and "slack" from the images provided, and the space on the right enables them to translate and/or take notes in their native language. It reduces the onus of dense text and is multimodal in nature (due to the presence of text, diagrams, equations etc.).

Speaking

As in any content class, speaking in a classroom can be initiated via traditional questioning and class discussions. ELLs can be encouraged to speak by: (i) the use of creative scaffolds, tools, and resources; (ii) purposeful grouping; (iii) Process-Oriented Guided

Inquiry Learning (POGIL); and (iv) creating opportunities to celebrate cultural and linguistic diversity. Each of these techniques will be considered individually.

Creative Scaffolds, Tools, and Resources to Promote Speaking of ELLs in Science. The participating science teachers adopted several creative ways to encourage ELLs to speak in class. A simple, non-technological way was with the use of white boards in combination with a common *think-pair-share* or small group activity. As low proficiency ELLs are often too timid to speak in a large classroom setting, in these cases, the teacher provided all students with a white board and marker at the beginning of class. Every time the teacher asked an open-ended question in class, students were asked to respond using their white board and then share their answer either with a partner or in a small group. This prompted discussion, allowing the teacher to act as a facilitator by moving around the room to listen to student responses. This was also a great opportunity for formative assessment.

During my classroom observations, the use of the whiteboards to promote speaking, especially by ELLs, proved to be very effective. In fact, I observed an increase in the number of ELLs speaking about science-related topics in class. Overall, the use of the whiteboard was a non-threatening and simple tool to engage ELLs in the process of speaking about science.

Games using chips or tokens, adopted by another teacher (Daisy), was also used as a creative tool for ELL inclusivity in class discussions. Whether in a small or in a large group, students were asked to form a circle and each student was given a token. The teacher then asked an open-ended question and encouraged each student to make an oral contribution and to then place their token in a jar. The goal of this game was to get rid of the token before the end of the activity. As in the previous example, the teacher was able to take on the role of a facilitator, giving ownership to the students for leading their own discussions about a scientific issue in a creative and engaging way. As the activity was student-centered and student-directed, ELLs felt more comfortable in participating orally in class.

The use of analogies is also an effective strategy to engage ELLs in the process of speaking. When the Grade 7 students were studying cell organelles and their functions for the unit on the *Variety of Life*, their teacher (Clara) actively encouraged students to make “real life” analogies to cell functions. For example, a policeman was used as an analogy for the cell membrane in an animal cell. It protected what went in and out of the cell. The nucleus was considered the brain of the cell; it controlled all the cell functions and activities. The vacuole was a swimming pool; it contained and stored water and minerals etc. Once these analogies were discussed and agreed upon consensually by all ELLs, they then made a rap song about the cell and acted it out. Students brought props and costumes to class, and did a role-play of the parts and functions of the cell. This was a very effective manner in which to consolidate their scientific understanding of cells. In fact, during their unit assessment on “Cells”, many students mentioned to the teacher (Clara) that they had rehearsed the analogies and skits in their heads while taking their test.

Lastly, video or audio-recordings using, *WhatsApp*, *Flipgrid*, *Stream*, or *Voxer* (a free app which acts as a “walkie-talkie” and enables students to easily make audio-recordings of their science responses), are not only excellent tools to encourage ELLs to speak, but they also reduce the burden of writing, and provide immediate feedback/responses via an integrated play-back system. Audio-recordings via the use of *Flipgrid* (Daisy) or other audio-recording systems (Adele, Clara) provide ELLs with the opportunity to orally share their responses and demonstrate their scientific understanding, as well as engage them with their peers in a non-judgemental way. Technology, used effectively, is a powerful way of promoting the speaking of ELLs in science. Speaking can also be enhanced by utilizing methods such as purposeful grouping.

Purposeful Grouping. If we are to truly have culturally inclusive classrooms, the inclusion of ELLs goes without saying. This is not always easy as it is contingent on the teachers' or English speakers' perceptions of ELLs in the class. Purposeful grouping for class activities such as experiments, class discussions, cooperative learning activities, etc. can be very beneficial. Pairing and/or grouping native speakers with non-native speakers is one option. All ten teachers regularly did this in their science classes. Daisy states, "Non-ELLs are super-supportive of ELL needs, and oftentimes, when I use modified resources in groups, I offer the same resources to everyone who wants it, so that nobody feels left out".

In addition, forming mother-tongue language groups can likewise be beneficial. Adele, Amelie, Clara, Daisy, Eva and Frank mentioned the importance of clustering ELLs in primary language groups. Students who speak the same primary language can discuss a scientific concept or theory in detail, and then attempt to transfer that understanding into English with the help of resources such as visual dictionaries, science textbooks in their native language, videos, etc. While lesson objectives can still be met, the process involved in reaching those objectives needs to be scaffolded for ELLs.

One teacher (Clara) works extensively with purposeful grouping. Clara shared a wonderful classroom experience in which several East Asian students transferred their knowledge about the periodic table from their Saturday mother tongue school textbook into their Chemistry unit at their regular, weekly school. The students worked together in small groups using their mother tongue texts to understand the organization of the periodic table and then proceeded to decode and transfer the knowledge gained into English for their science class. The benefit of purposeful grouping of students was a success-story in this example and there are multiple benefits to be gained in terms of children's cultural and linguistic identities.

Process-Oriented Guided Inquiry Learning (POGIL). POGIL was also used by two of the participating teachers (Brooke, Eva). Although only two of the ten teacher-participants used POGIL, observations revealed this to be a very valuable resource for ELLs to develop their science literacy. This was largely because of its adaptability and versatility for ELLs. POGIL is a student-centered instructional approach which helps to develop content (i.e., science content) as well as communication, critical thinking, and problem-solving skills within a small group of students. Most importantly, it allows students to work at their own pace, thus reducing the stress induced by time pressures.

In the science class of one teacher (Eva), students worked in teams of three or four and had assigned roles (such as a note-taker, reader, presenter, etc.) which were then rotated for every new POGIL activity. In one observed example, this teacher (Eva) used POGIL to teach the periodic table to Grade 10 students (see Appendix G). Eva described this type of approach as follows.

> I might give POGIL as an individual task at the beginning of a class, then use it as the foundation for small group conversations about what they think the most important key ideas, vocabulary or modelling might be. Then we'd do a whole class plenary. It gives the ELLs a chance to speak to their peers, and identify key vocabulary and ideas, as a group.

POGIL is versatile and allows for purposeful grouping by mixing ELLs and non-ELLs together, or alternatively, clustering all the ELLs together. The choice on how ELLs will be grouped is made by the teacher, depending on the task and composition of students in the class. Another teacher (Brooke), for example, uses POGILs in groups to focus on those students with lower English proficiency. One example is a POGIL using ray boxes during a science inquiry about *angles of incidence* and *angles of reflection*. Students who are fluent in English use the POGIL for guided learning and student-led inquiries. Those students work independently to inquire about the *angles of incidence* and *angles of reflection*. In the meantime, the teacher (Brooke) works with the ELLs to scaffold the language and explain the task. Brooke might also choose to use the POGIL as an extension activity to explore *total internal reflection*, while the first group writes up their findings independently. Overall, POGIL enables the teacher to provide ELLs with extra support (if needed) and/or to differentiate activities during the science class.

Creating Opportunities to Celebrate Cultural and Linguistic Diversity. It is important to celebrate cultural and linguistic diversity in science, as well as in other content areas. Teachers (Adele, Clara, Daisy, Eva) explicitly shared the importance of validating the cultural and linguistic diversity of ELLs in the science classroom. Two examples of this type of inclusion were observed in the teacher-participant classrooms. One teacher (Adele) had students organize themselves into groups of three from the same or neighbouring countries and asked them to present an environmental problem which activists were currently opposing. Adele mentioned that the Brazilian students in the class addressed the *slash-and-burn* method which is destroying the Amazon Forest; Asian students spoke about air pollution in their hometowns; a Danish student spoke about the *Envirobank*, a machine that is used to collect plastic in exchange for money, to combat pollution generated from plastics; and a Portuguese student discussed the pollution left behind by cruise ships, since Lisbon is one of the common destinations of cruise liners. Vis-à-vis native speakers, the ELLs were given the opportunity to share an environmental issue affecting their own country. This was an issue they were both concerned and/or passionate about.

During this task, the students were expected to present both sides of the opposing case, to take a stand, and then to debate it. This activity not only linked the students to their culture, but it engaged them in the research process of an authentic and relevant environmental problem affecting their own country, culminating in a debate (argumentation) of an environmental topic (see Figure 27).

Figure 27

Debating Environmental Issues by Embedding Cultural Diversity

During the second interview, Adele referred to this activity as the *environmental click*, or what made the students aware of environmental issues. The students shared these environmental concerns with their class, and in so doing, raised awareness among fellow students about a broad array of local issues. Adele concluded this class activity by showing students two videos which illustrated how two specific "environmental clicks" managed to create a worldwide movement.

Another teacher (Daisy) celebrated cultural and linguistic diversity during a science unit on "Diet and Nutrition". The class was discussing the use of energy bars, and students were asked to research the ingredients in energy bars sold in their own countries. Students then presented the different ingredients of these energy bars to the class. The result was a diverse and culturally specific representation of energy bar ingredients which reflected and celebrated the diversity of the science classroom. The oral presentation also allowed students to work on their oral skills in science. Similarly, while teaching a unit on "Solutions" in a class with mostly Asian pupils, one teacher (Eva) had students explain the solutions needed to make *tofu*, instead of yoghurt, as prescribed by their science textbook. This was indeed a simple, yet practical way to make a textbook activity more culturally relevant and to celebrate student diversity. Getting to know one's students, their backgrounds, their cultures and creating science activities which validate them, can be very powerful for ELLs.

Listening

Listening is often a difficult skill to monitor, especially for ELLs, as they tend to "mask" their understanding, or lack thereof. As Clara mentions:

> ELL students work so hard and cope so well that they often give the impression that they understand. This is often not the case. Therefore, I need to work on the nitty-gritty details in science, to ensure their true understanding of the content.

The teachers mentioned three ways to support and encourage the listening skills of ELLs in science. These included: (i) the use of technology to promote listening; (ii) using grouping to maximise listening skills; and (iii) *Dictogloss,* an effective tool for promoting listening skills among ELLs.

Use of Technology to Promote Listening. The use of technology to promote listening skills includes the use of subtitles to complement videos sourced from YouTube, scientific DVDs, TED talks, songs, documentaries, podcasts etc. Five of the teacher-participants (Adele, Aisha, Anna, Clara, Daisy), mentioned the potentials of technology to reinforce the listening skills of ELLs in science. ELLs need to be exposed to authentic, scientific, audible texts and then to extract the academic language by teaching and/or reviewing those terms explicitly. By mixing audio and texts, ELLs are more likely to make sense of what they hear. For example, narrated PowerPoints of teacher notes (Adele, Anna) is one way to promote the listening skills of ELLs. This was observed among the teacher-participants as a complementary support for ELLs during Covid-19 school closures and online teaching. Anna also mentions the use of a video called *Hewitt Drew-It* (by Paul Hewitt), who poses questions at the end of the video to ascertain the listening skills of all students (both ELLs and non-ELLs).

Additionally, Anna spoke highly of the tool*, Communities for Physics and Astronomy Digital Resources in Education* (ComPADRE) which includes animations and videos complemented by transcripts. Anna states the following:

> The combination of visual, audio and text are very effective for my ELLs who often find it challenging to keep up with the rapid pace in video. In ComPADRE, usually these animations have a theoretical part where they explain the physics and how they built the animation and then they challenge the student to explore the animation by changing the variables. There is an interactive component as well.

Several other apps, software, and audibles can be used to promote listening skills in science. One teacher (Clara) mentioned the simple technique of stopping a video every three minutes and doing a *think-pair-share* activity to ascertain listening skills amongst students via peer exchanges on the topic.

Using Grouping as a Way to Maximise Listening Skills. Depending on the level of English proficiency, ELLs may not always grasp the full extent or details of oral (auditory) instructions in science. A review of steps involved in a lab experiment serves as an example of how to mitigate this problem. Ideally, teaching ELLs about a lab experiment would need to be complemented by other modalities such as written text, images, gestures, a demonstration, a virtual experiment, a YouTube video etc. Asking students to respond by summarizing an experiment would be one approach. One scaffolded way of creating a summary of an experiment, used by Aisha, was to ask the students, "What did you hear? Summarize it! Quickly! Think-Pair-Share!"

Aisha also used the *Number Heads Together* technique. Students were seated at tables of four and assigned a number from #1-4. Talking partners were formed, and then rotated. Doing this on a regular and systematic basis was very effective because it created a routine for checking students' understanding as well as identifying any misconceptions. The ELLs were not only accustomed to this technique, but since they worked in a small group, there was no pressure to talk in a large classroom setting. Additionally, the use of "exit cards" (by Daisy) or "Post-it notes" (by Aisha) was also employed to gauge students' understanding in science. ELLs were able to discretely inform their teacher as to whether they understood the lesson, or to write down anything they were unclear about. This information could then be reinforced in the next class.

Another teacher (Eva) adopted another interesting *Group-of-Four* system to assess listening skills. The teacher asked an open-ended question and the first person in the group had 60 seconds to respond to the question, the second person had 40 seconds, the third person had 20 seconds, and the last person needed to provide a concise and efficient, one- or two-sentence response. This process enabled the students to work not only on their scientific understanding, but also on the conciseness and accuracy of their scientific language. In fact, their final response needed to be scientific, concise, and accurate. If it was not, then the students needed to re-negotiate a consensual response.

Aisha, Clara, and Frank have students question each other (in pairs) to ascertain student listening as well as to correct any misconceptions. Whereas, Brooke starts a new unit of science with a word game. Students are asked to cross out any “key words” they hear their teacher use from their vocabulary list. This is another way to monitor students’ listening skills in the classroom.

Dictogloss: A Listening Technique to Promote Social Engagement. *Dictogloss* is a well-known technique to promote listening skills for all students, but especially for ELLs. Used often by two of the participating teachers (Clara, Daisy), Dictogloss consists of three steps. First, all students are split into pairs and initially the teacher reads a science text at a slow pace. Students are urged to simply listen carefully. After reading the text, the teacher asks the students to talk about the text in pairs.

The teacher then re-reads the same text at a normal pace, but this time allows students to write down “key words” or main ideas about the text. Students are encouraged to write down anything that will aid their recollection of the material. The final step is that the teacher asks all students to summarize their understanding of the text in one concise paragraph.

Students can use both sets of their notes, discuss them with their peers, and write down a final joint-response. This response will be shared with the class, so that the teacher can identify any misconceptions and/or clarify any misunderstandings.

Dictogloss not only develops listening, speaking, reading, and writing skills in science, but it also promotes social engagement and allows the teacher to act as a facilitator. It is a student-centered activity based on peer interaction and exchanges. Clara used Dictogloss to review the differences between acids and bases in a unit on Chemistry. Clara extended the Dictogloss activity even further by later having the students write a song or poem about acids and bases and share these in class, on a voluntary basis.

Doing (Science Inquiry)

When teacher-participants were interviewed regarding this “doing” constituent of science, or in other words, their use of science inquiry for ELLs in science, they all mentioned the critical role of inquiry in science education. A myriad of inquiry activities was cited, but three major categories seemed to dominate this conversation: (i) hands-on activities and problem-based learning; (ii) flipped classroom approaches to science; as well as (iii) the use of virtual labs, virtual simulations, and animations.

Hands-on Activities and Problem-Based Learning. *Doing* or *science inquiry*, involves a plethora of experiments or hands-on activities and problem-solving. It also includes active thinking and the use of scientific language. Science inquiry is a social process which includes communication, interaction, the sharing of scientific knowledge using critical thinking, and the use of scientific terminology. Science inquiry also includes the co-construction of new knowledge. All the teachers stated the fundamental role of science inquiry in their classrooms. ELLs usually enjoy science inquiry because it often occurs in pairs, triads, or small groups and may also include students who share the same mother tongue. It is a way to validate student cultures and identities. Hands-on activities are tangible, concrete activities which reduce the burden of written text. They offer ELLs the opportunity to generate scientific understanding via experimentation and first-hand experiences.

Problem-based learning (PBL) is a helpful way to contextualize scientific learning by giving students problems to solve and/or to create. Authentic problem-based learning is likely to enhance the academic skills of ELLs, integrate them more into the content, as well as increase their motivation in science. Like science inquiry, this is largely due to its social nature whereby students can communicate, plan, and negotiate the steps needed to solve a specific problem, or alternatively, to create something together. The opportunities for hands-on activities and problem-based learning in science are astronomical.

Flipped Classroom Approaches to Science. A *flipped classroom* is a pedagogical approach which is designed to promote both student engagement and active learning. The flipped classroom is more student-centered versus teacher-centered. Content is learned predominantly via videos or third parties such as guest speakers, TED talks, podcasts etc. and is then complemented by planned activities requiring extensive social collaboration and engagement. This can indeed be a good approach for ELLs, if they are given adequate support because the students can work at their own pace and/or with peers sharing content at similar English levels to their own. However, both assessment and feedback need to be well-designed and integrated into the flipped-classroom activity, if they are to benefit ELLs.

A Chemistry teacher (Eva) described starting her flipped-classroom by using a 10-minute video. Students were given the opportunity to take their own notes, to research the information online, and to discuss the video in mother tongue groups, etc. Eva mentioned that in a flipped classroom, each student can take the approach which works best for his/her linguistic and learning needs. As in any class, if a flipped classroom is planned and scaffolded well, it can be a versatile approach which is student-centered and which celebrates students' linguistic, cultural, and diverse learning styles. Students will adopt whichever learning technique that works best for him/her.

Another example of an "active" flipped classroom was observed with Brooke who used this approach when teaching a unit on *Earth and Space*. Brooke purposely grouped all ELLs with native speakers. Five groups of three students were created by the teacher. Students were initially asked to write down three "burning questions" about *Earth and Space* in their teams. The questions were then to be prioritized in 1^{st}, 2^{nd} and 3^{rd} place. The teacher then prompted each group to consensually select one question before beginning their research. The students then conducted their research and taught (or led) a science class about what they had learned using the following three guidelines.

Figure 28

Guidelines for a Flipped Classroom Unit on Earth and Space

1. Starter: Get your classmates (students) to think about the lesson or remember what they already know about the subject (5-10 minutes long).
2. Main: Try to incorporate activities for as many different learning styles as you can (4 or 5 learning styles; 10-minute activities). Deliver your content using pictures on a PowerPoint, models, pupil modelling, worksheets, fill-in-the-blanks, small practical activities, mind maps, posters etc.

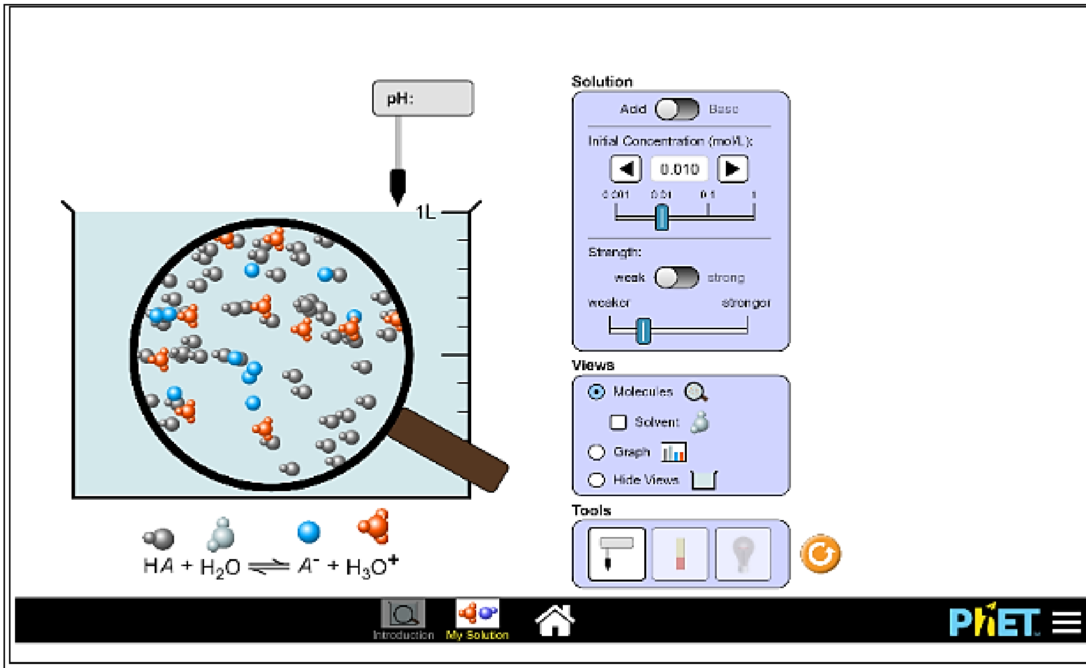
3. Plenary: In the last part of the lesson, encourage your classmates (students) to reflect and self-assess (10 minutes). This could be in the form of a small quiz, such as Kahoot!

