2020

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

International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

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To cite this article: Melanie Williams & K.-S. Tang (2020): The implications of the non-linguistic modes of meaning for language learners in science: a review, International Journal of Science Education, DOI: 10.1080/09500693.2020.1748249

To link to this article: https://doi.org/10.1080/09500693.2020.1748249

Published online: 09 Apr 2020.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2020.1748249

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

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ABSTRACT

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

ARTICLE HISTORY
Received 30 May 2019
Accepted 24 March 2020

KEYWORDS
Science; multiliteracies; translanguaging; non-linguistic modes; language learner

Introduction

Widespread global migration has caused an influx in student diversity that has seen a rise in the number of language learners in science classrooms (Gibbons, 2015). International migrants now account for 3.3% of the global population and over a third of the population in cities such as Sydney, Auckland, Singapore and London (International Organization for Migration, 2015). This has renewed efforts to address language learners' problematic expectation to simultaneously learn the language of instruction (LOI) as well as the

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content area language (Haneda, 2014). Yet research has remained guided by outdated theories of language with a linguistic focus (Wu et al., 2019). If we are to tackle the long-standing interests of language learners in contemporary societies, who are more culturally and linguistically diverse and globally connected via technology, then we must apply theories of language that correspond to the communication of today.

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

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

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

Theoretical framework

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

Contemporary language theories, such as social semiotics, embrace the semiotic resources found in societies today, which can be actions or artefacts (Halliday, 1978; Van Leeuwen, 2005). Resources that have representational elements can develop over time into distinctive semiotic systems termed modes (Hodge & Kress, 1988). While

linguistic modes such as speech and writing have been the predominant meaning-making resources in the past, each mode has the potential to make complex meanings, including non-linguistic modes such as action, image, gesture and sound (Kress & Van Leeuwen, 1996; Martinec, 1998; McNeill, 1992; O'Toole, 1994; Van Leeuwen, 1999). The multiplicity of modes implies language learners have diverse ways to communicate in science. For the scope of this review we limited our focus to the modes described by the theory of multiliteracies, as they pertained to a classroom setting. These included visual (e.g. images and graphics), spatial (e.g. episodic movement), gestural (e.g. hand, arm, and body movements), auditory (e.g. sound effects and music), tactile (e.g. sensory and hands-on), oral (e.g. speech) and written (Kalantzis et al., 2016).

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

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

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

various modes of what are described as autonomous languages, in order to maximise communicative potentials (Baker, 2001; Garcia, 2009). Therefore it embraces all semiotic modes and suggests language is interconnected in a dynamic way to form linguistic and communication repertoires (Garcia, 2009).

Learning science through language

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

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

Review methods

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

Methodological approach

As the outcomes of non-linguistic modes were piecemeal and dispersed in studies, we required an methodological approach comparable to empirical research that allowed

the findings of studies to be re-conceptualised. Randolph (2009) provided a fitting review protocol that included problem formulation, data collection, data evaluation, analysis and interpretation, and public presentation. In the following, we share how we engaged in each of the review stages.

Problem formation

The research focus for this review was the use of non-linguistic modes by either language learners or their teachers in science. We created questions to guide this literature review. The first question directed our search of the literature, while the second broadened the scope of our findings and allowed us to form interpretations.

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

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

Data collection

Since the topic of the review was vast and wide-ranging we conducted an expansive search of international peer-reviewed journals from 1995 to 2019 using three methods: (1) a database search of ProQuest, Web of Science and Scopus; (2) a manual search, as the findings