This flipped classroom allowed the teacher to work closely with the ELLs in the class. As mentioned earlier, in the flipped classroom, all the tasks demanded are student-centered; the teacher can act as a facilitator and circulate in the classroom, providing additional support to all students in the class, especially to ELLs. Brooke mentioned, “This is a great opportunity for me to help the ELLs and to scaffold for language, as I normally don’t have the chance to do so if I am teaching the content up front.”

Use of Virtual Labs and Simulations and Animations. Given the significant number of instructional technologies available to teach science, focus has been placed only on those technologies mentioned “most frequently” by the participating teachers. These included: virtual labs, simulations, and animations. One such resource commonly used by four teachers (Adele, Aisha, Anna, Brooke) was *Physics Education Technology* (*PhET*). PhET, a University of Colorado designed website that includes virtual labs, videos and several interactive simulations about Math, Chemistry, Physics, Earth Science, and Biology. The same four teachers (Adele, Aisha, Anna, Brooke) mentioned making use of several PhET experiments on the SMARTBOARD during their teaching. Students also accessed PhET on their laptops. In addition to being a mix of audio and video, several simulations are interactive and allow students to manipulate variables in the experiment. PhET is also available in many languages – a great asset for the wide spectrum of ELLs in international schools, and in today’s classrooms overall. Figure 29 is a screenshot of PhET showing the variables which can be manipulated, as well as the different formats (graphical, tabular data, etc.) which can be viewed by clicking on the "Views" tab (see Figure 29).

Figure 29

Screenshot of PhET



https://phet.colorado.edu/en/simulation/acid-base-solutions)

Interpreting

As evident from the PhET screenshot used in a Chemistry class, interpreting and analyzing data are critical processes in science. However, when interpretation and analysis are combined with the complexity of the multimodal nature of scientific language or data (i.e., text, tables, graphs, diagrams etc.), the challenges for ELLs are compounded even further.

The modality of interpreting may include: (i) the use of technologies; (ii) the ability to predict and make inferences; and (iii) the ability to use metaphors and analogies to support decisions related to science matters. Each of these will be addressed individually. Data analysis with the use of databases and software such as *Excel* to collect, organize, and process data are key tools for interpretation in science.

Interpreting with the Use of Technology. One teacher (Anna) stressed the role of interpreting and data analysis in Physics. This teacher (Anna) claimed that when it comes to ELLs, they were generally very good with data analysis skills because it relies on greater numeracy versus literacy skills. Hence, the use of technology for interpretation in science comes easily for ELLs. In addition, when hands-on experiments are not possible, such as in the case of topics like nuclear energy, radioactive decay, astrophysics etc., the use of PhETs (used by Adele, Aisha, Anna, Brooke) as well as COMPadre (Anna) is very effective for ELLs because these programmes combine a mix of different modalities such as technology, animations, audio, video, interactive simulations, and the ability to work at one's own pace — all positive features for ELLs.

Another teacher (Adele) used a software called *Gizmos* to study the water and carbon cycles as well as predator/prey relationships in Ecology. The advantage of such software is that students can manipulate variables in the experiments, especially those which cannot be conducted in "real time", and students can predict and make inferences about the outcomes of such experiments. Lastly, three Biology teachers (Adam, Adele, Brooke) used virtual dissections of organs and entire species such as frogs, in their classes eliminating the need to use real specimens and granting greater accessibility for dissection labs to all students, especially during school closures.

Predicting and Making Inferences. By looking at tabular and/or graphical data, scientists need to make predictions and inferences about important scientific, societal, and environmental issues. All teachers mentioned the importance of predicting and making inferences in science. Frank scaffolded the interpretational task required of ELLs during experimentation, by asking them to write one sentence about their data, instead of an entire paragraph, requested of English native speakers. He stated: "Explain what your data shows you about this experiment. Do you see any patterns? If so, which ones? Please write one concise sentence about your data." This gave the teacher (Frank) an inkling as to whether the ELLs understood the data and/or the presence of trends or patterns in the data. The result of such a simple modification was that ELLs did very well with interpretational tasks. One concise and accurate statement sufficed for Frank to assess their understanding of the data, versus a longer more laborious text-intensive paragraph.

Another teacher, Clara, provided ELLs with sentence frames to support predicting and inferencing. The language associated with inferencing was rehearsed orally in class and applied in context. Clara also regularly provided ELLs with graphs portraying data about "real life" events such as in transportation, population growth, air pollution levels etc., and systematically reinforced the language surrounding inferencing and/or the explanation of trends throughout the academic year. This was an ongoing activity designed to consolidate students' interpretational skills in science.

Use of Metaphors and Analogies. Metaphors and analogies are also often used in science to explain a complex phenomenon. For example, many parts of the human body are often compared in these ways. Blood vessels are like highways; a cell is like a factory; the immune system is like the police force, etc. These metaphors and analogies may be visual or verbal, either in text, picture, diagram, 3-D format, or presented by the teacher.

One of the teachers (Adam) extended the skill of interpretation further by asking students to make analogies in their ESS class. The objective was to make a scientific concept more concrete for all students. The class assignment involved identifying a connection or link between two phenomena. Adam asked the students to first describe (in writing) and later to discuss (orally), the association between "convection cells" and the "Ice Ages". Identifying associations as well as making analogies with "real-life", concrete examples is another way of developing interpretative skills in science.

It is interesting to note that two other teachers (Clara, Daisy) also used analogies to explain cell parts and functions. Daisy, for example, had the students compare the cell parts and functions to a factory. Daisy used the following activity made by *Science NetLinks*, a project of the Directorate for Education and Human Resources Programs of the *American Association for the Advancement of Science* (AAAS). Each part and function of the cell was compared to its job in a factory (Figure 30). The "Answer Key" (Figure 31) clearly illustrates these relationships.

Figure 30

Using Analogies in Science: The Cell and Factory

Job in the Factory	Cell Organelle	Function of the Organelle
Shipping/Receiving Department		
Chief Executive Officer (CEO)		
Factory floor		
Assembly line (where workers do their work)		
Workers in the assembly line		

Finishing/packaging department		
Maintenance crew		
Support beams (walls, ceilings, floors)		
Power plant		

http://sciencenetlinks.com/student-teacher-sheets/comparing-cell-factory/

Figure 31

Answer Key: The Cell and Factory

Job in the Factory	Cell Organelle	Function of the Organelle
Shipping/Receiving Department	Plasma membrane	Regulates what enters and leaves the cell; where cell makes contact with the external environment.
Chief Executive Officer (CEO)	Nucleus	Controls all cell activity; determines what proteins will be made.
Factory floor	Cytoplasm	Contains the organelles; site of most cell activity.
Assembly line (where workers do their work)	Endoplasmic Reticulum (ER)	Site where ribosomes do their work.
Workers in the assembly line	Ribosomes	Build the proteins.
Finishing/packaging department	Golgi apparatus	Prepares proteins for use or export.
Maintenance crew	Lysosomes	Responsible for breaking down and absorbing materials taken in by the cell.
Support beams (walls, ceilings, floors)	Cytoskeleton	Maintains cell shape.
Power plant	Mitochondria/chloroplasts	Transforms one form of energy into another.

http://sciencenetlinks.com/student-teacher-sheets/comparing-cell-factory-answer-key/

Representing

Representing in science is used to allow students to articulate and refine their understanding of science ideas and to allow teachers to evaluate students' conceptions (Klein & Kirkpatrick, 2010). There are many ways that both teachers and students can use representations in science, with or without the use of technology. Representations are ways teachers can teach scientific concepts without the burden of *text-only* approaches. In fact, the use of representations are effective ways to scaffold for ELLs. For example, dioramas can be used to represent an animal habitat; mobiles to represent the planets of the solar system; drawings and labels to represent human organ systems; 3-D models to represent cells and their parts, etc. The same could be said about the representational power of designing posters.

The use of varied methods of representation, with or without the use of technology, allows teachers to move beyond print (text) and has been recommended as an alternative way to formatively assess the scientific understanding of ELLs. Three of the most commonly used representations mentioned by the participating teachers included: (i) making of models; (ii) the use of science kits; and (iii) drawing. Let's take a closer look at each of these.

Making of Models. The making of models is a common way to represent the understanding of scientific concepts. Six teachers (Aisha, Brooke, Clara, Daisy, Eva, Frank) mentioned the use of models in their classes. In the unit on *Forces*, for example, Daisy scaffolded the concepts of *density* and *buoyancy* by asking her students to conduct a boat competition. Students were asked to make an aluminium foil boat able to carry a load of 10g masses as cargo while it floats in a basin filled with water. The boat able to withstand the greatest number of 10g masses, would be the winning one. Daisy then extended and transformed this boat activity by using 3-D printers. Students designed and made their boat using the same criteria (i.e., a boat able to carry a load of 10g masses as cargo), but this time, using a 3-D printer.

Once again, the boat able to support the highest number of 10g masses, was the winner. With or without technology, all students were able to experience a hands-on, competitive challenge which clearly demonstrated the concept of buoyancy. This boat model taught them the phenomenon of buoyancy in an authentic and relevant way — a much more effective way of learning than the traditional rote memorization of the definition for *buoyancy*, typically given as "the quality of being able to float". Cambridge University Press. (n.d.) Buoyancy. In *Cambridge dictionary*. Retrieved April 1, 2021, from https://dictionary.cambridge.org/dictionary/english/buoyancy.

Use of Science Kits. The use of science kits is another effective way to make abstract concepts such as atoms and bonding more concrete and visual (Minner et al., 2010). Many science teachers (Adam, Aisha, Anna, Daisy, Eva, Frank) mentioned the use of molecular bonding kits to demonstrate 3-D chemical structures; DNA kits to represent the double helix structure; electric circuitry kits to make series and parallel circuits; forensic chemistry kits to test blood and bodily fluids; geology kits to test the properties of rocks and soil samples, and so on. The sheer number of science kits available today is extraordinary. With so many options available for teachers to use, it could be said with certainty that via the use of such kits or manipulatives, all students can more readily access and demonstrate their understanding of abstract phenomena. By using science kits in pairs or in groups, students not only socially interact to create meaning, but they are mentally and physically engaged in a hands-on, minds-on approach (Minner et al., 2010).

Drawing. Drawing was mentioned unanimously by all the teachers as a means by which students can demonstrate understanding in science, and as an effective means which can be employed for representation purposes. Drawing can be used explicitly when teaching *sketch-noting skills* (or notetaking with the use of illustrations, symbols, structures, and texts) or alternatively, to encourage student representations of their understanding in science. Use in the participating classrooms ranged from drawing and labelling human organ systems, to using symbols such as arrows to show the direction of forces etc.

One teacher (Adele) discussed the drawings of particles to demonstrate the differences between solids, liquids, and gases. Anna mentioned the importance of drawing diagrams in Physics; whereas Clara discussed the drawing and labelling of cells in Biology, as well as the drawing and matching of lab equipment to their scientific names in Chemistry. The affordances of drawing are numerous. Drawings are visual and reduce the need for an abundance of text. They are also a quick way to demonstrate scientific understanding as well as to show processes, causes-and-effects, sequential patterns, etc. Drawing is universal and understandable to all, independent of linguistic skills and abilities. It is also creative, highly representational, and useful during problem-solving activities.

In conclusion, it seems fair to say that these seven modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, offer multiple benefits to ELLs in science. With this in mind, what do teachers "need" in order to effectively integrate science literacy for ELLs? These needs will be considered, in light of the research responses gathered.

Although all the teacher-participants interviewed were very empathetic and sensitive to the ELLs in science, of the ten teacher-participants interviewed, three of them were noteworthy in terms of their instructional strategies and multimodal approaches in meeting the needs of ELLs. These three teachers included: Daisy, Eva, and Clara. This in no way implies that the other teachers were unsatisfactory in this regard. On the contrary, they all adopted explicit and targeted approaches to meet the needs of their ELLs in science. These three teachers (Daisy, Eva, Clara) have been highlighted based on three criteria: (i) their extensive professional development and experience with ELLs; (ii) the creativity of their instructional approaches; and (iii) their effective and extensive use of multimodality.

Portrait of Daisy

Daisy is one of those teachers who takes full advantage of in-service training as well as professional development opportunities both in and out of school. Daisy has been a science teacher for 22 years and has taught in international schools in the United States, the Middle East, South and Central America, as well as in Europe. In addition to being certified in teaching ELLs, Daisy has taken several professional development courses specifically on how to teach science content to ELLs. Lastly, Daisy has worked collaboratively with ELL/ELD teachers for many years and has co-teaching experience with ELL/ELD teachers in the science classroom.

While interviewing Daisy, it was obvious that she adopts an impressive diversity of strategies to support ELLs in the science classroom on a regular basis. These include: the use of levelled pre-reading or reading activities to support science literacy development; the use of sentence starters and/or grammar frames; the use of templates, graphic organizers and visuals as support material; the systematic practice of front-loading science vocabulary before starting a new unit of science; the ongoing use of working word walls; the deliberate use of modified assessments (i.e., inclusive of word banks, visuals, and reduced text); the provision of opportunities for ELLs to provide oral feedback on assessments versus the traditional written responses; the use of creative technology options such as the use of screencasts, videos with subtitles, interactive whiteboards, *Flipgrid, Kahoot!, Poll Everywhere*, *iMovie*, and finally, the use of *Exit Cards* as a way to check for scientific understanding.

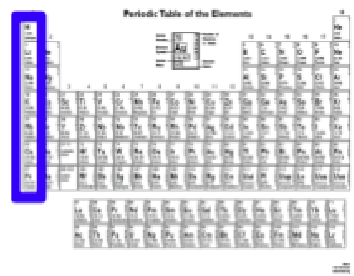
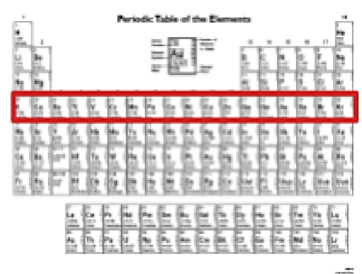
During the second interview, Daisy shared that ELLs will succeed if they have a genuine willingness to learn English. Daisy also mentioned that parents' attitudes towards learning English are also a determining factor for ELLs. Daisy shared an inspiring story with me about an ELL student whose attitude toward learning English changed radically because of the effective use of technology in the classroom. Daisy recounts:

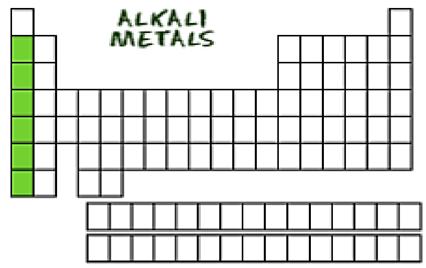
> I taught a Russian boy who was adamant about learning English. He did not want to learn English and was resistant to anything we did in science. Then one day, while were on the unit of *Forces* and discussing the concept of buoyancy in science, I had the students design and make a boat using a 3-D-printer. This is the first time that I saw him get excited about science. He could totally relate to this building project. He felt successful. There was joy in his eyes, instead of the anger he normally showed about learning in English. This is one of my success stories as a science teacher!

Portrait of Eva

Eva is a Chemistry teacher who has taught internationally for 24 years. Eva is very versatile with her teaching approaches and diversifies instructional strategies depending on student needs. Eva resorts to the use of whiteboards, purposeful grouping, POGILs, as well as supporting text with visuals. A brief extract from a Chemistry review sheet (Figure 32) is an example of how Eva supports text with visuals. Students can easily locate *groups* and *periods* in a periodic table. With the use of a few bullet points, Eva also provides students with a short, yet concise definition of these words. Color-coding also assists students in locating the position of *Group 1* (*Alkali Metals*) on the periodic table. Figure 32 shows how simple it is to scaffold scientific text using a visual support.

Figure 32 *Visual-to-Text Supports in Chemistry*

Content of Lesson	Key words	Context
Identify parts of the periodic table	1. group	 • vertical column • same number of valence electrons • similar chemical and physical properties • small gradual change down the group
	2. period	 • horizontal row • number of valence electrons increases from left to right • changing properties from metals on the left to non-metals on the right.

Group 1: The alkali metals properties and patterns down the group	1. Group 1 2. Physical properties	 1. Group 1 are called the **alkali metals**. 2. They are all soft and can be cut like cheese. They have lower density that water, so they float. These are examples of **physical properties.**

Eva also provides ELLs with sentence frames to develop skills such as writing a research question in a lab report. This is reinforced orally in class as well. Using a very simple *fill-in-the-blank* scaffold, students can create a research question. An example (Figure 33) is also provided as a model for the students: "How does the number of elastic bands affect the length of stretch when a "Barbie" is thrown off a wall attached to elastic bands like a bungee cord?"

Figure 33

Using Sentence Frames to Support Lab Reports

Research Question:

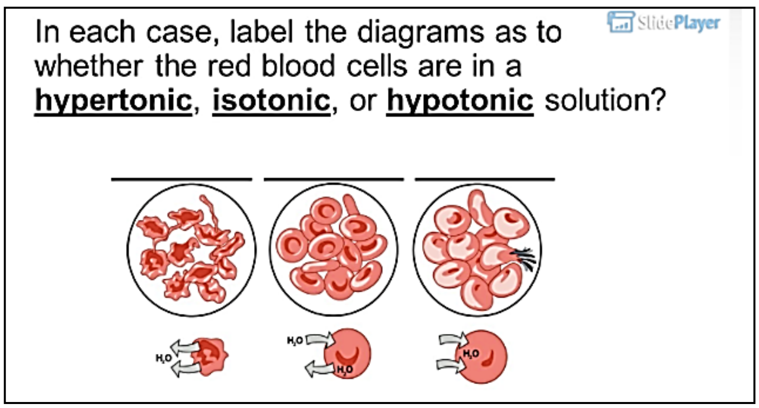
Your research question goes here (How does ____________(the thing you change) affect______________(the thing you measure) when________________(the system you use).

How does the number of elastic bands affect the length of stretch when a "Barbie" is thrown off a wall attached to elastic bands like a bungee cord?

Scientific concepts and vocabulary are also enhanced via visual thinking using videos or diagrams such as these red blood cells (see Figure 34). Students can visually notice the effects of diffusion and osmosis on red blood cells placed in different types of solutions (i.e., hypertonic, isotonic, or hypotonic solutions). With this diagram/visual, the complex phenomena of *hemolysis* (bursting of red blood cells) and *crenation* (shrivelling of red blood cells) can easily be represented with a diagram. The benefits gained by coupling reduced text and visual representation is extraordinary.

Figure 34

Supporting Scientific Vocabulary with Visuals



In order to encourage speaking, Eva allows ELLs to make an audio- or video-recording since they may be shy and/or lack the confidence to respond orally in front of the class. Students use *Flipgrid* or *Voxer* to do this. Of final note, in terms of representing scientific understanding, with or without the use of technology, Eva assesses student understanding with the use of structured science journals on *Googledocs* (see Figure 35). This allows students to compile all their science notes digitally in one place and to complement their science notes by inserting diagrams, pictures, drawings, additional notes in their own language and/or from other sources, to add video links, audio-notes, other websites, and more!

Figure 35

Science Journal Guidelines

Journal Guidelines

- This journal is where you can store all of your notes from class in one place
- You will be instructed to add important notes, however feel free to use your journal to add additional notes
- Your journal will be helpful when preparing for upcoming assessments
- This is your journal- decorate it however you wish, however remember it should be relevant to our class
- I (-------------------), will constantly check your journal progress, so try and stay up to date!

Portrait of Clara

Finally, Clara is a very experienced ELL science-support teacher who also has co-taught for many years with a science teacher. An educator with 23 years of teaching experience, this teacher uses a mix of multimodal techniques to support science understanding. Clara shared several strategies on how to meet the needs of ELLs using all seven modalities of teaching (i.e., reading, writing, listening, speaking, doing, interpreting, and representing, with or without the use of technology). However, rather than provide these strategies in a "recipe-like" list, I will describe a concrete example shared by Clara.

During the unit on *Life Sciences,* in order to teach plant and animal cells, Clara scaffolds science vocabulary in the unit by building digital glossaries in the primary language of the students, as well as in English. The students also make use of *Four-Corner Vocabulary Cards* and then share their cards with their peers, recite them, and discuss them. Complementing vocabulary with talk, gestures, drawing, images, and/or role-playing, aids students' understanding of scientific words. Additionally, Four-Corner Vocabulary Cards make use of primary language, and as such validates the cultural identity of ELLs. Figures 36 and 37 represent one example of the use of the Four-Corner Vocabulary Card.