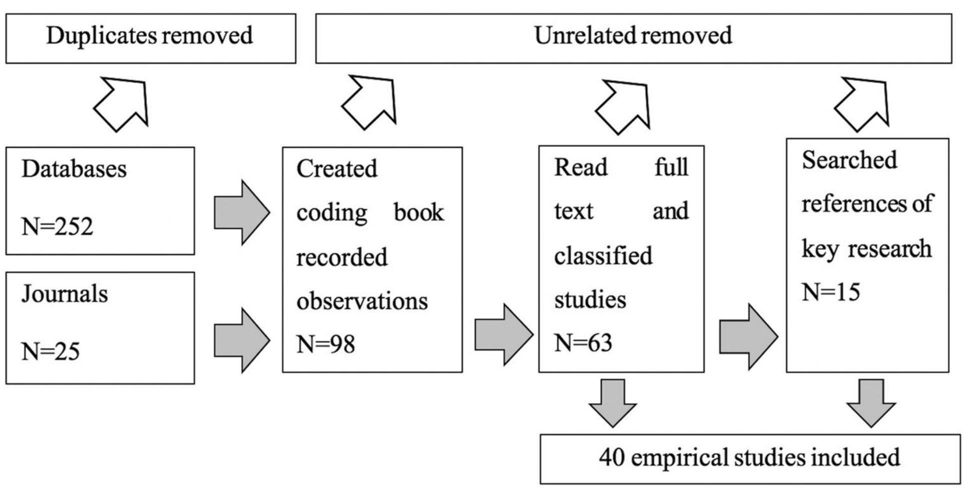

Figure 1. The data collection method used.

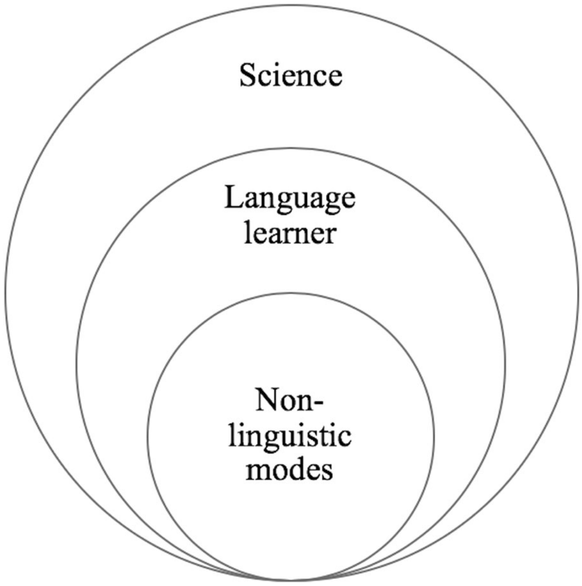

Figure 2. The three concepts used in the search.

we sought were frequently hidden within the text; and (3) a search of the reference lists of noteworthy studies. (See Figure 1).

We chose search terms related to three concepts (see Figure A1 and Figure 2) and refined these during the initial searches by tailoring terms to specific databases. Diverse terms describing language learners were also included. We excluded the search terms 'inquiry'/ 'enquiry' and 'experiment' due to their frequency and broad definitions, respectively.

Data evaluation

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

Analysis procedure

As the findings of non-linguistic modes needed to be interpreted, we adopted a theoretical thematic analysis that provided a recursive process and allowed inferences to be conceptualised over time (Braun & Clarke, 2006). However, since the studies were located worldwide and included multiple inherent social and cultural influences, we could only infer implications

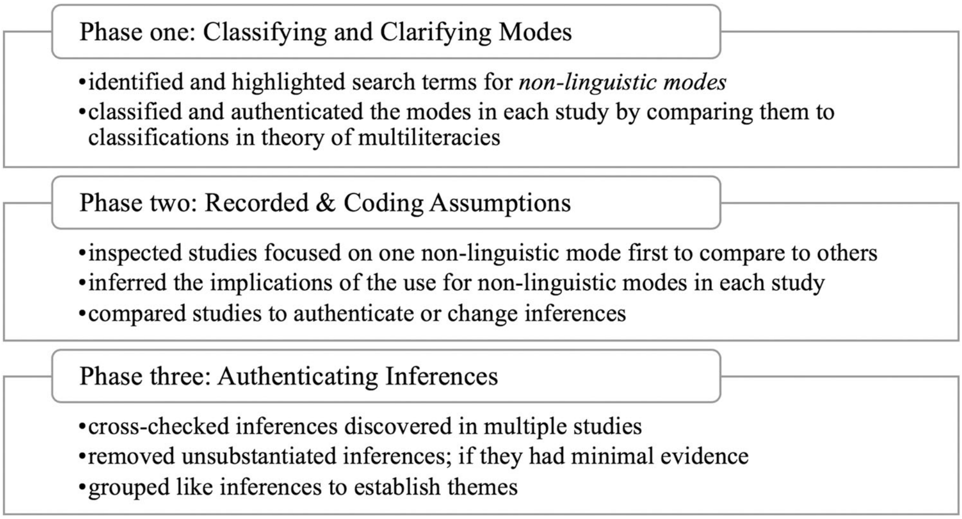

Figure 3. The phases of analysis.