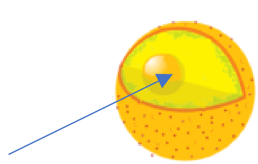
Figure 36

Four-Corner Vocabulary Card Template

Write down the science concept or term.	**Write the definition in your primary language.** **Write the definition in English.**
Make a drawing or sketch of your word.	**Use the word in a sentence.**

Figure 37

Sample of Four-Corner Vocabulary Card

Write down the science concept or term. **Nucleus**	**Write the definition in your primary language.** *Le noyau d'une cellule contrôle toutes ses fonctions : il est considéré comme le «cerveau» de la cellule.* **Write the definition in English.** *The nucleus of a cell controls all its function; it is considered the "brain" of the cell.*
Make a drawing or sketch of your word. 	**Use the word in a sentence.** The nucleus of the cell is usually in the centre and is very important because it controls everything the cell does.

After completing these cards and sharing them, the students then read selected articles on cells to reinforce the needed vocabulary in context and to experience the concept of cells as “real-life” science. Depending on their level of English proficiency and/or preference, these articles could be read in English (using levelled text supports) or in the students’ native language. In addition to vocabulary development (i.e., cell types and parts), students were expected to also learn the functions of the cell parts.

Rather than rote memorization, Clara offered the students the opportunity to make cell models, to engage in drama and/or role-play, to use choreographic movement or gestures, write stories or poems, compose songs etc., to demonstrate their scientific understanding of cells. Students could select their activity of choice, individually or in small groups. During my research, a superb skit on cell parts and their functions was observed. All students were fully engaged, regardless of their level of English proficiency. They handled their tasks with utmost commitment and motivation, and it was evident that they fully understood both the concepts and functions of the cell parts. No student remained passive or was excluded from the activity. On the contrary, the confidence and engagement of all the students was commendable throughout the duration of their project on cells.

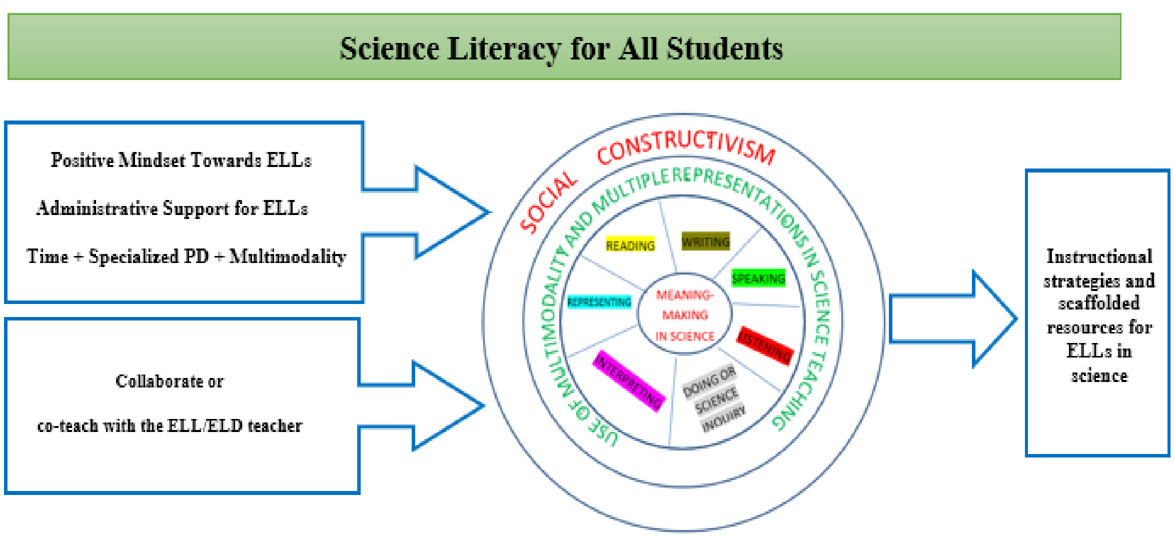
Last but not least, the students observed the cells under a microscope. They drew sketches of the slides and jotted down their observations in their science notebooks. It was observed that, Clara adopted all seven modalities to support this unit on cells and their functions. Reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, were all used in a holistic manner. Given the rapid change in today’s classrooms, these three teachers demonstrated significant expertise in teaching “All” of their students, but especially ELLs, though they are far from being the norm. There are many in-service and pre-service teachers who need to be trained on how to teach ELLs in their science classes. Let us take a closer look at their needs to do so.

Needs of Science Teachers to Integrate Science Literacy for ELLs

After an in-depth and thorough analysis of all the data sources in response to RQ#3, five major themes concerning the needs of teachers to effectively teach ELLs in science, were noted down. These themes included: (i) the need for a positive mindset and awareness (among teachers) towards teaching science to ELLs; (ii) the importance of administrative support for ELLs; (iii) the need for time, multimodality and specialized PD for teachers to adequately scaffold science content and meet the needs of ELLs in science; (iv) the need for scheduled opportunities to collaborate with the ELL/ELD teacher; and (v) the need for valuing the importance of co-teaching science with an ELL/ELD teacher. Figure 38 is a schematic diagram of these findings. It illustrates that for my conceptual framework to work effectively, the five above-mentioned criteria need to be in place.

Figure 38

Teacher Needs to Integrate Science Literacy for ELLs



Positive Mindset Towards Teaching ELLs Science. All ten teachers mentioned the importance of having a positive mindset for ELLs in the science class. As mentioned earlier, all the teacher participants shared this positive mindset. None of them viewed ELLs as "slowing down" their science class. Clara stated the following about her ELLs: "Given their cultural and linguistic richness and their life experiences, ELLs have so much to offer to their peers. Non-ELLs know this. It's just a matter of creating opportunities for them to engage in the mainstream class". Hence, promoting a positive mindset towards teaching ELLs largely depends on creating a "culture of openness" and commitment to an equitable education. This needs to trickle down from the leadership and school administration. It cannot simply rely on the goodwill of the teachers.

Administrative Support to Teach ELLs Science. All the teacher participants agreed that there needs to be a priority and adequate administrative support provided to teachers within schools to effectively meet the needs of ELLs in all content areas. This implies the implementation of a robust *language policy* as well as a commitment to establishing a strong ELL/ELD Department with solid human resources, adequate scheduling, and on-going professional development. The role of school administrators should be to uphold the status and parity of ELL/ELD teachers within the school establishment. Developing a school culture of equity in all subject areas as well as a culture of collaboration and support is the first step. This means that ELL/ELD teachers should not be viewed as classroom assistants, but as language specialists with the role to support the linguistic needs of students in content courses.

In addition, it is important for school administrators to allot scheduled time for science teachers (during their *non-contact* hours) to scaffold their science content and develop resources for their ELLs. This does not imply providing a diluted science curriculum to ELLs, but rather one which maintains science content, while decreasing the linguistic load for ELLs, simultaneously. Unfortunately, given the growing demands on teachers during times of fiscal restraint in education, time itself is always at a premium. Therefore, if there is a genuine commitment to investing in ELLs, prioritization of science teachers receiving adequate time to prepare modified resources and materials for their students, is essential.

Time + Specialized PD + Multimodality to Teach ELLs Science. Following this issue of time, one factor that six teacher-participants (Adam, Aisha, Amelie, Brooke, Clara, Daisy) spoke about was indeed the need for time to scaffold science resources for their ELLs. Given their many demands and overloaded curricula, they did not have enough time to make new resources or to scaffold their existing resources to meet the needs of their ELLs. This was a great source of frustration for them and they resented the fact that they could not fully meet all of their students' needs.

Long-term and on-going specialized PD for teachers of ELLs in science was also a priority expressed by all the teacher-participants. Adele mentioned the importance of learning specific "strategies" and/or "tricks" to teach ELLs. Aisha sought for opportunities to access specialized PD material on how to teach ELLs in science. Whilst, another teacher (Adam) mentioned the need for a course on vocabulary development in Biology for ELLs. Daisy, who was a teacher who invested a great deal of her time in PD courses, both inside as well as outside of school, mentioned: "All subject teachers should have a general refresher course on teaching science for ELLs every few years." Last but not least, all the teacher participants stressed the importance of multimodality to teach ELLs effectively in science, and they welcomed more training in this area. This view will be elaborated on in the next chapter.

Collaboration or Co-Teaching Between the Science and ELL/ELD Teacher. All participating teachers described different forms of collaboration in which they engaged in at their schools. This included collaboration with the Math department as well as intra-departmental collaboration. All of the science teacher-participants (Adam, Adele, Aisha, Anna, Brooke, Daisy, Eva, Frank) mentioned a willingness and desire to co-teach with an ELL/ELD specialist and/or alternatively, co-plan and co-assess with a language specialist. Likewise, the two ELL science-support teachers (Amelie and Clara), also welcomed collaboration with the science teachers. The science teachers were unanimously open to a co-teacher sharing their class, although they were fully aware of the financial implications that this would entail for any school — be it private or public.

Scheduling is a key requisite for any type of co-teaching relationship. Currently, teachers are left to meet on their own time, before- or after-school, during recess or lunch, in the staff room or school corridors, etc. The result is often frustration for both parties involved, including a lingering feeling of “a job not being well done”. Hence, scheduling allocated time for co-planning, co-assessing, and co-reflecting for teachers of science and ELL/ELD is very important.

Recognizing that the imminent possibility of co-teaching with an ELL/ELD teacher was unrealistic, all of the science teachers (Adam, Adele, Aisha, Anna, Brooke, Daisy, Eva) with the exception of Frank, who already co-taught with an ELD teacher, welcomed having planning time with the ELL/ELD specialist in order to appropriately scaffold for their ELLs in science. In five schools (Schools A, B, C, D, and E), this was further compounded by the fact that the ELL departments were both understaffed and overworked in order to effectively meet the needs of all the ELLs in Grades 7-12. Brooke states the following:

> Part of our EAL/ELL Department is understaffed, so in terms of their timetable, they are overworked. This is one factor, but part of it is that they would prefer to work with us [science teachers], to help us understand the type of language we are using…

However, given their current time constraints and existing school structures, even finding a common planning time was often not possible. As a result, they had to accommodate ELLs "as best as they could."

What was most astounding in my findings was that all ten teachers welcomed a co-teacher in science. I was not expecting this and had to set aside my own personal biases about co-teaching, and really fully immerse myself into the comments of my teacher-participants regarding co-teaching. Eva stated, "I would like to collaborate with second- or third-language teachers. Get advice from them on language acquisition skills." Whilst, Adele shared this story, "I once had a co-teacher of ELLs. It was very helpful to me. She was in my class for an entire semester. I would like to have that again. She was a great help". Aisha also mentioned, "I would like another person in the classroom with whom to collaborate. Opportunities to work with someone and get feedback from him or her, would be great!" Lastly, Adam stated the following, "Every month I would like an ELL specialist to introduce a new unit of Biology and its vocabulary to the class."

Frank was the only teacher who had an existing co-teacher partnership. Frank commended this programme as this was the first school he had ever worked at, which offered specialized support for its ELLs. Frank shared with me that co-teaching with an ELD colleague in School F was a very positive experience. Frank received support for ELLs three times, over a two-week cycle. Students received support on labs, research papers, and on science vocabulary development. When the co-teacher went to the science class, he/she shared the same role and status as the science teacher; not that of a classroom assistant. In School F, ELL support was regarded as a high priority by the existing school leadership. The school *ethos* of equity in education applied in all content areas.

Daisy who had worked with a co-teacher at a previous school, shared the affordances of co-teaching with a colleague who was a language specialist. Having a co-teacher with an ELL/ELD focus enabled Daisy to scaffold for both science content and language. Daisy viewed the co-teacher as a specialist in language acquisition who could positively complement the teaching of science content. Daisy remarked, "The co-teacher also reduces the pressure of having to make instructional resources/materials for ELLs."

While Daisy taught, the co-teacher supported science content by jotting down notes and diagrams on the board; by making a word wall for vocabulary development; by providing sentence starters and grammar frames; and by complementing oral instructions made in class with texts, visuals, and drawings. Daisy stated, "This form of live support during co-teaching is really phenomenal."

Time for co-planning, co-teaching, co-assessing and co-reflection were all factored into the daily working schedule of the teachers in School F, creating legitimacy for the support of ELLs. This is rather exceptional and not very common in many international schools. The content teacher and ELL/ELD teacher also collaborated on creating assessments together. Figure 39 is one example of an assessment which was created to focus on the similarities and differences between ionic and covalent compounds. It provides ELLs with language scaffolds, as well as a Venn diagram to support comparative writing skills on these two types of compounds.

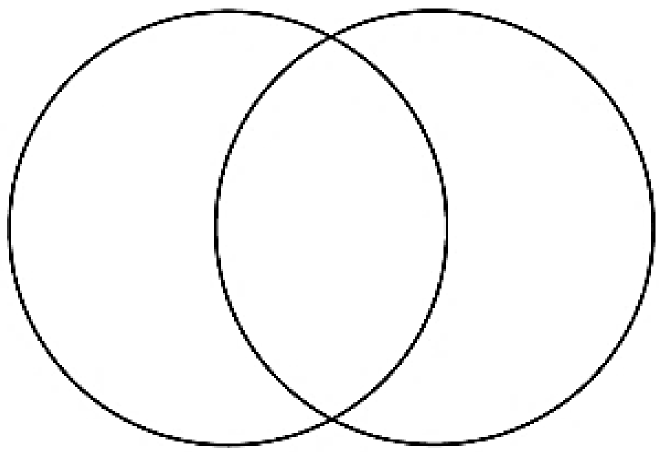
Figure 39

Use of Venn Diagrams to Support Comparative Writing in Science

Criterion A Knowledge & Criterion B Language for Learning

1. Write a paragraph to compare ionic and covalent compounds. Be reminded that a comparative paragraph identifies both the similarities and the differences in what is being compared.

But	Also	However	Whereas
Like	Unlike	Similar to	Different from
And	Both		



It is, however, important to be cautiously aware that co-teaching is not a panacea for all the challenges facing teachers of ELLs in science classes. Co-teaching will be discussed more in the next chapter, along with an extensive discussion of the main findings of this research.

Chapter 5: Discussion

This chapter is a discussion of the research findings supported by evidence-based literature and empirical studies. The discussions of these findings are congruent with the research questions. The literature review, classroom observations, interviews with all ten teacher-participants, and the data analysis, support the use of multimodality for ELLs in science. This chapter will also address the need for specialized professional development and collaboration between the science and ELL/ELD teachers. Fully cognizant of its affordances and its limitations, it will conclude by addressing the potentials of co-teaching between the science and the ELL/ELD teacher.

All ten teacher participants, as well as several researchers in favor of promoting a *culturally responsive pedagogy* (Lee, 2004, 2005; Lee & Avalos, 2002; Settlage & Southerland, 2012) agree that to truly meet the needs of ELLs, there needs to be a shift in mindset towards linguistically and culturally diverse students. In-service teachers should become cognizant of the changing landscape of today's classrooms, and embrace the idea that to meet the linguistic and cultural needs of all students, an open and positive mindset towards ELLs, accompanied by appropriate teaching strategies and instructional resources, is now required.

Greater awareness of ELL linguistic and cultural needs also implies abandoning the "deficit views" of ELLs (Cummins, 2000), especially regarding limited ELL proficient students. It has been stated that some teachers are in fact disinclined to teach beginner ELLs because they feel that they are unequipped or lack the proper training to do so (Reeves, 2006). To compound these problems even further, some content-teachers have difficulty with scaffolding and/or are resistant to changing their teaching practices (Munro et al., 2013).

Overall, most teachers seem to be open to providing ELLs with "extra time" to complete their work, however, modifying their material or reducing their workload is not always favorably regarded (Reeves, 2006). Whereas other teachers, tend to lower their expectations for ELLs or avoid calling on them in class because they do not want to embarrass them in front of their peers (Olson et al., 2009).

Given the large spectrum (i.e., diversity) amongst ELLs, depending on their level of English proficiency, educational and cultural backgrounds, their life-stories, etc. (Estrella et al., 2018), it is impossible to select a single pedagogical approach that works "best" for all ELLs in science. This provides a case to advocate for a *holistic approach* to teaching science to ELLs; one that embeds all seven modalities of teaching: reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology.

Multimodality: An Effective Way to Teach ELLs in Science

Multimodality is not a new concept in the field of education. It has been in existence since 1996 (Jewitt, 2008). Siegel (2012) defines multimodality as "the social practice of making meaning by combining multiple semiotic resources" (p. 671). This includes visual, auditory, gestural, and kinaesthetic modalities, among others. After extensive research on ELLs in science, Early et al. (2015) state that the most effective way to teach ELLs science is via multimodality. Multimodal pedagogy provides diverse ways of teaching that go beyond text alone and create understanding in science (Ajayi, 2009).

During the second interview, the participating teachers were asked to prioritize what they thought were the "top-three" modalities (out of the seven) for teaching science to ELLs (see Appendix H). The ELL science-support teachers (Amelie, Clara) mentioned that all seven modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, were equally important for ELLs to access science. They maintained that a combination of these modalities was necessary to make science accessible to ELLs. Amelie stated, “There is not one thing that will do it; visuals, manipulatives, gestures, sentence frames, models etc. are all equally important for ELLs”. Clara further argued that in addition to these seven modalities, the two key factors of “socialization” and “interaction” were missing but ought to be included as a strategic constituent of any robust teaching pedagogy. ELLs need to be encouraged to engage in all these modalities, both actively and socially, in order to create meaning in science. These ideas are based in a philosophy of learning supported by *social constructivism.*

Dong (2002) also stresses the importance of language in science. Dong states that by talking, reading, writing, thinking, and socially engaging in meaningful contexts of science, students can gain a better understanding of science. Additionally, Weinburgh et al. (2014), also remind us of the importance of engaging in science practices which include active discourse surrounding science phenomena.

In Table 8, it can be observed that the “top three” modalities for teaching science to ELLs included: *speaking*, *doing* and *representing*, with or without the use of technology. It is important to note that seven out of eight of the science teachers (Adam, Adele, Aisha, Anna, Brooke, Daisy, Eva) mentioned that they would like to do more reading in their science classes, but given the sheer volume of science content in their secondary school curricula, they were unable to dedicate more time to reading, especially the reading of different genres of science texts such as journals, fiction, graphic novels, trade books etc. This resonates and confirms the research of Rivard et al. (2012) who state that very little reading is conducted in secondary school content courses. The reasons for this are many: (i) time constraints; (ii) curricular pressures; (iii) the view that reading is not part of the domain of science; as well as (iv) a feeling of inadequacy to effectively embed literacy within science.

Similarly, with regards to writing, as mentioned in Chapter 4, the science teachers stated that writing tasks were limited to note-taking, lab write-ups, and assessments. Once again, given the time-constraints, especially in high school, there was little time to engage in the writing of different genres of science such as narratives, journals, reflections, research papers, scripts etc.

Table 8

Most Commonly Used Teaching Modalities for ELLs in Science

Modality	Teachers	Total
1. Reading	Anna, Frank, Amelie, Clara	2
2. Writing	Eva, Frank, Amelie, Clara	2
3. Speaking	Adam, Adele, Anna, Brooke, Daisy, Eva, Amelie, Clara	**6**
4. Listening	Adam, Brooke, Amelie, Clara	2
5. Doing	Adele, Aisha, Brooke, Daisy, Frank, Amelie, Clara	**5**
6. Interpreting	Aisha, Anna, Eva, Amelie, Clara	3
7. Representing	Adam, Adele, Aisha, Daisy, Amelie, Clara	**4**

Note. Amelie and Clara were the ELL support-science teachers and mentioned that all seven modalities were important for ELLs.

As evident from the findings gained, the interlacing of science discourse (talking), hands-on activities (doing or science inquiry) and multimodal representations (representing) were viewed as the most effective ways to teach science to ELLs. I posit that a combination of all seven modalities is, by far, the most effective way to make science accessible to ELLs.

The current reality is that there are not enough ELL/ELD teachers for all "push-in" science courses, especially at the secondary school level (Reeves, 2006). In addition, it is unrealistic to expect ELL/ELD teachers to know all the science curricula covered at each grade level. Hence, an important consideration for the future is to recognize the need for specialized PD aimed at helping content teachers to meet the needs of ELLs in science, and to make such training accessible at the secondary school level.

Specialised Professional Development in Science

All ten teachers supported the importance of specialized PD to meet the needs of ELLs in science. Batt (2008) states that "…all educators need the requisite knowledge and skills to effectively educate linguistic minority students" (p. 42). Unfortunately, to date, there still seems to be a notorious unbalance in expertise to teach ELLs.

> If novice teachers are to learn to effectively teach science to diverse learners, there must be coherence between their own learning experiences of science content, the pedagogy taught and modelled in science teacher education methods courses, and the models they observe in their field placements (Stoddart et al., 2010, p. 174).

Content teachers have openly expressed their lack of confidence and training in teaching of ELLs, especially those with limited English proficiency levels (Reeves, 2006). While several researchers have also addressed the disappointing history of *stand-alone* PD courses occuring in the form of single-session workshops or in-service courses. They argue that the effects of these courses have been rather poor (Batt, 2008; Penner-Williams et al., 2017; Reeves, 2006). "As the linguistic minority population increases, teacher education must give higher priority to include coursework in diversity issues and ESL methods for all teachers" (Batt, 2008, p. 41).

The diversity and cultural richness that ELLs bring to today's classrooms are extraordinary. However, there needs to be a structure and administrative commitment to supporting, inclusively, the education of ELLs within schools. Adam, Adele, Aisha, Amelie, and Anna from School A, had experienced six years of annual professional development with a visiting educational consultant on ways to teach ELLs in content areas and were very positive about the training they had received. They articulated the importance of having specialized PD for ELLs and acknowledged that this type of in-service training was critical to their work in an international school context.

Examples of commendable PD courses mentioned by the participating teachers included: *EAL in the Mainstream*, a certificate course offered by Dr. Virginia Rojas; *Unlocking the World* (a programme of the Department of Education and Child Services, South Australia); and an educational consultant, Beth Skelton (bethskelton.com). Of course, this list could go on exhaustively; these few merely represent those mentioned by the teachers involved in this study.

Having perused many interventions and PD programmes for ELLs in science during this research (August et al., 2014; Hart & Lee, 2003; Lee et al., 2004; Lucas & Villegas, 2013; Weinburgh et al., 2014 and others), it is my belief that PD can no longer take the form of a band-aid approach. It needs to be designed and implemented systemically for both pre-service and in-service teachers. Even at the university level, in the Bachelor of Education programmes, modifications for ELLs continue to remain contingent on the professors' openness and willingness to include them. Overall, this approach remains rather ad hoc. For example, in a study of 43 Bachelor of Education programmes in the United States, only 10% offered ELL courses (Li et al., 2017). At the university level, especially within the Bachelor of Education programmes, training faculty on the full SIOP Model, may be advantageous (Batt, 2008). Some universities are using online modules and/or online courses to remedy this situation, although a more systemic approach is necessary, if the goal is to reach all teacher-preparatory programmes. "When faculty members have more knowledge and expertise in EL education, they are more likely to include language-related issues in their course content" (Li et al., 2017, p. 17).

Promoting Collaboration Between the Science and ELL/ELD Teacher

Lee and Avalos (2002), Carrier (2005), Fu et al. (2007) and others remind us of the importance for science and ELL/ELD teachers to work together. In order to support ELLs' learning, those in leadership roles such as school principals, vice-principals, Heads of Department etc., need to prioritize and show a concrete commitment to inclusion, equity in education, as well as to establish a robust support-structure which endorses inclusiveness in the sciences. Oftentimes, the leadership in private international schools receives direct instructions from their governing boards regarding their programmes. ELL/ELD support is usually mandated in their mission statement or language policy (if they have one). Whichever is the case, if the school leadership places low priority on ways to strengthen the ELL/ELD Department and/or its support to content teachers, then language support exists in the form of "lip service" only (Fu et al., 2007). Whereas, in those schools that demonstrate a high priority for ELL support, the level of ELL engagement in content classes is a testimony of this. School F is an example of this commitment.

One of the biggest constraints observed in the classrooms of content teachers is the reduced ratio of specialized ELL/ELD teachers to ELL students (Reeves, 2006). ELL/ELD teachers are usually busy teaching their own students in "pull out" classes, and given the sheer number of content classes in need of assistance, they are left unable to provide "push-in" (in-class) support for all content classes. They are already *spread too thin* (Fu et al., 2007). Therefore, the time remaining to meet and/or plan effectively for ELLs in science is very limited. This leaves science teachers, as well as other non-language arts content teachers, who may have limited expertise with language acquisition and scaffolding strategies, at a disadvantage. In spite of the practical challenges involved to successfully do so, if there is a true commitment to support ELLs, time for science teachers to collaborate with the ELL/ELD teacher needs to be factored into the teachers' daily schedules (Meskill & Oliveira, 2019). This may also require the hiring of additional ELL/ELD specialists.

Collaboration between content and ELL/ELD specialists and the development of *Professional Learning Communities* (PLCs) can indeed be a dynamic form of professional development for working with culturally and linguistically diverse students. Penner-Williams et al. (2017) conducted a study on PLCs focussed on the endorsement of ELLs in content areas using the CLASSIC© model (a copyrighted acronym for Critically reflective, Lifelong Advocacy for Second language learners, Site-specific Innovation, and Cross-cultural competence). The study included 41 educators in six school districts and focussed on five standards of effective pedagogy for ELLs. These included: (i) joint productive activity; (ii) language and literacy development; (iii) contextualization; (iv) challenging activities; and (v) instructional conversations. The outcomes of this research, one of the few studies conducted on PLCs for ELLs, showed “that teachers perceived their PLC as the most relevant program component in learning how to work more effectively with ELs in their classrooms and a vital contributor to their teacher effectiveness” (Penner-Williams et al., 2017, p. 225). The conversations, reflective dialogues, and *Try It Outs,* aimed at teacher implementation of new strategies, not only affected teachers’ perspectives towards the teaching of ELLs, but most importantly, resulted in the direct transfer of learning into their daily practice.

PLCs provide opportunities to promote collaboration amongst “like-minded” teachers who are interested in culturally and linguistically diverse learners, promoting dialogical and reflective conversations *in situ*, and above all, for transferring and improving teacher practice in context. Another form of teacher collaboration which has gained a great deal of attention as of late, is co-teaching.

Co-teaching: What Is it? Its Affordances and Limitations

Co-teaching between the science and ELL/ELD teacher essentially means that the content teacher teaches science by integrating both learning and linguistic objectives (LLO) which have been co-planned in unison with the ELL/ELD specialist. Moje (2015) reminds us of the importance of planning time as an imperative if teachers are to meet the literacy needs of students in content areas.

The benefit of this approach is that it embeds both science content and the linguistic needs of diverse learners in science curriculum planning. Its practical implementation in the classroom may occur using different models, but whichever model is used, several affordances can be gained for both the students and the teachers. Co-teaching may occur in six ways. Friend et al. (2010) summarized these as follows.

1. **One Teaching, One Observing**: One teacher directly instructs students in the class, while the other teacher observes students and jots down notes or evidence of learning. This role is interchangeable between the science and ELL/ELD teacher. Both teachers share equal roles in the class, no matter whether they are instructing or not.

2. **One Teaching, One Assisting**: One teacher directly instructs students, while the other assists individual students, as needed. These may be mainstream, ELL, and/or students with *exceptionalities*. In this model, all students are benefitting equally from the extra support provided by one of the teachers.

3. **Parallel Teaching**: The class is divided into two groups and each teacher teaches the same information at the same time. The pace of the group may however differ, allowing one of the teachers the opportunity to possibly scaffold language, rephrase concepts, use repetition or paraphrasing etc. Purposeful grouping can also be used here.

4. **Station Teaching**: Each teacher teaches a specific part of the content to different groups as the students rotate between the two teachers. This exposes students to different teaching styles and has the added benefit of smaller groups versus a large classroom setting.

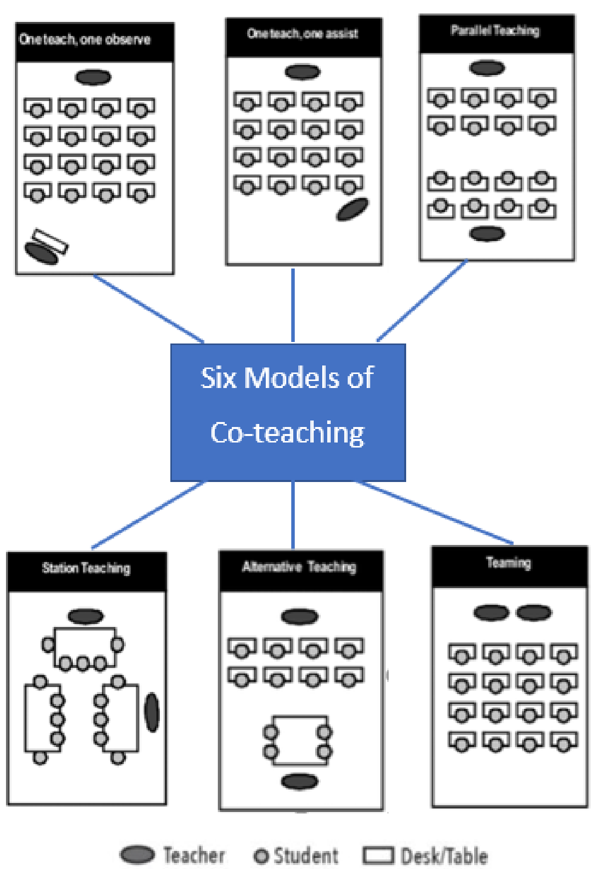
5. **Alternative Teaching**: One teacher teaches “most” of the students, and the other teacher teaches a small group, based on need. This provides an in-class opportunity for extra support in science content for linguistic support and/or other reasons, as needed. During alternative teaching, depending on the group of students, one teacher can explain the same concepts in greater depth, or can alternatively, use this model as an opportunity for enrichment and/or extension purposes.

6. **Team Teaching**: Both teachers are directly instructing students at the same time. This is sometimes called "tag team teaching" (Friend et al., 2010). Team-teaching usually requires effective planning and/or extensive experience with co-teaching.

These six models (see Figure 40) are versatile and can be alternated with effective planning or gained experience. The benefits of having two teachers in a class are remarkable, especially in cases of large class sizes. In addition, it provides new opportunities to scaffold for culturally and linguistically diverse students.

Figure 40

Six Models of Co-teaching



Adapted from https://buildingmathematicians.wordpress.com/2017/09/28/co-teaching-in-math-class/

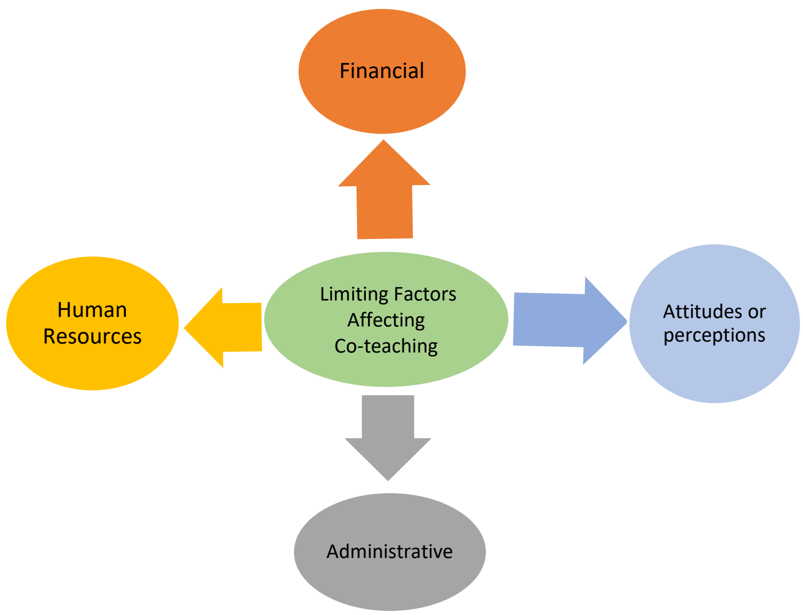
Co-teaching allows for the science and ELL/ELD teacher to interact with one another and to give more individualized attention to all students. However, it does not always mean that both teachers need to teach a class. On the contrary, WIDA informs us of the importance of co-planning, co-assessing, and co-reflecting in this professional relationship - all components or phases which are equally important. Co-teaching merges two areas of expertise: science and second language acquisition. The language specialist can assist in scaffolding the science content with visuals, sentence starters and frames, graphic organizers, support texts, technology supports, etc. However, caution should be taken in disseminating these modified resources, so as not to embarrass and/or perpetuate the deficit views of ELLs in a classroom setting (Manavathu & Zhou, 2012). The affordances of appropriately modified ELL material in science are great, as these not only assist ELLs, but in the end, benefit all students in the class. Of final consideration, is the importance and value found when co-teachers have opportunities for dialogue and reflection together (Kohler- Evans, 2006; Mcclure & Cahnmann-Taylor, 2010).

Co-teaching, with all of its benefits, can be complicated to execute. Co-teaching is often imposed from the *top-down* without any provisions in the schedule to plan and/or scaffold for ELLs (Mcclure & Cahnmann-Taylor, 2010). It can be extremely frustrating and involves functional and logistical issues such as scheduling, meeting time to co-plan, co-assess, and co-reflect, while navigating power and status relationships among teachers (Rabin, 2020), mediating personality issues between the co-teachers, as well as reconciling differing teaching epistemologies and pedagogies (Arkoudis, 2003; Mcclure & Cahnmann-Taylor, 2010). With these concerns in mind, co-teaching works best when it is voluntary versus mandated by school administrators.

There are tangible limitations to co-teaching which need to be addressed. These may be attributed to: (i) financial constraints; (ii) inaccurate attitudes or perceptions; (iii) administrative problems; and/or (iv) human-resource limitations (see Figure 41). Each of these constraints will be addressed individually.

Figure 41

Limitations of Co-teaching



(i.) Financial constraints

Financially, it is expensive to pay two practitioners to teach a class instead of the traditional, one-teacher-per-class *modus operandi*. Given today's budgetary constraints, this is problematic. What is key however, is to view the long-term educational gains of co-teaching, especially for students with linguistic, cultural, and/or cognitive needs. Analogically speaking, the investment required for co-teaching can be likened to that of investing in an electric car for the purpose of abating climate change. The initial costs of buying an electric car are significant, however, the long-term gains of avoiding petrol costs and achieving reduced carbon gas emissions are great. It is important to note that, when evaluating co-teaching, educational policymakers need to shift their focus from a *micro*- to a *macro*- view of its long-term gains in science literacy development for all students.

(ii.) Inaccurate attitudes or perceptions

Also, important to consider, is the necessity of changing the traditional attitudes and perceptions of the science teacher as “the indispensable provider of knowledge” to a more collaborative view which recognizes the importance of partnerships in education. This needs to be celebrated as an “additive approach” for the benefit of all involved — co-teachers and students. In fact, students are not the only ones gaining more support in the science classroom; the teachers are also benefitting from each other’s collaboration, support, and expertise. Co-teaching should not be viewed as an attack on one’s personal autonomy, but rather as a celebration of collaboration and professional partnership.

(iii.) Administrative problems

Administrative structures, as currently organized, can often be problematic in establishing the collaborative relationships necessary for the effective implementation of co-teaching. School schedules need to be adjusted in order for collaboration and co-teaching to occur successfully between the content and ELL/ELD teachers. Jurkowski and Miller (2018) discuss at length the difficulties of multi-professional cooperation given today’s school schedules. The days of planning in the staff room, of planning five minutes before class, or in the corridor, need to change. If there is a genuine commitment from school leadership for co-teaching to exist, sufficient resources and complementary schedules need to be established.

Collaborative time needs to be perceived as a valuable investment in co-planning, co-teaching, co-assessing and/or co-reflecting.

(iv.) Human resource limitations

Finally, there needs to be an investment in human resources. This means hiring enough staff, especially ELL/ELD teachers, to serve as co-teachers. Additionally, it involves a commitment to long-term and specialized PD for both in-service and pre-service teachers as well as increased budgets to pay for co-teaching. Mentoring or coaching programmes also need to be in place to support teachers throughout the co-teaching process.

Co-teaching is not always an easy partnership. Some of the most common difficulties of co-teaching include interpersonal or gender differences; diverse personality and/or communication styles; conflicting teaching styles; lack of time to co-plan, which often leads to frustration; as well as the need for professional development (Conderman, 2011; Mcclure & Cahnmann-Taylor, 2010). Like any marriage or partnership, co-teaching requires hard work, conflict resolution, and sometimes the need for mediation. This mediation can be provided internally via mentors or qualified administrators, or alternatively, be outsourced externally. It is argued that collaboration and teamwork are the key skills and requisites needed for any employment in the 21st century, but what does the future of science education for today's classrooms really look like? The concluding chapter (Chapter 6), will seek to address this.

Chapter 6: Conclusion

This final chapter will provide some concluding remarks and recommendations on how to effectively meet the needs of ELLs in the science classroom and the implications of this research for future practice. It is hoped that this dissertation has shined a spotlight on an area of education which needs to be both highlighted and corrected. The multicultural context of our schools, paired with the constraints that both institutions and teachers face, has created a "gap" in education which needs to be lovingly repaired. This dissertation has intended to provide some practical tools for teachers, as well as some recommendations for why such an undertaking is necessary.

Concluding Remarks

The existing literature on science literacy shows that despite the main science educational reforms in Canada (*Common Framework for Science Learning Outcomes; Council of Ministers of Education, Canada* [CMEC] 1997), the United States (*Science for All Americans; Project 2061; American Association for the Advancement of Science* [AAAS] 1990, 1994; *National Science Education Standards* [NSES], NRC 1996), *New Generation Science Standards* [NGSS], (2013, 2017), other educational science reforms in Australia, New Zealand, the United Kingdom, and elsewhere in the world, problems still persist with the current methods of teaching science. Especially within the European contexts, there is still a focus on memorization and recall of scientific facts and theories (Osborne, 2002; Vieria & Tenreiro-Vieira, 2016). In addition, there is somewhat of a disconnect between the science curricula and students' everyday scientific interests and realities. Thirdly, a disparity persists between the teaching and learning results from the science classroom, literature, research, and science programmes. Teachers, researchers, scientists, and publishers should work together to ensure that classroom strategies as well as instructional resources meet the needs of “All” students in science (Fradd et al., 2001; Reid & Norris, 2016).

Unfortunately to date, the current gap in science literacy continues to be larger for ELLs (Lucas & Villegas, 2013). To be truly equitable, the cultural and linguistic profiles of ELLs should be integrated in science education (Hart & Lee, 2003) because when instruction is congruent with students’ culture, experiences, skills, linguistic abilities, and student diversity, students are more likely to be engaged in science (Lee, 2003). Settlage and Southerland (2012) emphasize the importance of being culturally aware of students’ heritage in the science classroom. They state the importance of teachers “having knowledge about the cultures of the students and also making teaching decisions, so … practices are aligned with the learner’s culture” (p. 360). In addition, adequate scaffolding needs to be in place without compromising the integrity of the science content.

The goals emerging from this research for the future of science education for English language learners approved by uOttawa, *Office of Ethics and Integrity* (see Appendix I), are comprehensive in sweep, but certainly worthy of the effort involved in achieving them. They imply that some changes are needed in science education, especially regarding ELLs. These include: (i) a shift in attitudes and perspectives towards ELLs; (ii) providing exposure to instructional resources which embed linguistic and diverse, culturally-sensitive methodologies; (iii) building and strengthening collaborative relationships between science and ELL/ELD teachers; (iv) the adoption of teaching strategies with a “holistic” focus on multimodality, complemented by the use of multiple representations; (v) shifting the traditional manner in which lesson-plans are conceived, designed, and implemented in the science classroom; as well as (vi) introducing new modes of assessment, inclusive of modifications and an element of “choice” for ELLs (Meltzer & Hamann, 2005; Olson et al., 2009; Osborne, 2002).

Although this research within the context of six European private international schools may represent a small and rather exclusive “nugget” of knowledge in the field of science literacy development for ELLs, there are certainly some lessons to be gained. It seems fair to say that the findings attained from this research cannot easily be generalizable to the realities of teachers working in other private or public schools. On the other hand, the instructional practices and strategies used by these teachers, working in “more favorable” environments, can indeed be used as examples to open-up professional discourse in the field of science literacy development for ELLs. Specific strategies and resources might also be transferrable and/or attempted in science classrooms elsewhere.

The findings gained from this research advocate that an all-inclusive combination of multimodalities is necessary to successfully teach science to ELLs. The use of all seven modalities of reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology, is critical to students’ understanding of science. Grapin (2019) states that modes are, in fact, not simple scaffolds or supports; they are semiotic tools which are integral components to the domain of science (p. 34). Teachers are therefore encouraged, on the basis of these research findings, to plan and/or co-plan each unit of science by using all seven modalities in order to ensure greater equity in science education for ELLs now, as well as for those in future generations.

Consider the multiple benefits for both teachers and students in taking the necessary steps to couple school-based and pedagogical changes in a school context. Imagine what could be achieved by organizing schools to include team-teaching, expanding teachers' skills portfolio through professional development, and adopting new perspectives, intentions, and practices of inclusion in science classrooms. These changes alone would be transformational, especially if they were adopted not only at the school level, but more so if they were implemented on a systemic (school board) basis.