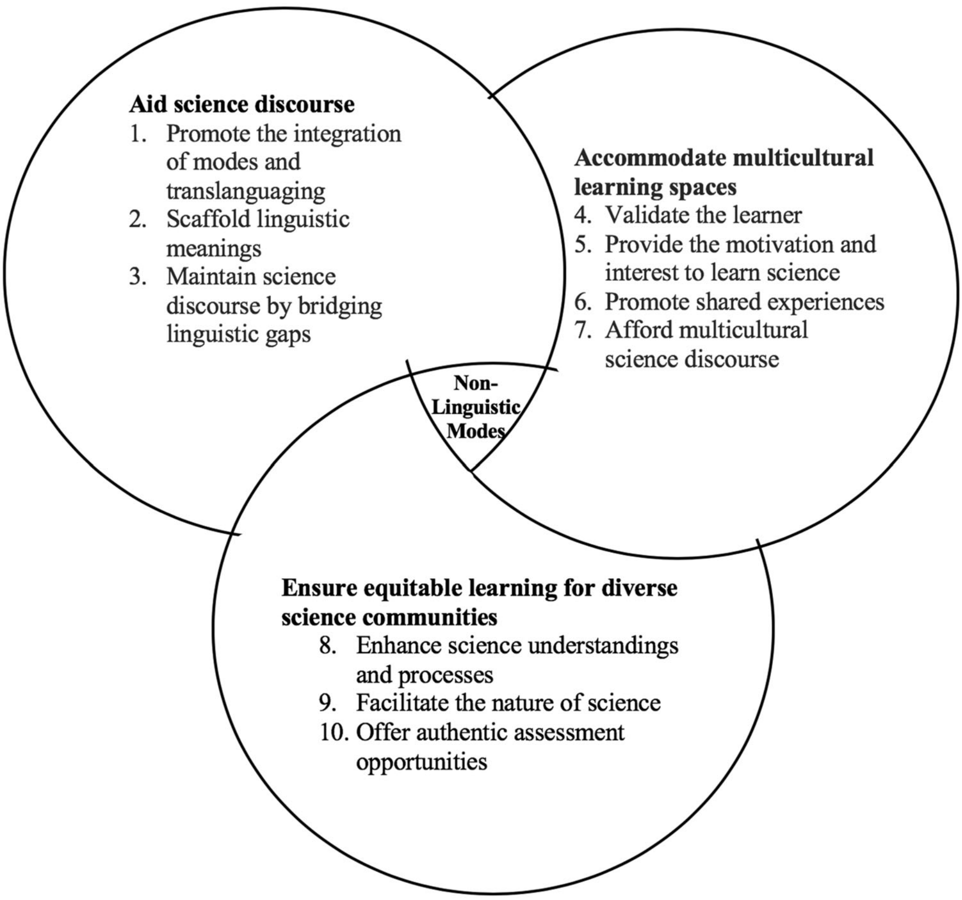

Figure 4. The ten inferences depicting how non-linguistic modes support language learners.

from the material influences. We relied heavily on the descriptions of the results to inform us of three things: first, the way modes were used by students and teachers to design a meaning; second, the way a mode was used in relation to other modes; and, third, to provide a context for the meanings made. The analysis occurred in three phases (see Figure 3). Phase one addressed the first research question and ensured we made valid interpretations. Phase two was an evolving process that addressed question two. Inferences solidified as evidence accumulated. During the final phase, we substantiated the value of our suppositions for language learners in science by returning to our theoretical framework and literature.

Analysis and interpretations

From our analysis we deduced 10 inferences (see Figure 4) for how non-linguistic modes support language learners. These have been conceptualised within three themes (see Figure 2) and the studies harbouring evidence for each assertion are located in Table 1.

Since a discussion of an entire data set used to surmise each inference was not possible due to space constraints, the following discussion includes noteworthy findings from studies of significance or controversy. First, a general overview of the data is provided.