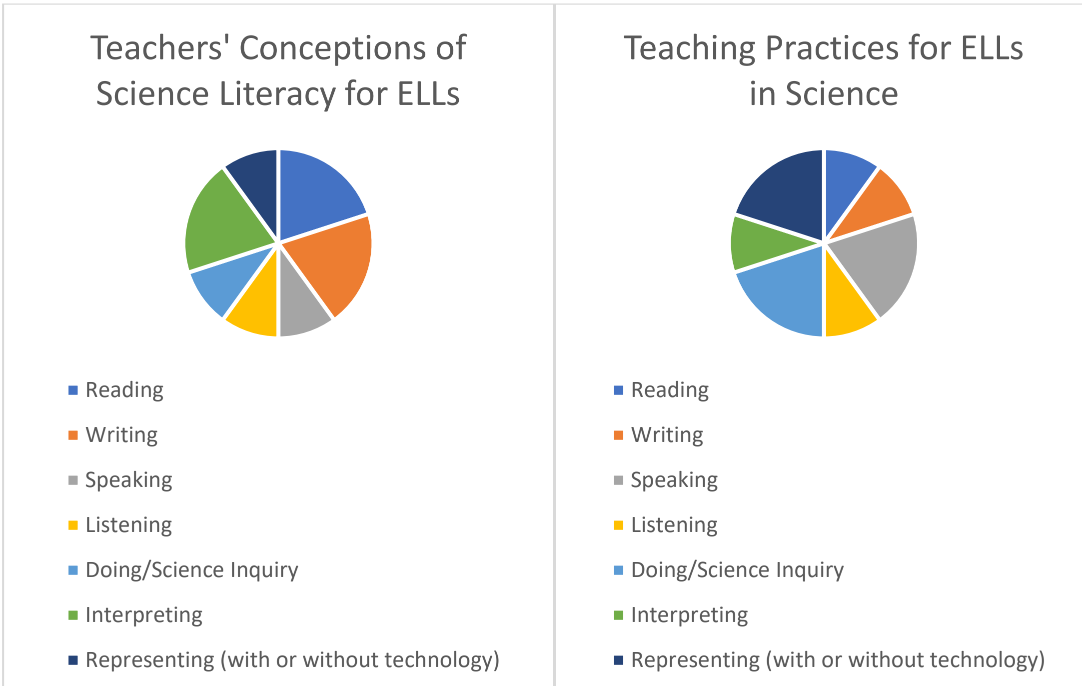
However, think, in addition, what could then be accomplished by also adopting the pedagogically significant classroom practices of sequential scaffolding of science concepts through the use of multimodality, multiple representations and social connections among learners, all highlighted in this research. The results would not only be fruitful for ELLs but for "All" learners. Any one of the changes recommended from this research may seem simple and familiar to most educators, but the employment of them in concert (i.e., together) will yield the most powerful results currently needed in the approach to science education for ELLs, both in middle and high school.

Implications for Future Practice and Research

After gleaning though all my findings, one of the interesting things I found was that there seemed to be somewhat of a disconnect between the "teachers' conceptions" of what ELLs needed in order to develop their science literacy and the "teacher practices" that they used in their classrooms. Oftentimes, people may have an ideal in their mind, but their actions and/or behaviour may not necessarily follow suit. This leaves us with the following question: How do we reconcile what teachers conceive is "best" for SL development for ELLs versus their daily practice? Figure 42 clearly shows the dissonance between teacher conceptions and practice. This is a question which is certainly worthy of future research.

Figure 42

Teacher Conceptions Versus Teacher Practices for ELLs in Science



Another interesting question is related to the issue of teacher accountability. Why can't teachers be held *self-accountable* for implementing a holistic approach for teaching science to ELLs. Is it necessary to "control" what teachers do with checklists and/or new protocols? Again, these are interesting questions which deserve further investigation in the future.

The final message I would like to convey in this dissertation is the following. If there is a true commitment to work towards developing scientifically literate generations of successful science graduates from elementary through to secondary school levels, both for ELLs and non-ELLs alike, then the following conditions need to be in place: (i) adequate school administrative structures and resources for ELLs, inclusive of technology supports; (ii) long-term, specialized pre-service and in-service teacher professional development on how to teach science to ELLs; (iii) time for collaboration between the science and ELL/ELD teachers in order to co-plan, co-teach, co-assess, and co-reflect; and most importantly; (iv) a holistic approach to multimodal teaching in science. Specifically, this means planning every unit of science by incorporating all seven modalities of teaching (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology). In addition, complementing these modalities with the use of both teacher and student representations is also important because multiple representations give teachers greater insights into student understanding and/or lack thereof, allowing teachers to then modify their own use of representations in science (Berthold & Renkl, 2009).

Considering these factors, a *unit plan template* has been designed and included with this study (see Figure 43) for use by science teachers working in today's diverse classes. This template is highly multimodal, accesses all seven teaching modalities; is user-friendly; and embeds both science and literacy for students at different levels of English proficiency. It also directly promotes the development of scientific vocabulary in context.

Astonishingly, one of the factors that none of the ten teacher-participants mentioned during this research, was the importance of teaching Latin and Greek *prefixes* and *suffixes* to ELLs in science (see Appendix J). This area of instruction is paramount to the development of scientific vocabulary. Between the years 1500-1650, it is estimated that nearly 12,000 words from Latin and Greek entered the English language; of these, many filtered into the domain of science (Hadi-Tabassum & Reardon, 2017; Rivard et al., 2012). Researchers not only inform us of the need to teach Latin and Greek *prefixes* and *suffixes*, but they also remind us of the importance of *cognates* (a word having the same linguistic derivation as another word) in science (DeLuca, 2010; Fleenor & Beene, 2019).

One example of a cognate used in science is the word *cell* (English), *cellula* (Italian), *célula* (Spanish), *cellule* (French) and *Zelle* (German). Although demonstrating this similar derivation of words between languages is often difficult to do in multilingual classes, it is very effective in bilingual classrooms or in classes where two main languages dominate (for example, English/Spanish or English/French). “While English may share very few cognates with a language like Chinese, 30-40% of all words in English have a related word in Spanish” (Colorín Colorado, 2018).

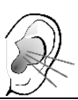
This unit plan template which was designed to assist teachers in their practice of science, is a simple template which embeds both content and linguistic objectives, providing language supports, as well as a holistic multimodal approach to teaching science. In addition, it provides ELLs with a choice of different formative and summative assessments. The end of the unit plan also provides a quick and easy way for reflection or co-reflection. Whether this lesson-plan template is used “solo” or in partnership with the ELL/ELD teacher, it is a user-friendly tool for co-planning, co-teaching, co-assessing, and/or co-reflecting. An exemplar of a unit plan on the *Variety of Life: Cell Types, Structures, and Functions* is provided in Appendix K.

Figure 43

Unit Plan Template for Science Teachers

UNIT PLAN TEMPLATE FOR SCIENCE TEACHERS

Unit or Topic	
Content Objectives	

<table>
<tr><td>Language Objectives</td><td colspan="3"></td></tr>
<tr><td>Language Supports</td><td>Key Vocabulary</td><td>Roots
(Prefixes and Suffixes)</td><td>Sentence Frames</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Teaching Modalities</td></tr>
<tr><td> Reading</td><td colspan="3"></td></tr>
<tr><td> Writing</td><td colspan="3"></td></tr>
<tr><td> Speaking</td><td colspan="3"></td></tr>
<tr><td> Listening</td><td colspan="3"></td></tr>
<tr><td> Doing</td><td colspan="3"></td></tr>
<tr><td> Interpreting</td><td colspan="3"></td></tr>
<tr><td>Representing  (with or without the use of technology)</td><td colspan="3"></td></tr>
<tr><td>Types of Assessment (involving choice)</td><td colspan="2">Formative Assessment:</td><td>Summative Assessment:</td></tr>
<tr><td>Teacher Reflections</td><td colspan="3">The students were……………………………………………………………
Overall, I feel this unit went………......because…………………………….….
Next year, I will…………………….…………….………………………......</td></tr>
</table>

This research has been able to provide insight and knowledge on how some teachers in middle and secondary school (Grades 7-12) have successfully integrated science literacy for ELLs, as well as illustrate an array of constructive methods for supporting ELLs in science classes. The recommendations emerging from this research can increase teachers' perceptions and awareness regarding the importance of science literacy for ELLs. It is hoped that this dissertation will be used as a pedagogical model and/or tool for future pre-service or in-service teachers in meeting the needs of ELLs in their science classrooms.

REFERENCES

Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 191–208). Springer.

Ajayi, L. (2009). English as a second language learners' exploration of multimodal texts in a junior high school. *Journal of Adolescent & Adult Literacy*, *52*(7), 585-595. https://doi.org/10.1598/JAAL.52.7.4

Alvermann, D. E. (2004). Multiliteracies and self-questioning in the service of science learning. In W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 226–238). NSTA Press.

Amaral, O. M., Garrison, L., & Klentschy, M. P. (2002). Helping English learners increase achievement through inquiry-based science instruction. *Bilingual Research Journal, 26*, 213–239. https://doi.org/10.1080/15235882.2002.10668709

American Association for the Advancement of Science. (1990). *Science for All Americans – Project 2061.* Oxford University Press.

American Association for the Advancement of Science. (1994). *Benchmarks for science literacy*. Oxford University Press.

Anthony, R. J., Tippett, C. D., & Yore, L. D. (2010). Pacific CRYSTAL project: Explicit Literacy instruction embedded in middle school science classrooms. *Research in Science Education*, *40*(1), 45-64. https://doi.org/10.1007/s11165-009-9156-7

Arkoudis, S. (2003). Teaching English as a second language in science classes: Incommensurate epistemologies. *Language and Education*, *17*(3), 161-173. https://doi.org/10.1080/09500780308666846

Attride-Stirling, J. (2001). Thematic networks: an analytic tool for qualitative research. *Qualitative Research*, *1*(3), 385-405. https://doi.org/10.1177/146879410100100307

Atwater, M. M. (1996). Social constructivism: Infusion into the multicultural science education research agenda. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *33*(8), 821-837. https://doi.org/10.1002/(SICI)1098-2736(199610)33:8<821::AID-TEA1>3.0.CO;2-Y

August, D., Branum-Martin, L., Cárdenas-Hagan, E., Francis, D. J., Powell, J., Moore, S., & Haynes, E. F. (2014). Helping ELLs meet the Common Core State Standards for literacy in science: The impact of an instructional intervention focused on academic language. *Journal of Research on Educational Effectiveness*, *7*(1), 54-82. https://doi.org/10.1080/19345747.2013.83676

August, D., & Hakuta, K. (1997). *Improving schooling for language-minority children: A research agenda*. National Academy Press.

Bächtold, M. (2013). What do students "construct" according to constructivism in science education? *Research in Science Education*, *43*(6), 2477-2496. https://doi.org/10.1007/s11165-013-9369-7

Baker, C. (2011). *Foundations of bilingual education and bilingualism* (5th Ed.). Multilingual Matters.

Baker, L. & Saul, W. (1994). Considering science and language arts connections: A study of teacher cognition. *Journal of Research in Science Teaching*, 31, 1023-1037. https://doi.org/10.1002/tea.3660310913

Banilower, E., Cohen, K., Pasley, J. & Weiss, I. (2010). *Effective science instruction: What does research tell us?* (2nd Ed.). RMC Research Corporation.

Barwell, R. (2005a). Integrating language and content: Issues from the mathematics classroom. *Linguistics and Education, 16*(2), 205-218. https://doi.org/10.1016/j.linged.2006.01.002

Barwell, R. (2005b). Critical issues for language and content in mainstream classrooms: Introduction. *Linguistics and Education, 16*(2), 143-150. https://doi.org/10.1016/j.linged.2006.01.003

Batt, E. G. (2008). Teachers' perceptions of ELL education: Potential solutions to overcome the greatest challenges. *Multicultural Education*, *15*(3), 39-43.

Beare, K. (2018, May 11). English only? An opinion on speaking only English in class? ThoughtCo. https://www.thoughtco.com/english-only-in- class-1211767

Berthold, K., & Renkl, A. (2009). Instructional aids to support a conceptual understanding of multiple representations. *Journal of Educational Psychology, 101*(1), 70-87. https://doi.org/10.1037/a0013247

Bialystok, E. (2007). Acquisition of literacy in bilingual children: A framework for research. *Language Learning*, *57*, 45-77. https://doi.org/10.1111/j.1467-9922.2007.00412.x

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Brown, C. L., & Bentley, M. (2004). ELLs: Children left behind in science class. *Academic Exchange Quarterly*, *8*(3), 152–158.

Brown, B. A., & Ryoo, K. (2008). Teaching science as a language: A "content-first" approach to science teaching. *Journal of Research in Science Teaching*, *45*(5), 529-553. https://doi.org/10.1002/tea.20255

Bruna, K. R., Vann, R., & Escudero, M. P. (2007). What's language got to do with it? A case study of academic language instruction in a high school "English Learner Science" class. *Journal of English for Academic Purposes, 6*(1), 36–54. https://doi.org/10.1016/j.jeap.2006.11.006

Carlsen, W.S. (2007). Language and science learning. In S. K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 57-74). Routledge.

Carrejo, D. J., & Reinhartz, J. (2014). Teachers fostering the co-development of science literacy and language literacy with English language learners. *Teacher Development*, *18*(3), 334-348. https://doi.org/10.1080/13664530.2014.914564

Carrier, K. A. (2005). Supporting science learning through science literacy objectives for English language learners. *Science Activities*, *42*(2), 5-11. https://doi.org/10.3200/SATS.42.2.5-11

Case, R. E. (2002). The intersection of language, education, and content: Science instruction for ESL students. *The Clearing House*, *76*(2), 71-74. https://doi.org/10.1080/00098650209604952

Cazden, C., Cope, B., Fairclough, N., Gee, J., Kalantzis, M., Kress, G., Luke, A., Luke, C., Michaels, S., & Nakata, M. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, *66*(1), 60–92.

Cervetti, G., & Pearson, P. (2012). Reading, writing, and thinking like a scientist. *Journal of Adolescent & Adult Literacy*, *55*(7), 580-586. https://doi.org/0.1002/JAAL.00069

Chamot, A. U. (1995). Implementing the cognitive academic language learning approach: CALLA in Arlington, Virginia. *Bilingual Research Journal*, *19*(3-4), 379-394. https://doi.org/10.1080/15235882.1995.10162680

Chamot, A. U., Dale, M., O'Malley, J. M., & Spanos, G. A. (1992). Learning and problem solving strategies of ESL students. *Bilingual Research Journal*, *16*(3-4), 1-28. https://doi.org/10.1080/15235882.1992.10162635

Chamot, A. U., & O'Malley, J. M. (1986). *The CALLA Handbook: Implementing the Cognitive Academic Language Learning Approach.* Addison-Wesley.

Chen, Y. C. (2019). Using the science talk–writing heuristic to build a new era of scientific literacy. *The Reading Teacher*, *73*(1), 51-64. https://doi.org/10.1002/trtr.1808

Clark, S. K., & Lott, K. (2017). Integrating science inquiry and literacy instruction for young children. *The Reading Teacher*, *70*(6), 701-710. https://doi.org/10.1002/trtr.1572

Cline, Z., & Necochea, J. (2003). Specially designed academic instruction in English (SDAIE): More than just good instruction. *Multicultural Perspectives*, *5*(1), 18-24. https://doi.org/10.1207/S15327892MCP0501_4

Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: Implications from research. *International Journal of Science Education*, *27*(2), 183-198. https://doi.org/10.1080/0950069042000276712

Collier, V. (1989). How long? A synthesis of research on academic achievement in a second language. *TESOL Quarterly, 23*(3), 509–531. https://doi.org/10.2307/3586923

Collier-Reed, B., & Ingerman, A. (2014). Phenomenography: From critical aspects to knowledge claim. In J. Huisman, & M. Tight (Eds.), *Theory and method in higher education research: International perspectives on higher education research* (Volume 9, pp. 43-260). Emerald Group Publishing Ltd. https://doi.org/10.1108/S1479-3628(2013)0000009016

Colorín Colorado, (2018, October 24). Using Cognates to Develop Comprehension in English. Colorín Colorado. https://www.colorincolorado.org/article/using-cognates-develop-comprehension-english

Conderman, G. (2011). Methods for addressing conflict in cotaught classrooms. *Intervention in School and Clinic*, *46*(4), 221-229. https://doi.org/10.1177/1053451210389034

Coyle, D. (2007). Content and language integrated learning: Towards a connected research agenda for CLIL pedagogies. *International Journal of Bilingual Education and Bilingualism*, *10*(5), 543-562. https://doi.org/10.2167/beb459.0

Creese, A. (2005). *Teacher collaboration and talk in multilingual classrooms* (Vol. 51). Multilingual Matters.

Creswell, J.W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd Ed.). SAGE.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *42*(3), 337-357. https://doi.org/10.1002/tea.20053

Cummins, J. (2000) Immersion education for the millennium: What have we learned from 30 years of research on Second Language Immersion? OISE.

Cummins, J. (2007). *What works? Research into practice*. Literacy and Numeracy Secretariat, Ontario Ministry of Education. Queen's Printer of Ontario.

Dalton-Puffer, C. (2011). Content-and-language integrated learning: From practice to principles? *Annual Review of Applied Linguistics*, *31*, 182-204. https://doi.org/10.1017/S0267190511000092

Dalton-Puffer, C., & Smit, U. (2013). Content and language integrated learning: A research agenda. *Language Teaching*, *46*(4), 545-559. https://doi.org/10.1017/S0261444813000256

Davis, B. (2004). *Inventions of teaching: A genealogy*. Lawrence Erlbaum Associates.

Dawes, L. (2004). Talk and learning in classroom science. *International Journal of Science Education*, *26*(6), 677-695. https://doi.org/10.1080/0950069032000097424

DeLuca, E. (2010). Unlocking academic vocabulary. *The Science Teacher*, *77*(3), 27-32.

de Oliveira, L. C., & Wilcox, K. C. (Eds.). (2017). *Teaching science to English language learners: Preparing pre-service and in-service teachers*. Springer.

Denzin, N. K., & Lincoln, Y. S. (2005). *The SAGE handbook of qualitative research.* (3rd Ed.). SAGE.

Dionne, L., Couture, C., Savoie-Zajc, L., & Petringa, N. (2019). The Tableau ST project: inspiring francophone teachers with effective science practices. *Alberta Journal of Educational Research*, *65*(4), 360-380.

Dong, Y. R. (2002). Integrating language and content: How three biology teachers work with non-English speaking students. *International Journal of Bilingual Education and Bilingualism*, *5*(1), 40-57. https://doi.org/10.1080/13670050208667745

Early, M., Kendrick, M., & Potts, D. (2015). Multimodality: Out from the margins of English language teaching. *TESOL Quarterly*, 447-460. https://doi.org/10.1002/tesq.246

Echevarria, J. (2005). Using SIOP in Science: Response to Settlage, Madsen, and Rustad. *Issues in Teacher Education*, *14*(1), 59-62.

Echevarria, J., & Vogt, M. (2010). Using the SIOP model to improve literacy for English learners. *New England Reading Association Journal*, *46*(1), 8-15.

Echevarria, J., Vogt, M., & Short, D. (2008). Making content comprehensible for English learners: The SIOP model. Pearson Education.

Elliott, R., & Timulak, L. (2005). Descriptive and interpretive approaches to qualitative research. *A Handbook of Research Methods for Clinical and Health Psychology*, *1*(7), 147-159.

Estrella, G., Au, J., Jaeggi, S. M., & Collins, P. (2018). Is inquiry science instruction effective for English language learners? A meta-analytic review. *AERA Open*, *4*(2), 1-23. https://doi.org/10.1177/2332858418767402

Evnitskaya, N., & Morton, T. (2011). Knowledge construction, meaning-making and interaction in CLIL science classroom communities of practice. *Language and Education*, *25*(2), 109-127. https://doi.org/10.1080/09500782.2010.547199

Fang, Z., & Wei, Y. (2010). Improving middle school students' science literacy through reading infusion. *The Journal of Educational Research*, *103*(4), 262-273. https://doi.org/10.1080/00220670903383051

Fisher, D., & Frey, N. (2014). Speaking and listening in content area learning. *The Reading Teacher*, *68*(1), 64-69. https://doi.org/10.1002/trtr.1296

Fisher, D., McDonald, N.L., & Frey, N. (2013). Integration of literacy and the arts: Creating classrooms that perform. In B. Taylor & N. Duke (Eds.), *Effective literacy instruction: A handbook of research and practice* (pp. 446 – 464). Guilford.

Fleenor, S., & Beene, T. (2019). *Teaching science to English leaners.* Seidlitz Education.

Foulger, T. S., & Jimenez-Silva, M. (2007). Enhancing the writing development of English language learners: Teacher perceptions of common technology in project-based learning. *Journal of Research in Childhood Education*, *22*(2), 109-124. https://doi.org/10.1080/02568540709594616

Fradd, S. H., Lee, O., Sutman, F. X., & Saxton, M. K. (2001). Promoting science literacy with English language learners through & materials development: A case study. *Bilingual Research Journal*, *25*(4), 479-501. https://doi.org/0.1080/15235882.2001.11074464

Friend, M., Cook, L., Hurley-Chamberlain, D., & Shamberger, C. (2010). Co-teaching: An illustration of the complexity of collaboration in special education. *Journal of Educational and Psychological Consultation*, *20*(1), 9-27. https://doi.org/0.1080/10474410903535380

Fu, D., Houser, W. R., & Huang, A. (2007). A collaboration between ESL and regular Classroom teachers for ELL students' literacy development. *Changing English*, *14*(3), 325-342. https://doi.org/10.1080/13586840701712014

Genesee, F. (1994). Integrating Language and Content: Lessons from Immersion. *UC Berkeley: Center for Research on Education, Diversity and Excellence*. Retrieved from https://escholarship.org/uc/item/61c8k7kh

Ghosh, R., & Galczynski, M. (2014). *Redefining multicultural education: Inclusion and the right to be different* (3rd Ed.). Canadian Scholars' Press.

Gibbons, B. A. (2003). Supporting elementary science education for English learners: A constructivist evaluation instrument. *The Journal of Educational Research*, *96*(6), 371-379. https://doi.org/10.1080/00220670309596620

Gillies, R. M., & Baffour, B. (2017). The effects of teacher-introduced multimodal representations and discourse on students' task engagement and scientific language during cooperative, inquiry-based science. *Instructional Science, 45(4*), 493-513. https://doi.org/10.1007/s11251-017-9414-4

Goldenberg, C. (2008). Teaching English language learners: What the research does — and does not — say. *American Educator*, *32(1),* 8–21, 44.

Government of Canada (2016). Annual Report to Government on Immigration. Retrieved from https://www.canada.ca/en/immigration-refugees-citizenship/corporate/publications-manuals/annual-report-parliament-immigration-2016.html

Grapin, S. (2019). Multimodality in the new content standards era: Implications for English learners. *TESOL Quarterly*, *53*(1), 30-55. https://doi.org/10.1002/tesq.443

Guthrie, J. T., & Wigfield, A. (2000). Engagement and motivation in reading. In M. Kamil, P. Mosenthal, R. Barr, & P. Pearson. (Eds.), *Handbook of reading research, (Volume III* 403-422). Routledge.

Guthrie, J. T., Wigfield, A., Barbosa, P., Perencevich, K. C., Taboada, A., Davis, M. H., & Tonks, S. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology*, *96*(3), 403-423. https://doi.org/10.1037/0022-0663.96.3.403

Hadi-Tabassum S., & Reardon E. (2017). Bridging language and content for English Language Learners in the science classroom. In de Oliveira L., Campbell Wilcox K. (Eds.), *Teaching science to English language learners* (pp. 31-57). Palgrave Macmillan. https://doi.org/10.1007/978-3-319-53594-4_3

Hakuta, K., Butler, Y. G., & Witt, D. (2000). *How long does it take English learners to attain proficiency?* University of California Linguistic Research Institute Policy Report.

Hand, B., Alvermann, D. E., Gee, J., Guzzetti, B. J., Norris, S. P., Phillips, L. M., Prain, C., & Yore, L. D. (2003). Message from the "Island Group": What is literacy in science literacy? *Journal of Research in Science Teaching*, *40*(7), 607–615. https://doi.org/10.1002/tea.10101

Hapgood, S., & Palincsar, A. S. (2006). Where literacy and science intersect. *Educational Leadership*, *64*(4), 56-60.

Hart, J. E., & Lee, O. (2003). Teacher professional development to improve the science and literacy achievement of English language learners. *Bilingual Research Journal*, *27*(3), 475-501. https://doi.org/10.1080/15235882.2003.10162604

Hayden, M., & Thompson, J. J. (2008). International schools: Growth and influence. United Nations Educational, Scientific and Cultural Organization.

Hershberg, R.M. (2014). Constructivism. In Coghlan, D. & Brydon-Miller, M. (Eds.), *The SAGE encyclopedia of action research* (Vols. 1-2, pp. 183-186). SAGE. https://doi.org/10.4135/9781446294406

Hipkins, R. (2011). The challenges of graph interpretation in science. *Set: Research Information for Teachers,* (3), 3–9.

Huang, J. (2004). Socialising ESL students into the discourse of school science through academic writing. *Language and Education*, *18*(2), 97-123. https://doi.org/10.1080/09500780408666870

Huang, J., & Morgan, G. (2003). A functional approach to evaluating content knowledge and language development in ESL students' science classification texts. *International Journal of Applied Linguistics*, *13*(2), 234-262. https://doi.org/10.1111/1473-4192.00046

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education, 40*(1), 5-28. https://doi.org/10.1007/s11165-009-9154-9

Huerta, M., & Jackson, J. (2010). Connecting literacy and science to increase achievement for English language learners. *Early Childhood Education Journal*, *38*(3), 205-211. https://doi.org/10.1007/s10643-010-0402-4

Hung, H. T. (2015). Flipping the classroom for English language learners to foster active learning. *Computer Assisted Language Learning*, *28*(1), 81-96. https://doi.org/10.1080/09588221.2014.967701

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership*, *16*(1), 13-16.

Janzen, J. (2008) Teaching English language learners in the content areas. *Review of Educational Research, 78*(4), 1010-1038. https://doi.org/10.3102/0034654308325580

Jäppinen, A. K. (2005). Thinking and content learning of mathematics and science as cognitional development in content and language integrated learning (CLIL): Teaching through a foreign language in Finland. *Language and Education*, *19*(2), 147-168. https://doi.org/10.1080/09500780508668671

Jewitt, C. (2008). Multimodality and literacy in school classrooms. *Review of Research in Education, 32*(1), 241-267. https://doi.org/10.3102/0091732X07310586

Johnson, R. K., & Swain, M. (Eds.). (1997). *Immersion education: International perspectives*. Cambridge University Press.

Jones, M. G., & Brader-Araje, L. (2002). The impact of constructivism on education: Language, discourse, and meaning. *American Communication Journal*, *5*(3), 1-10.

Jurkowski, S., & Müller, B. (2018). Co-teaching in inclusive classes: The development of multi-professional cooperation in teaching dyads. *Teaching and Teacher Education*, *75*, 224-231. https://doi.org/10.1016/j.tate.2018.06.017

Kareva, V., & Echevarria, J. (2013). Using the SIOP model for effective content teaching with second and foreign language learners. *Journal of Education and Training Studies*, *1*(2), 239-248. http://dx.doi.org/10.11114/jets.v1i2.173

Kessler, C., Quinn, M.E. (1995). ESL and science learning. In J.A. Crandall (Ed.), *ESL through content area* (pp. 53-84). ERIC Clearinghouse on Language and Linguistics.

Kim, S., & Hand, B. (2015). An analysis of argumentation discourse patterns in elementary teachers' science classroom discussions. *Journal of Science Teacher Education, 26*(3), 221-236. https://doi.org/10.1007/s10972-014-9416-x

Kim, E. J. A. (2018). *The relationships at play in integrating indigenous knowledges-sciences (IK-S) in science curriculum: a case study of Saskatchewan K-12 science curriculum*. McGill University (Canada). https://escholarship.mcgill.ca/concern/theses/76537349v?locale=en

Klein, P., & Kirkpatrick, L. (2010). Multimodal literacies in science: Currency, coherence and focus. *Research in Science Education, 40*(1), 87-92. https://doi.org/10.1007/s11165-009-9159-4

Klentschy, M. P. (2006). Science education in a no child left behind standards-based world. In R. Douglas, M.P. Klentschy, K. Worth, & W. Binder (Eds.), *Linking science and literacy in the K-8 classroom* (pp. 407–426). NSTA.

Klentschy, M. P., & Molina-Da La Torre, E. (2004). Students' science notebooks and the Inquiry process. In E.W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 340–354). International Reading Association & National Science Teachers Association.

Kohler-Evans, P. A. (2006). Co-teaching: How to make this marriage work in front of the kids. *Education*, *127*(2), 260-265.

Kruckeberg, R. (2006). A Deweyan perspective on science education: Constructivism, experience, and why we learn science. *Science & Education, 15*(1), 1-30. https://doi.org/10.1007/s11191-004-4812-9

Lasagabaster, D., & Sierra, J. M. (2010). Immersion and CLIL in English: More differences than similarities. *ELT Journal*, *64*(4), 367-375. https://doi.org/10.1093/elt/ccp082

Layton, D., Jenkins, E.W. & Donnelly, J. (1994). *Scientific and technological literacy. Meanings and rationales. An annotated bibliography*. Centre for Studies in Science and Mathematics Education, University of Leeds, in association with UNESCO.

Lee, O. (2003). Equity for culturally and linguistically diverse students in science education: A research agenda. *Teachers College Record, 105*, 465-489. https://doi.org/10.1111/1467-9620.00247

Lee, O. (2004). Teacher change in beliefs and practices in science and literacy instruction with English language learners. *Journal of Research in Science Teaching*, *41*(1), 65-93.

Lee, O. (2005). Science education with English language learners: Synthesis and research agenda. *Review of Educational Research*, *75*(4), 491–530. https://doi.org/10.1002/tea.10125

Lee, O., & Avalos, M. A. (2002). Promoting science instruction and assessment for English language learners. *Electronic Journal of Science Education, 7*(2).

Lee, O. & Buxton, C. (2012). Integrating science and English proficiency for English language learners*. Theory into Practice, 52*(1), 31-42.

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching*, *41*(10), 1021-1043. https://doi.org/10.1002/tea.20037

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex.

Li, G., Honojosa, D. M., Wexler, L., Bian, Y., & Matinez, J. M. (2017). Using multimodal modules to address pre-service teachers' knowledge gap in learning to teach English language learners. *TAPESTRY*, *8*(1), 1-35.

Lincoln, Y., & Guba, E. G. (1985). *Naturalistic inquiry*. SAGE.

Logan, M., & Skamp, K. (2008). Engaging students in science across the primary secondary interface: Listening to the students' voice. *Research in Science Education*, *38*(4), 501-527. https://doi.org/10.1007/s11165-007-9063-8

Long, M. H. (1983). Linguistic and conversational adjustments to non-native speakers. *Studies in Second Language Acquisition*, *5*(2), 177-193. https://doi.org/10.1017/S0272263100004848

Lucas, T., & Villegas, A. M. (2013). Preparing linguistically responsive teachers: Laying the foundation in preservice teacher education. *Theory into Practice*, *52*(2), 98-109. https://doi.org/10.1080/00405841.2013.770327

Lyster, R. (2007). *Learning and teaching languages through content: A counterbalanced approach*. John Benjamins.

Lyster, R., & Ballinger, S. (2011). Content-based language teaching: Convergent concerns across divergent contexts. *Language Teaching Research*, *15*(3), 279-288. https://doi.org/10.1177/1362168811401150

Manavathu, M., & Zhou, G. (2012). The impact of differentiated instructional materials on English language learner (ELL) students' comprehension of science laboratory tasks. *Canadian Journal of Science, Mathematics and Technology Education*, *12*(4), 334-349. https://doi.org/10.1080/14926156.2012.732255

Mcclure, G., & Cahnmann-Taylor, M. (2010). Pushing back against push-in: ESOL teacher resistance and the complexities of coteaching. *TESOL Journal*, *1*(1), 101-129. https://doi.org/10.5054/tj.2010.214883

Meltzer, J., & Hamann, E. T. (2005). *Meeting the literacy development needs of adolescent English language learners through content-area learning. Part Two: Focus on classroom teaching strategies*. Education Alliance at Brown University.

Merino, B., & Hammond, L. (2001). How do teachers facilitate writing for bilingual learners in "sheltered constructivist" science? *Electronic Journal in Science and Literacy*, *1*(1), 1-22.

Merino, J. A., & Lasagabaster, D. (2018). CLIL as a way to multilingualism. *International Journal of Bilingual Education and Bilingualism*, *21*(1), 79-92. https://doi.org/10.1080/13670050.2015.1128386

Meskill, C., & Oliveira, A. W. (2019). Meeting the challenges of English learners by pairing science and language educators. *Research in Science Education*, *49*(4), 1025-1040. https://doi.org/10.1007/s11165-019-9837-9

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded source book* (2nd Ed.). SAGE.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd Ed.). SAGE.

Miller, J. (2009). Teaching refugee learners with interrupted education in science: Vocabulary, literacy and pedagogy. *International Journal of Science Education*, *31*(4), 571-592. https://doi.org/10.1080/09500690701744611

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction — what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *47*(4), 474-496. https://doi.org/10.1002/tea.20347

Moje, E. B. (2015). Doing and teaching disciplinary literacy with adolescent learners: A social and cultural enterprise. *Harvard Educational Review*, *85*(2), 254-278. https://doi.org/10.17763/0017-8055.85.2.254

Munro, J., Abbott, M., & Rossiter, M. (2013). Getting to the science: Helping English-language learners show what they know. *Alberta Science Education Journal, 43*(1), 34-43.

National Academies of Sciences, Engineering, and Medicine. (2018). *English learners in STEM subjects: Transforming classrooms, schools, and lives*. National Academies Press.

National Research Council (NRC). (1996). *National Science Education Standards*. National Academies Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. National Academies Press.

Nikula, T. (2015). Hands-on tasks in CLIL science classrooms as sites for subject-specific language use and learning. *System*, *54*, 14-27. https://doi.org/10.1016/j.system.2015.04.003

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224-240. https://doi.org/10.1002/sce.10066

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods*, *16*(1), 1-13. https://doi.org/10.1177/1609406917733847

Olson, J. K., Levis, J., Vann, R., & Bruna, K. R. (2009). Enhancing Science for ELLs: Science strategies for English language learners that benefit all students. *Science and Children*, *46*, 46-48.

Ontario Ministry of Education. (2008). *Supporting English Language Learners: A Practical Guide for Ontario Educators, Grades 1 to 8*. Ontario Ministry of Education. Queen's Printer of Ontario.

Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal of Education*, *32*(2), 203-218. https://doi.org/10.1080/03057640220147559

Paillé, P. (1994). L'analyse par théorisation ancrée. *Cahiers de recherche sociologique*, *23*, 147-181.

Palincsar, A. S., & Brown, A. L. (1986). Interactive teaching to promote independent learning from text. *The Reading Teacher*, *39*(8), 771-777. https://www.jstor.org/stable/20199221

Parkinson, J., Jackson, L., Kirkwood, T., & Padayachee, V. (2007). A scaffolded reading and writing course for foundation level science students. *English for Specific Purposes*, *26*(4), 443-461. https://doi.org/10.1016/j.esp.2007.01.001

Patterson, A., Roman, D., Friend, M., Osborne, J., & Donovan, B. (2018). Reading for meaning: The foundational knowledge every teacher of science should have. *International Journal of Science Education*, *40*(3), 291-307. https://doi.org/10.1080/09500693.2017.1416205

Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science*, *328*(5977), 459-463. https://doi.org/10.1126/science.1182595.

Penner-Williams, J., Díaz, E. I., & Worthen, D. G. (2017). PLCs: Key PD component in learning transfer for teachers of English learners. *Teaching and Teacher Education*, *65*, 215-229. https://doi.org/10.1016/j.tate.2017.03.014

Pérez-Cañado, M. L. (2012). CLIL research in Europe: Past, present, and future. *International Journal of Bilingual Education and Bilingualism*, *15*(3), 315-341. https://doi.org/10.1080/13670050.2011.630064

Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multi-modal representations of concepts in primary science. *International Journal of Science Education*, *28*(15), 1843-1866. https://doi.org/10.1080/09500690600718294

Rabin, C. (2020). Co-Teaching: Collaborative and caring teacher preparation. *Journal of Teacher Education*, *71*(1), 135-147. https://doi.org/10.1177/0022487119872696

Ramirez, P. C., & Jimenez-Silva, M. (2014). Secondary English learners: Strengthening their literacy skills through culturally responsive teaching. *Kappa Delta Pi Record*, *50*(2), 65-69. https://doi.org/10.1080/00228958.2014.900846

Reeves, J. R. (2006). Secondary teacher attitudes toward including English-language learners in mainstream classrooms. *The Journal of Educational Research*, *99*(3), 131-143. https://doi.org/10.3200/JOER.99.3.131-143

Reid, G., & Norris, S. P. (2016). Scientific media education in the classroom and beyond: a research agenda for the next decade. *Cultural Studies of Science Education*, *11*(1), 147-166. https://doi.org/10.1007/s11422-015-9709-1

Ritchie, S. M., Tomas, L., & Tones, M. (2011). Writing stories to enhance scientific literacy. *International Journal of Science Education, 33*(5), 685-707. https://doi.org/10.1080/09500691003728039

Rivard, L., Cormier, M., & Turnbull, M. (2012). Reading strategies in French immersion science classes: Preparing our students for tomorrow. *Canadian Journal of Science, Mathematics and Technology Education, 12*(1), 86-102. https://doi.org/10.1080/14926156.2012.649051

Roberts, D. A., (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 729-779). Routledge.

Rollnick, M., & Rutherford, M. (1996). The use of mother tongue and English in the learning and expression of science concepts: a classroom-based study. *International Journal of Science Education*, *18*(1), 91-103. https://doi.org/10.1080/0950069960180108

Romance, N. R., & Vitale, M. R. (2012). Science IDEAS: A research-based K-5 interdisciplinary instructional model linking science and literacy. *Science Educator*, *21*(1), 1-11.

Roth, W. M., & Welzel, M. (2001). From activity to gestures and scientific language. *Journal of Research in Science Teaching*, *38*(1), 103-136. https://doi.org/10.1002/1098-2736(200101)38:1<103::AID-TEA6>3.0.CO;2-G

Saldaña, J. (2009). *The coding manual for qualitative researchers*. SAGE.

Sampson, V., Enderle, P., Grooms, J., & Witte, S. (2013). Writing to learn by learning to write during the school science laboratory: Helping middle and high school students develop argumentative writing skills as they learn core ideas. *Science Education*, *97*(5), 643-670. https://doi.org/10.1002/sce.21069

Savasci, F., & Berlin, D. F. (2012). Science teacher beliefs and classroom practice related to constructivism in different school settings. *Journal of Science Teacher Education*, *23*(1), 65-86. https://doi.org/10.1007/s10972-011-9262-z

Savoie-Zajc, L. (2000). La recherche qualitative/interprétative en éducation. In T. Karsenti and L. Savoie-Zajc (Eds.), *La recherche en éducation: étapes et approches* (pp. 123-147). ERPI.

Savoie-Zajc, L., & Karsenti, T. (2018). *La recherche en éducation: étapes et approches* (pp. 191-217). University of Montreal Press.

Schwandt, T. A. (2007). *The SAGE dictionary of qualitative inquiry.* SAGE.

Settlage, J., & Southerland, S. (2012). *Teaching science to every child: using culture as a starting point*. Retrieved from https://ebookcentral.proquest.com

Skouge, J.R., Rao, K., & Boisvert, P.C. (2007). Promoting early literacy for diverse learners using audio and video technology. *Early Childhood Education Journal*, *35*(1), 5-11. https://doi.org/10.1007/s10643-007-0170-y

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*(1), 40–59. https://doi.org/0.17763/haer.78.1.v62444321p602101

Siegel, M. (2012). New times for multimodality? Confronting the accountability culture. *Journal of Adolescent & Adult Literacy*, *55*(8), 671-681. https://doi.org/10.1002/JAAL.00082

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*(2-3), 235-260. https://doi.org/10.1080/09500690500336957

Slater, T., & Mohan, B. (2010). Cooperation between science teachers and ESL teachers: A register perspective. *Theory into Practice, 49*(2), 91-98. https://doi.org/0.1080/00405841003626478

Snow, M. A., Met, M., & Genesee, F. (1989). A conceptual framework for the integration of language and content in second/foreign language instruction. *TESOL Quarterly*, *23*(2), 201-217. https://doi.org/10.2307/3587333

Spender, J.C. (2008). Constructivism. In Thorpe, R. & Holt, R. (Eds.), *The SAGE dictionary of qualitative management research* (pp. 57-58). SAGE.

Statistics Canada (2016). Retrieved from http://www120.statcan.gc.ca/

Stoddart, T., Abrams, R., Gasper, E., & Canaday, D. (2000). Concept maps as assessment in science inquiry learning-a report of methodology. *International Journal of Science Education*, *22*(12), 1221-1246. https://doi.org/10.1080/095006900750036235

Stoddart, T., Pinal, A., Latzke, M., & Canaday, D. (2002). Integrating inquiry science and language development for English language learners. *Journal of Research in Science Teaching*, *39*(8), 664-687. https://doi.org/10.1002/tea.10040

Stoddart, T., Solis, J., Tolbert, S., & Bravo, M. (2010). A framework for the effective science teaching of English language learners in elementary schools. In D. W., Sunal, C. S., Sunal, & E. L. Wright (Eds.), *Teaching science with Hispanic ELLs in K-16 classrooms* (pp. 151-181). IAP.

Swanson, L. H., Bianchini, J. A., & Lee, J. S. (2014). Engaging in argument and communicating information: A case study of English language learners and their science teacher in an urban high school. *Journal of Research in Science Teaching*, *51*(1), 31-64. https://doi.org/10.1002/tea.21124

Tang, K. S., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning making in science education. *Science Education*, *98*(2), 305-326. https://doi.org/10.1002/sce.21099

Tong, F., Irby, B. J., Lara-Alecio, R., & Koch, J. (2014). Integrating literacy and science for English language learners: from learning-to-read to reading-to-learn. *The Journal of Educational Research*, *107*(5), 410–426. https://doi.org/10.1080/00220671.2013.833072

Torres, H. N., & Zeidler, D. L. (2002). The effects of English language proficiency and scientific reasoning skills on the acquisition of science content knowledge by Hispanic English language learners and native English language speaking students. *Electronic Journal of Science Education*, *6*(3), 1-59.

Verplaetse, L. S. (1998). How content teachers interact with English language learners. *TESOL Journal, 7*(5), 24-28.

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education*, *14*(4), 659-680. https://doi.org/10.1007/s10763-014-9605-2

Vygotsky, L.S. (1962). *Thought and language*. MIT Press.

Waldrip, B., Prain, V., & Carolan, J. (2010). Using multi-modal representations to improve Learning in junior secondary science. *Research in Science Education*, *40*(1), 65-80. https://doi.org/10.1007/s11165-009-9157-6

Wei, R. C., Darling-Hammond, L., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad*. National Staff Development Council.

Weinburgh, M., Silva, C., Smith, K. H., Groulx, J., & Nettles, J. (2014). The intersection of inquiry-based science and language: Preparing teachers for ELL classrooms. *Journal of Science Teacher Education*, *25*(5), 519-541. https://doi.org/10.1007/s10972-014-9389-9

Welsh, L. C., & Newman, K. L. (2010). Becoming a content-ESL teacher: A dialogic journey of a science teacher and teacher educator. *Theory into Practice*, *49*(2), 137-144. https://doi.org/10.1080/00405841003641485

Wessels, S. (2013). Science as a second language: Integrating science and vocabulary instruction for English language learners. *Science and Children, 51*(1), 50-53.

Wilson, A. A. (2008). Moving beyond the page in content area literacy: Comprehension instruction for multimodal texts in science. *Reading Teacher, 62*(2), 153-156. https://doi.org/10.1598/RT.62.2.7

Wu, H. K., & Puntambekar, S. (2012). Pedagogical affordances of multiple external representations in scientific processes. *Journal of Science Education and Technology*, *21*(6), 754-767. https://doi.org/10.1007/s10956-011-9363-7

Yore, L., Bisanz, G. L., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education*, *25*(6), 689-725. https://doi.org/10.1080/09500690305018

Yore, L. D., & Hand, B. (2010). Epilogue: Plotting a research agenda for multiple representations, multiple modality, and multimodal representational competency. *Research in Science Education*, *40*(1), 93-101. https://doi.org/10.1007/s11165-009-9160-y

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: language and science literacy - empowering research and informing instruction. *International Journal of Science Education, 28*, 291–314. https://doi.org/10.1080/09500690500336973

Young, C., & Rasinski, T. (2009). Implementing readers theatre as an approach to classroom fluency instruction. *The Reading Teacher*, *63*(1), 4-13. https://doi.org/10.1598/RT.63.1.1

Youngs, C. S. & Youngs, G. A. (2001). Predictors of mainstream teachers‶ attitudes toward ESL students. *TESOL Quarterly, 35*(1), 97-120. https://doi.org/10.2307/3587861

Zhang, Y. (2016). Multimodal teacher input and science learning in a middle school sheltered classroom. *Journal of Research in Science Teaching*, *53*(1), 7-30. https://doi.org/10.1002/tea.21295

Zwiep, S. G., & Straits, W. J. (2013). Inquiry science: The gateway to English language proficiency. *Journal of Science Teacher Education*, *24*(8), 1315-1331. https://doi.org/10.1007/s10972-013-9357-9

APPENDICES

Appendix A

Teacher Consent Form

Université d'Ottawa | University of Ottawa

--/--/---

Faculté d'éducation
Faculty of Education
613-562-5804
1-800-860-8577
613-562-5963
education.uOttawa.ca
145 Jean-Jacques Lussier
Ottawa ON K1N 6N5
Canada

Consent Form

Title of the study: Science Literacy for English Language Learners: A Case-Study of Teacher Practices in European Private International Baccalaureate (IB) Schools

Researcher: Natascia Petringa Faculty of Education University of Ottawa	Supervisor: Prof. Liliane Dionne Faculty of Education, University of Ottawa ldionne@uottawa.ca Tel: (613) 562-5800 Ext. 4138

I am invited to participate in the abovementioned research study conducted by Natascia Petringa, under the supervision of Prof. Liliane Dionne.

Purpose of the Study: The purpose of this study is to explore and understand how science teachers in International Baccalaureate (IB) schools teach science to their English Language Learners (ELLs). More specifically, focus will be on teacher practices in science literacy for ELLs. The research is designed as a case study of Gr. 7-12 science teachers working in European IB schools.

Participation: My participation with the researcher:

- Natascia will be observing 10 hours of my classroom sessions during the semester. In her visits, she will keep notes.
- She will conduct and possibly audio-record (with my consent) three interviews with me during the semester of approximately 1.5 hours each. The interviews will take place either on or off campus at a place and at a time that is convenient for me.
- Natascia might hold short discussions with me (of maximum fifteen minutes each) before or after a class during the semester about something that happened during the science class. With my permission, she might audiotape these discussions.
- She will collect the course's syllabus and any notes or other materials that I distribute and/or use with the ELL students.

Benefits: My participation in this study will engage me in a process where I will have space to reflect upon and discuss my professional practice as a science teacher with a special focus on ELLs. My participation in this research will contribute towards developing a repertoire on instructional and scaffolding techniques for future pre-service and/or in-service science teachers in both Canada and abroad.
Risks: The researcher has assured me that she will make every effort to protect my anonymity. Please read details below.

uOttawa

Appendix B

Background, School, Student Context and Views of Science Teachers

The following questions were addressed with the ten European science teachers (Grade 7-12).

FIRST INTERVIEW PROTOCOL (1.5 hours per teacher)

Past/Background Information:

1. Tell me about your background: Your education (Bachelor's degree, PGCE, Masters, PhD) and years of experience as a science teacher.
2. Did you receive any other type(s) of professional development which has/have helped you to become a better science teacher? If so, what kind?

School and Student Context:

1. Describe the school where you work, your schedule, the daily demands requested of you, and your peers.
2. Do you collaborate with any teacher in particular? If so, which one(s)? In what capacity? What is the frequency of this collaboration? How does this collaboration occur?
3. Describe your students: Who are they? What are their backgrounds?
4. How would you rate the level of linguistic diversity in your classroom? **Low** (0-25% of your students) – **Average** (25-50% of your students) – **High** (50-80% of your students) – **Very High** (80%-100% of your students)?
5. How would you rate the proficiency of English in your classroom? **Low** (0-25% of your students) – **Average** (25-50% of your students) – **High** (50-80% of your students) – **Very High** (80%-100% of your students)?

Teacher Views/Attitudes on:

A. Science Literacy:

1. As there are many definitions of science literacy, I would like to propose Yore, Bisanz and Hand's (2003) definition. They define science literacy as:

> abilities and habits-of-mind required to construct understandings of science, to apply these big ideas to realistic problems and issues involving science, technology, society and the environment, and to inform and persuade other people to take action based on these science ideas. (p. 690)

How would you define it? Please justify your definition as clearly as you can.

2. How does science literacy play a role in your classroom? How do you integrate science literacy in the classroom? Please focus on the ELLs in your classroom as you answer this question.

B. English Language Learners (ELLs):

1. What is your perception of ELLs in your classroom?
2. How do you adapt your science curriculum in accordance with the cultural and linguistic backgrounds of your students? If so, how? Please be specific.
3. What are the main difficulties/obstacles you face in your daily teaching of science with regards to your ELLs? How do you deal with these challenges? Please be specific.
4. Did you receive any training in teaching ELLs prior to teaching at this school? If yes, when and what type of training?

C. Effective practices for science with ELLs

1. In your opinion, what do you think is the most effective practice for teaching science to ELLs?
2. Which specific strategies do you feel work "best"? Why?

Please fill-in the following template for our next interview (interview # 2) scheduled on ____________________. You **DO NOT** need to choose **ALL** of the teaching modalities; rather select and describe the **THREE** you use most often. Please bring any **instructional resources and/or student artefacts** as supporting material. Note that the privacy of these artefacts is maintained at all times. Student names will never be used.

Appendix C

Grid on Effective Practices for Teaching Science to ELLs

SECOND INTERVIEW PROTOCOL (1.5 hours per teacher)

TEACHING MODALITY AND GUIDING QUESTIONS:	**DESCRIPTION OF ACTIVITY AND/OR INSTRUCTIONAL RESOURCE:** (with a specific focus on **adaptations** made for ELLs)	**SUCCESSES GAINED:** How is this/are these **adaptation(s)** effective for your ELLs?
Reading What types of texts do you use to promote reading for ELLs in your classroom (i.e., textbooks, science journals, plays, song lyrics, fiction, non-fiction, trade books, newspaper articles, etc.?) How do you integrate this in your science class?		
Writing What genres of writing do you use with ELLs in your classroom (i.e., notetaking skills, expository writing, narratives, technical writing, poetry, script writing, etc.?)		
Speaking How do you encourage your ELLs to speak in the science classroom (i.e., debates, cooperative learning groups, pair-share, individual responses, etc.)?		
Listening How do you teach, encourage and monitor the listening skills of your ELLs in relation to you, their peers, and towards other adults?		

Doing What kinds of hands-on activities do you conduct with your ELLs in the science classroom (i.e., experiments, making of models, prototypes, STEM activities etc.)? How do ELLs cope with these activities?		
Interpreting How do you enable your ELLs to make predictions, inferences, or draw conclusions from data or evidence?		
Representing and the Use of Technology How do you use technology to teach science to ELLs? How do you encourage your ELLs to organize data and/or information? How do they demonstrate their understanding to you and/or to their peers?		

Questions related to the grid above:

1. Can you explain why you chose these three modalities? Please be specific.
2. Tell me of a story or personal experience featuring one of these modalities and why it was successful in teaching your ELL student(s).
3. Which of these teaching modalities do you feel is the *most* effective for ELLs? Why? Which one is the *least* effective? Why?
4. What kind of support(s), if any, would you need in order to better meet the needs of your ELLs in the science classroom?
5. Can you think of a specific type or area of professional development that could help you to improve your teaching of ELLs in the science classroom?

Appendix D

Reflections on Teaching/Instructional Strategies for ELLs in Science

THIRD INTERVIEW PROTOCOL (1.5 hours per teacher)

1. What have you learned about your ELLs during your teaching of science?

2. What specifically has supported, helped or guided you in your teaching/instructional approaches? [These could include: prior training, collaborating with teachers and/or support staff, interdisciplinary work, professional development inside or outside the school, administrative support, district support, resource books etc.].

3. Describe the above-mentioned source(s) of support– how has/have they influenced your teaching and informed what you do in the classroom?

4. How have you learned from your practice?

5. As a teacher, how do you evaluate the impact of the above-mentioned approaches in terms of how they support the learning of your ELLs?

6. Any other comments?

Appendix E

Data Analysis Grids for the Research Questions

Research Question 1: What are teachers' perceptions and beliefs regarding science literacy for English Language Learners (ELLs) in the classroom?

Themes:	Teacher Perspectives and Beliefs About ELLs in Science:	Teachers:
Hardworking and Motivated	- Brave; extra work.	All teachers
	- The majority of ELLs do try.	All teachers
	- Can feel part of the community if given the required support.	Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy, Eva, Frank,
	- ELLs are the most hard-working; most humble; most quiet; "sweetest" in room.	All teachers
	- Simply need encouragement to communicate.	All teachers
	- May "mask" what they don't understand.	Amelie, Clara
	- Need extra time to complete tasks	All teachers
Benefit from Multimodality and Scaffolding	- Use of gestures and verbal cues	Adele, Aisha, Amelie, Anna, Clara, Daisy, Eva
	- Combine multimodalities	Aisha, Amelie, Anna, Clara, Daisy, Eva, Frank
	- Supporting images/visuals/*realia/* texts and drawings	All teachers
	- Color-coding	Amelie, Brooke

	- Need modified assessments for language; not content.	Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank
Encouraged to Use Native Language	- Provide access to native language; transfer language into English.	Adele, Brooke, Clara, Eva
Need Explicit Language Instruction	- ELLs interested in language do better. Those who invest time in languages acquisition, do better in science.	Anna
	- Teachers must teach language to ELLs.	Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank
	- ELLs should be encouraged to use the “Writing Club” or ELL Support provided during lunch break as support.	Aisha, Adam, Adele, Amelie, Anna, Brooke
	- Learning Chemistry is like learning a new language.	Eva
	- Teach prioritization and summarizing skills to ELLs.	Aisha, Amelie, Brooke, Clara, Daisy, Eva
	- Go over wording on IB science exams.	Aisha, Anna, Eva
	- Need consistency, repetition paraphrasing and rephrasing.	Adele, Adam, Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank
	- Focus on the language/discourse of science.	Clara
	- Practice science writing.	Aisha, Amelie, Clara, Daisy
	- Incorporate more reading in science.	All teachers

Research Question 2: What teaching strategies and/or instructional resources do teacher-participants use to teach science to ELLs?

a) What teaching modalities (i.e., reading, writing, speaking, listening, doing, interpreting, and representing, with or without the use of technology) and/or instructional resources do they use?
b) How and why do they use these modalities to meet the needs of ELLs?

Teaching Modality:	Teaching Strategies, Tools and Resources:	Teacher(s):
Reading	**Levelled reading for ELLs**	
	- Newsela.com	Daisy, Frank
	- Britannica online	Amelie, Brooke, Clara, Daisy, Eva, Frank
	- Newsademic	Clara, Daisy
	- Special science textbook for ELLs (modified explicitly for language)	Amelie, Clara, Daisy, Frank
	- ReadWorks.org = has audio versions, translations in seven languages	Clara, Eva
	Other types of reading	
	- Peer reviewed journals	Anna, Adam, Adele, Aisha, Daisy, Eva
	- Textbooks	Adam, Adele, Aisha, Anna, Clara
	- Newspapers online (NY Times)	Adele, Anna
	- Science magazines (Scientific American, National Geographic)	Adele, Aisha, Anna

	- Non-fiction (*Ishmael* by Daniel Quinn and *Silent Spring* by Rachel Carson)	Adam, Adele, Clara
	- Websites (Ex. Sustainable Human, Nature is Speaking, Khan Academy, BBC Bitesize etc.)	Adele, Aisha, Anna, Clara
	- Glossaries from different books	Adele, Clara
	Vocabulary development strategies	
	- Provide ELLs with printed script of the YouTube clip after showing the video. They can highlight all the words they have not understood.	Anna, Eva
	- Make a glossary or using a visual glossary	Adam, Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy
	- Working word wall with definitions of key terms	Aisha, Amelie, Clara
	- *Quizlet* to build vocabulary or *Quizlet Live* for a competitive and fun element.	Brooke, Daisy
	- *Science BINGO* with "key words"	Brooke, Clara, Daisy
Writing	**Class notes and lab reports**	All teachers
	Sentence and grammar frames	Aisha, Amelie, Brooke, Clara, Daisy, Eva, Frank
	Use of templates or exemplars	Aisha, Brooke, Clara, Daisy, Eva, Frank
	Visual-to-text supports (PowerPoints with notes) - Teacher provides students with class notes (on PowerPoints) and leaves space on the right side for them to take their own notes and/or to translate them into their mother tongue.	Adele, Aisha, Anna, Brooke, Clara, Frank
	Research outlines and essays	Clara

Speaking	**Ways to engage ELLs to speak in the science class**	
	- White boards	Daisy, Eva, Frank
	- Use of chips (tokens)	Daisy
	- Video or audio recordings to avoid having to speak out loud in front of the class.	Clara, Daisy
	- Movement: Have students move to different parts of the room to talk in small groups.	Aisha, Clara
	- Oral presentations	Adele, Aisha, Adam, Anna, Brooke, Clara, Daisy
	- *Think-pair-share*	All teachers
	- Questioning (students ask questions of each other)	Aisha, Clara, Frank
	- Teacher questioning	All teachers
	- Argumentation/debate	Adele, Anna
	- Role play	Clara
	Purposeful grouping	
	- Clustering *versus* non-clustering of ELLs	Adele, Amelie, Clara, Daisy, Eva, Frank
	- Mix of native and non-native speakers	All teachers
	POGILs (Process-Oriented Guided Inquiry Learning).	Brooke, Eva
	- This is a *student-centered* approach which helps to develop content as well as communication, critical thinking and problems solving within a group of students. Students are able to work at their own pace, hence reducing the time pressure. This is one way to scaffold labs for ELLs. Students work in teams of 3 or 4 and have assigned roles (such as a speaker, recorder etc.) which are rotated for every new activity. It is a guided form designed to develop "critical thinking."	

	Celebrating cultural and linguistic diversity in the classroom	
	- Sustainability project: research and present an environmental problem currently affecting your country (Eg. *Slash-and-burn* deforestation in Brazil; ocean pollution by cruise-liners in Portugal).	Adele, Clara, Daisy, Eva
	- Making a food item from their own country ("Making an Energy Bar")	Daisy
Listening	**Use of technology**	
	- Subtitles on YouTube	Aisha, Anna, Clara, Daisy
	- Narrated PowerPoints: since these can be repeated as reinforcement for ELLs.	Adele, Anna
	- Ask questions at the end of a PowerPoint or video. (Ex. Paul Hewitt (*Hewitt Drew-It)* in Physics, asks a question at the end of his videos in order to ensure that students are listening.	Anna
	- ComPADRE: Use of animations and videos with transcripts and texts so that the ELLs can be exposed to a combination of visual, audio and texts.	Anna
	Using "grouping" as a way to maximize listening skills	
	- Summarize what you heard/understood by sharing it with the person near you.	Aisha, Eva
	- Use of exit cards	Aisha, Daisy
	- Questioning	Aisha, Clara, Frank
	- Word Game: Students cross out the "key words" when they hear the teacher use it.	Brooke
	- Break up information (*chunking*) and have the students teach each other.	Aisha, Amelie, Clara
	Dictogloss: an effective tool for promoting listening skills amongst ELLs.	Clara, Daisy

Doing	**Science inquiry** and **experimentation** (lab work)	All teachers
	Flipped Classroom - A pedagogical approach which promotes student engagement and active learning. It is student-centered instead of teacher-centered and content is learned predominantly via videos or third parties (such as guest speakers etc.).	Brooke, Eva
	Use of technology (Virtual labs, simulations and animations)	All teachers
	- Virtual labs (Eg. Lactose enzyme) - Simulations - Animation - Virtual dissections	Adam, Adele, Brooke
Interpreting	**Use of technology**	
	- **PhET (Physics Education Technology)** but PhET site now includes simulations about other subjects besides Physics.	Adele, Aisha, Anna, Brooke
	- Use **databases** (Eg. *Engineering Toolbox*)	Anna
	- Use **Excel** to collect and work with data (make graphs).	All teachers
	- Use of Vernier **probes** and **data-loggers** (such as *Logger Pro*)	Adam, Adele, Aisha, Anna, Brooke, Daisy, Eva, Frank
	Predicting and making inferences	All teachers
	- Summarize a graph in **one sentence**	Frank
	Use of metaphors and analogies	Adam, Clara, Daisy

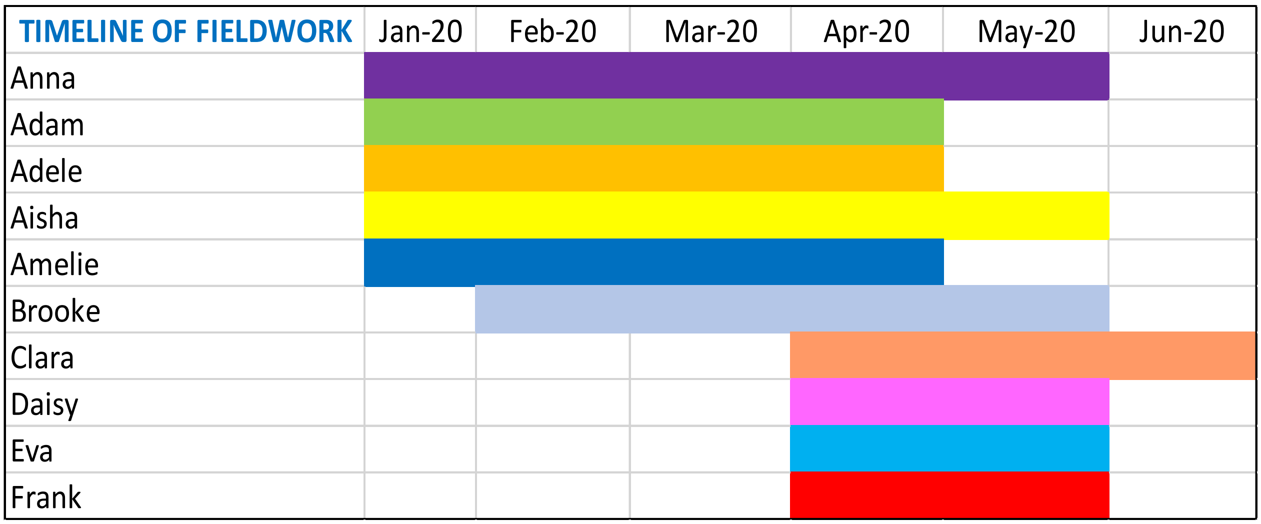
Representing (with or without the use of technology)	**Making of models**, (Making mobiles, dioramas, protein-folding with paper, making models using 3-D printers).	Aisha, Brooke, Clara, Daisy, Eva, Frank
	Using of Science Kits (DNA kits, molecular kits etc.).	Adam, Aisha, Anna, Brooke, Daisy, Eva, Frank
	Drawing (Figures, cartoon strips, comics, posters, energy diagrams, drawing of seed germination etc.) Consider the effective use of **whiteboards**.	Adele, Aisha, Amelie, Anna, Brooke, Clara, Daisy, Eva
	Gestures and role play (i.e., students in ESS assume acting roles as reporters to present an environmental problem; to portray functions of a "Cell" or the circulatory system; or to demonstrate the movement of particles).	Adele, Aisha, Brooke, Clara

Research Question 3: What do science teachers need in order to effectively integrate science literacy for ELLs (e.g., structures, resources, administrative support, types of professional development, "other" needs etc.)?

Themes:	Teacher Comments:	Teachers:
Administrative Support and Scheduling of Collaborative Time	- Administrative support and scheduling of collaboration. - Co-teach with an ELL/ELD teacher. - Collaboration with the ELL/ELD teacher. - Collaborate with ESS colleagues at other schools. - Collaborative time with science colleagues (Biology, Chemistry, Physics and ESS) would be extremely useful. - Collaborate with Math colleagues. - Open door policy; peer coaching; greater collegiality.	All teachers
Professional Development and the Need for Specialized Courses to Teach ELLs	- Hands-on activities to promote speaking of ELLs. - Take the *ESL in the Mainstream* course. - Long-term PD; conferences; webinars. - Access to specialized PD books on teachings ELLs. - Targeted PD opportunities for science/ELLs. - Learn specific strategies & tricks to teach ELLs. - PD on tools for teaching Content-Based Learning (CBL). - ELLs would benefit from a programme with a focus on technical words for ELLs. - Teacher resources about environmental issues for my ESS class. - Specific science training (Eg., Astrophysics/Cosmology).	Adele, Aisha Anna, Brooke Daisy, Eva, Frank
Time	- Time for making of differentiated resources. - Have a period with an ELL/ELD teacher to make material/resources. - Our curriculum is already over-challenging for mainstream students. This makes it especially challenging for ELLs; more time is needed.	Adam, Aisha, Amelie, Brooke, Clara, Daisy
	- Reflection time is important for teachers to improve their practices with a focus on ELLs. We don't have much of this.	Aisha, Brooke, Clara, Daisy, Eva, Frank

Appendix F

Timeline of Field Work (January 6, 2020 to June 30, 2020)



Appendix G

Example of a POGIL in Chemistry

PERIODIC TRENDS

Can the properties of an element be predicted using a periodic table?

Name: ___________________________

The periodic table is often considered to be the "best friend" of chemists and chemistry students alike. It includes information about atomic masses and element symbols, but it can also be used to make predictions about atomic size, electronegativity, ionization energies, bonding, solubility, and reactivity. In this activity you will look at a few periodic trends that can help you make those predictions. Like most trends, they are not perfect, but useful just the same.

Use information shown on the interactive Periodic Table to answer the following questions. http://www.ptable.com/

Atomic Radius

a. Write a complete sentence defining atomic radius. Note: You may not use the word "radius" in your definition, but be sure to use terms like nucleus, electrons, and atom.

b. i. Look at the Interactive Periodic Table. In general, what happens to the value for atomic radius as you go down a group on the Periodic Table?

Support your answer, using examples from two groups.

ii. Using your knowledge of Coulombic attraction and the structure of the atom, explain this trend in atomic radius. Hint: You should discuss either a change in distance between the nucleus and outer shell of electrons or a change in the number of protons in the nucleus.

c. i. Look at the Interactive Periodic Table. In general, what happens to the value for atomic radius as you go across a period from left to right on the Periodic Table? Support your answer, using examples from three periods.

ii. Using your knowledge of Coulombic attraction and the structure of the atom, explain this trend in atomic radius.

d. For each pair of atoms listed below, circle the atom with the larger atomic radius.

i. Argon and Sodium ii. Fluorine and Bromine iii. Aluminum and Calcium

First Ionization Energy

The first ionization energy is the amount of energy needed (absorbed by an atom) to remove the first electron from an atom.

a. Using your knowledge of Coulombic attraction, explain why ionization — removing an electron from an atom requires (absorbs) energy.

b. Which takes more energy removing an electron from an atom where the nucleus has a tight hold on its electrons, or a weak hold on its electrons? Explain.

c. i. Look at the Interactive Periodic Table. In general, what is the trend in ionization energy as you go down a group? Support your answer using examples from three groups.

ii. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified above.

d. i. Look at the Interactive Periodic Table. In general, what is the trend in ionization energy as you go across a period? Support your answer using examples from two periods.

ii. Using your knowledge of Coulombic attraction and the structure of the atom, explain the trend in ionization energy that you identified above.

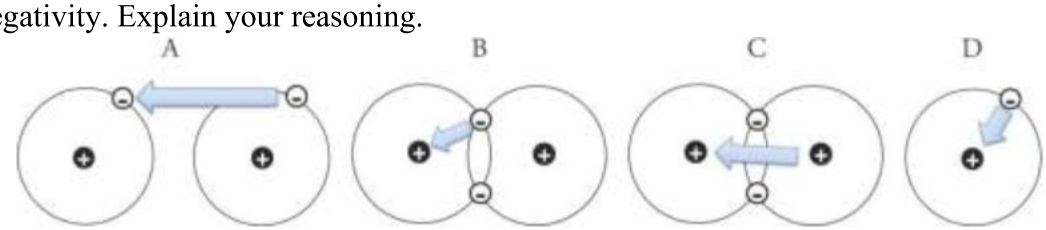
e. Atoms with loosely held electrons are usually classified as metals. They will exhibit high conductivity, ductility, and malleability because of their atomic structure. Would you expect metals to have high ionization energies or low ionization energies? Explain your answer in one to two complete sentences.

f. Circle the atom in each pair with the highest ionization energy.
i. Beryllium and Fluorine ii. Oxygen and Selenium iii. Chlorine and Calcium

Electronegativity

Electronegativity is a measure of the ability of an atom's nucleus to attract electrons from a different atom within a covalent bond. A higher electronegativity value correlates to a stronger pull on the electrons in a bond. This value is only theoretical. It cannot be directly measured in the lab.

a. Using the definition stated above, select the best visual representation for electronegativity. Explain your reasoning.



Look at the Interactive Period Table information that represents electronegativity.

b. i. What is the trend in electronegativity going down a group on the Periodic Table?

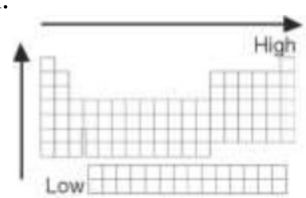
ii. Explain the existence of the trend described in part a in terms of atomic structure and Coulombic attraction.

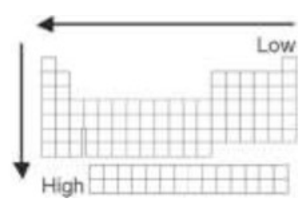
c. i. What is the trend in electronegativity going across a period on the Periodic Table?

ii. Explain the existence of the trend described in part c in terms of atomic structure and Coulombic attraction.

d. Rank the following elements from smallest to largest electronegativity based on the trends you have discovered thus far in the periodic table: barium (atomic number 56), bromine (atomic number 35), and iron (atomic number 26). Explain your reasoning.

4. The two diagrams below can summarize each of the three trends discussed in this activity. Write "atomic radius," "ionization energy," and "electronegativity" under the appropriate diagram.





Appendix H

"Top-Three" Teaching Modalities for ELLs in Science

Anna	1. Reading 2. Interpreting 3. Speaking (asking questions)
Frank	1. Doing 2. Reading 3. Writing
Daisy	1. Representing (with the use of technology) 2. Doing 3. Speaking
Brooke	1. Doing 2. Speaking 3. Listening
Adele	1. Doing 2. Representing (with the use of technology) 3. Speaking (emphasizing certain words)
Aisha	1. Doing 2. Interpreting 3. Representing with the use of technology
Eva	1. Speaking 2. Writing 3. Interpreting
Adam	1. Representing (with the use of technology) 2. Speaking 3. Listening
Amelie	All seven modalities (reading, writing, speaking, listening, doing, interpreting, and representing with or without the use of technology).
Clara	All seven modalities + socialization & interaction

Appendix I

Ethics Approval Certificate

13/07/2020

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	S-11-19-5078
Titre du projet / Project Title	SCIENCE LITERACY FOR ENGLISH LANGUAGE LEARNERS: A Case-Study of Teacher Practices in European Private International Baccalaureate (IB) Schools
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	13/07/2020
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	12/12/2020

Équipe de recherche / Research Team

Chercheur / Researcher	**Affiliation**	**Role**
Natascia PETRINGA	Faculté d'éducation / Faculty of Education	Chercheur Principal / Principal Investigator
Liliane DIONNE	Faculté d'éducation / Faculty of Education	Superviseur / Supervisor

Conditions spéciales ou commentaires / Special conditions or comments

This certificate is issued with the understanding that the Principal Investigator is responsible for the following:

1. ensuring that the research protocols comply with the most up-to-date advice, recommendations, directives, orders, advisories, guidelines about the spread of COVID-19 from government and public health officials and with those from institutions, organizations or funding agencies relevant to the research; and
2. establishing, maintaining and implementing an up-to-date continuance plan that includes reasonable precautions to help prevent the spread of COVID-19 to participants, research team members and ensure safe research practises, for example, training of research team members, use of personal protective equipment, standards of sanitization, handwashing and physical distancing.

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Appendix J

Scientific Root Words, Prefixes, and Suffixes

Scientific Root Words, Prefixes, And Suffixes

a-, an-	not, without, lacking, deficient	centi-	hudredth	-escent	becoming
ab-	away from, out from	centr-	center	eso-	inward, within, inner
-able	capable of	cephal-	head	eu-	well, good, true, normal
ac-	to, toward	cerat-	horn	eury-	widen
-aceous	of or pertaining to	cerebr-	brain	ex-	out of, away from
acou-, acous-	hear	cervic-	neck	extra-	beyond, outside
ad-	to, toward	chel-	claw	-fer-	bear, carry, produce
aden-	gland	chem-	dealing with chemicals	ferro-	iron
adip-	fat	chir-	hand	fibr-	fiber, thread
aero-	air	chlor-	green	-fid, fiss-	split, divided into
agri-	field, soil	chondr-	cartilage	-flect, -flex	bend
-al	having the character of	chrom-, -chrome	color	flor-	flower
alb-	white	chron-	time	flu-,fluct-,flux	flow
alg-, -algia	pain	-chym-	juice	foli-	leaf
alto-	high	-cid-, -cis-	cut, kill, fall	fract-	break
ambi-	both	circa-, circum-	around, about	-gam-	marriage
ameb-	change, alternation	cirru-	hairlike curls	gastr-	stomach
amni-	fetal membrane	co-	with, together	geo-	land, earth
amphi-, ampho-	both	cocc-	seed, berry	-gen, -gine	producer, former
amyl-	starch	coel-	hollow	-gene-	origin, birth
ana-	up, back, again	coll-	glue	-gest-	carry, produce, bear
andro-	man, masculine	coni-	cone	-glen-	eyeball
anemo-	wind	contra-	against	-glob-	ball, round
ang-	choke, feel pain	corp-	body	gloss-	tongue
angi-	blood, vessel, duct	cort-, cortic-	outer layer	gluc-, glyc-	sweet, sugar
ante-	before, ahead of time	cosmo-	world, order, form	glut-	buttock
anter-	front	cotyl-	cup	gnath-	jaw
antho-	flower	counter-	against	-gon	angle, corner
anti-	against, opposite	crani-	skull	-grad-	step
antrhopo-	man, human	cresc-, cret-	begin to grow	-gram, graph	record, writing
-ap-, -aph-	touch	crypt-	hidden, covered	grav-	heavy
apo-, ap-	away from	-cul-, -cule	small, diminutive	-gross-	thick
aqu-	water	cumul-	heaped	gymno-	naked, bare
archaeo-	primitive, ancient	cuti-	skin	gyn-	female
-ary, -arium	denotes a place for something	cyan-	blue	gyr-	ring, circle, spiral
arteri-	artery	-cycle, cycl-	ring, circle	-hal-, -hale	breathe, breath
arthr-	joint, articulation	-cyst-	sac, pouch, bladder	halo-	salt
-ase	forms names of enzymes	cyt-, -cyte	cell, hollow container	hapl-	simple
aster-, astr-	star	dactyl-	finger	hector-	hundred
-ate	verb form – the act of	de-	away from, down	-helminth-	worm
anther-	fatty deposit	deca-	ten	hem-	blood
-ation	noun form – the act of	deci-	tenth	hemi-	half
atmo-	vapor	deliquesc-	become fluid	hepar-, hepat-	liver
audi-	hear	demi-	half	herb-	grass, plants
aur-	ear	dendr-	tree	hetero-	different, other
auto-	self	dent-	tooth	hex-	six
bacter-, bactr-	bacterium, stick, club	derm-	skin	hibern-	winter
barb-	beard	di-, dipl- (Latin)	two, double	hidr-	sweat
baro-	weight	di-, dia- (Greek)	through, across, apart	hipp-	horse
bath-	depth, height	dia- (Latin)	day	hist-	tissue
bene-	well, good	digit-	finger, toe	holo-	entire, whole
bi- (Latin)	two twice	din-	terrible	homo- (Latin)	man, human
bi-, bio- (Greek)	life, living	dis-	apart, out	homo- (Greek)	same, alike
-blast-	sprout, germ, bud	dorm-	sleep	hort-	garden
brachi-	arm	dors-	back	hydr-	water
brachy-	short	du-, duo-	two	hygr-	moist, wet
brady-	slow	-duct	lead	hyper-	above, beyond over
branchi-	fin	dynam-	power	hyph-	weaving, web
brev-	short	dys-	bad, abnormal, difficult	hyphno-	sleep
bronch-	windpipe	ec-	out of, away from	hypo-	below, under, less
cac-.	bad	echin-	spiny, prickly	hyster-	womb, uterus
calor-	heat	eco-	house	-iae	person afflicted with disease
capill-	hair	ecto-	outside of	-iasis	disease, abnormal condition
capit-	head	-elle	small	-ic	(adjective former)
carcin-	cancer	-emia	blood	-ichthy-	fish
cardi-	heart	en-, endo-, ent-	in, into, within	ign-	fire
carn-	meat, flesh	-en	made of	in-, il-, im-, ir-	not
carp-	fruit	encephal-	brain	in-, il-, im-, ir-	to, toward, into
carpal-	wrist	enter-	intestine, gut	in-	very, thoroughly
cata-	breakdown, downward	entom-	insects	-ine	of or pertaining to
caud-	tail	-eous	nature of, like	infra-	below, beneath
-cell-	chamber, small room	epi-	upon, above, over	inter-	within, inside
cen-, cene-	now, recent	-err-	wander, go astray	intra-	between
cente-	pierce	erythro-	red	-ism	a state or condition

https://www.biologyjunction.com/scientific-root-words-prefixes-and-suffixes/

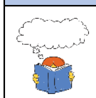
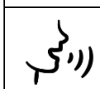
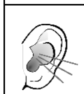
Appendix K

Sample of a Unit Plan on Plant and Animal Cells

UNIT PLAN TEMPLATE FOR SCIENCE TEACHERS

Unit or Topic	*Variety of Life*: *Cell Types, Structures, and Functions*		
Content Objectives	• Summarize the structures and functions of the major parts of plant and animal cells (cell wall, cell membrane, nucleus, nuclear membrane, chloroplasts, chlorophyll, cytoplasm, mitochondria, and vacuoles). • Recognize the relationship between the structure and function of cells • Compare plant and animal cells • Compare the structure and function of specialized cells • Calculate cell magnification • Learn how to make a wet mount		
Language Objectives	**Shape**: Oval, round, rectangular, amorphous (no specific shape). **Size**: Large, larger, largest; big, bigger, biggest; and small, smaller, smallest. **Functions**: Enters, exits, protects, stores, provides, controls, uses, and photosynthesize.		
Language Supports	**Key Vocabulary**	**Roots (Prefixes and Suffixes)**	**Sentence Frames**
	- cells - cell membrane - cell wall - chlorophyll - chloroplasts - cytoplasm - mitochondrion (*singular*) - mitochondria (*plural*) - nuclear membrane - nucleus - photosynthesis - vacuole	*cell* – Latin "storeroom or chamber" *cyto* - Greek *kutos* "vessel" *chloro* - Greek *khlōros* “"green" *khondrion* - Greek "little granule" *micro* -Greek *mikros* "small" *membrana* - Latin "thin layer of skin or soft tissue of the body" *mitos* - Greek *mitos* "thread" *kary* - Greek *karyon* "nut or kernel" *photo* - Greek *phōs*, "light" *synthesis* - Greek "putting together" *plasma* - Greek "something molded or created"	All living things are made of ____________. The ______________ **protects** the cell. The ____________ **is present** only in plant cells; not in animal cells. ___________ is the green fluid present in the chloroplasts. _____________ use sunlight during the process of **photosynthesis**.

		phyll - Greek *phyllon* "leaf" *vacuus* - Latin "empty"	The ___________ keeps all cell parts together and gives cells their shape. The mitochondria **provide** ___________ for the cell. The ___________ protects the nucleus of a cell. The ___________ is the "brain" of the cell. _______________ is when plants use carbon dioxide, water and sunlight to make food. The ___________ **stores** water and minerals.

Teaching Modalities	
 Reading	- Students will read about plant and animal cells in their science textbook. This will be assigned for homework. - Students can read a website on plant and animal cells.
 Writing	- Students will write a paragraph on the differences between plant and animal cells. They will also research and write five examples of specialized cells. - Write a narrative (story) about a plant and animal cell. Be creative!
 Speaking	- Students will split into pairs and discuss the differences between plant and animal cells. - Using flashcards, they will play a game on the differences between plant and animal cells.
 Listening	- The students will see a YouTube titled Plant and Animal Cells. https://www.generationgenius.com/videolessons/plant-and-animal-cells-video-for-kids/ - Students will listen to a rap song on plant and animal cells. They will also get a copy of the song's text. https://englishthroughmusic.bandcamp.com/track/cells-rap-animal-plant

<table>
<tr><td>
Doing (Science Inquiry)</td><td colspan="2">- Do a lab titled “Human Cheek and Onion Cells”. Students will make their own wet mounts.
- Observe plant and animal cells using a microscope.</td></tr>
<tr><td>
Interpreting</td><td colspan="2">- Draw the cell slides in science notebooks.
- Identify the difference shapes between plant and animal cells.
- Identify the relationship between cell shape and function.</td></tr>
<tr><td>Representing (with or without the use of technology)
</td><td colspan="2">- Draw a Venn diagram to show the similarities, differences and commonalities between plant and animal cells.
- Compare a cell to a factory (i.e., analogy activity)
- Make a 3-D model of a plant or an animal cell.</td></tr>
<tr><td>Types of Assessment (involving choice)</td><td>Formative Assessment:

- Homework assignment on differences between plant and animal cells
- Venn diagram on plant and animal cells
- 3-D Model of a plant or an animal cell
- Cells Alive online activity and calculation of cell magnification
- Narrative (story): plant and animal cells
- Drawings of cell slides
- Analogy activity (cells -vs- factory)
- Lab worksheet on “Human Cheek and Onion Cells”</td><td>Summative Assessment:

- Unit exam on Cells (written).
AND
- Option 1: Make a model of an edible plant and animal cell. Label it clearly and orally present its parts and main functions to the class (kinaesthetic and oral).
OR
- Option 2: Make your own song (any type) on plant and animal cells. Make sure your song contains its parts and functions (written and oral).
OR
- Option 3: Write and act out a play or skit on plant and animal cells. Make sure your skit contains its parts and functions (written, oral, gestures, drama).</td></tr>
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Teacher Reflections	The students were very engaged in this unit. They enjoyed the diversity of the tasks provided to them. Overall, I feel this unit went well because the students enjoyed the freedom and choice of assessments they were provided with. This unit embedded multimodality as well as multiple representations. Next year, I will need to explain the calculation of magnification in more detail. Students seemed to have difficulties with this. The *Cells Alive* online activity was insufficient.