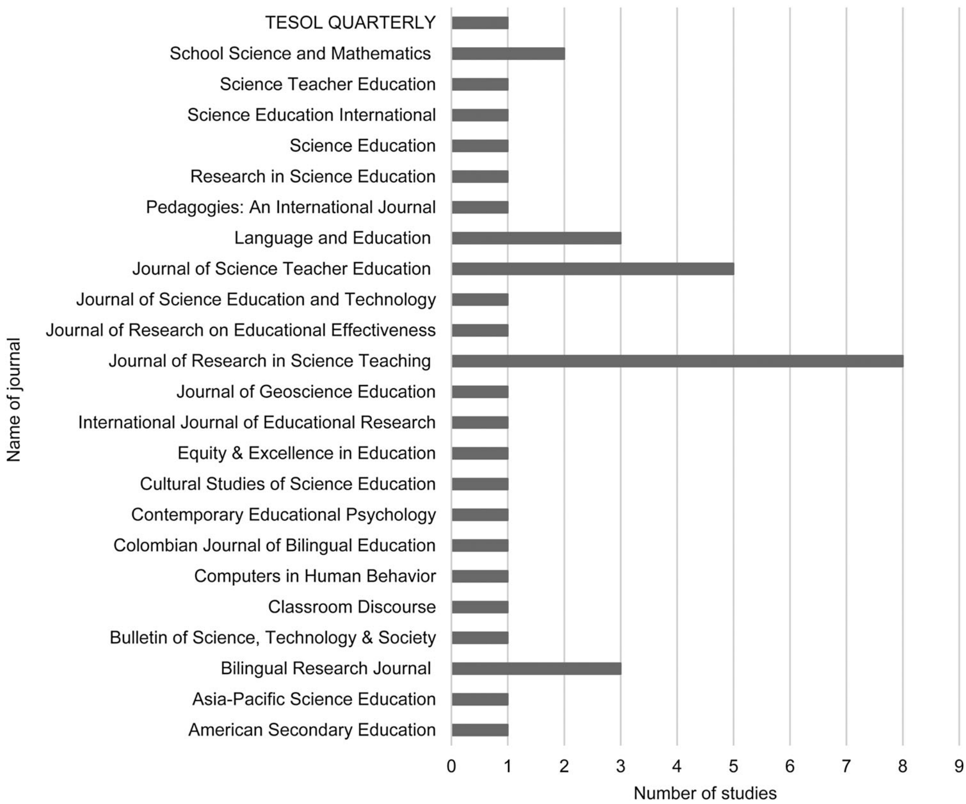

Figure 5. The journals that included the empirical studies found.

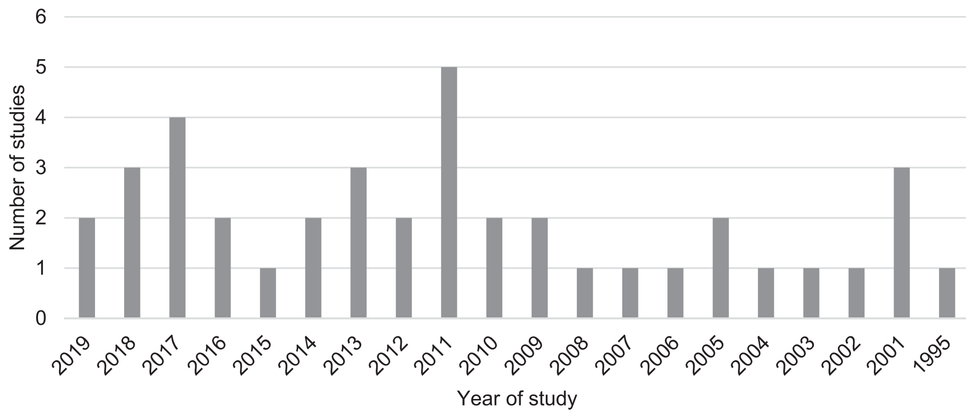

Figure 6. The publication dates of the studies in this review.

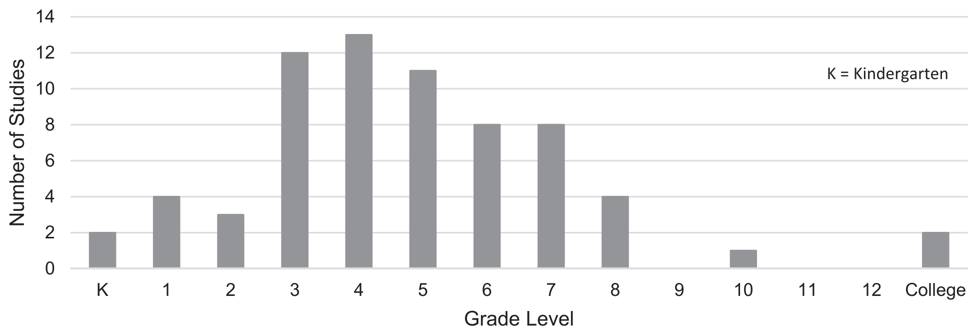

Figure 7. The distribution of grades included in the empirical studies.

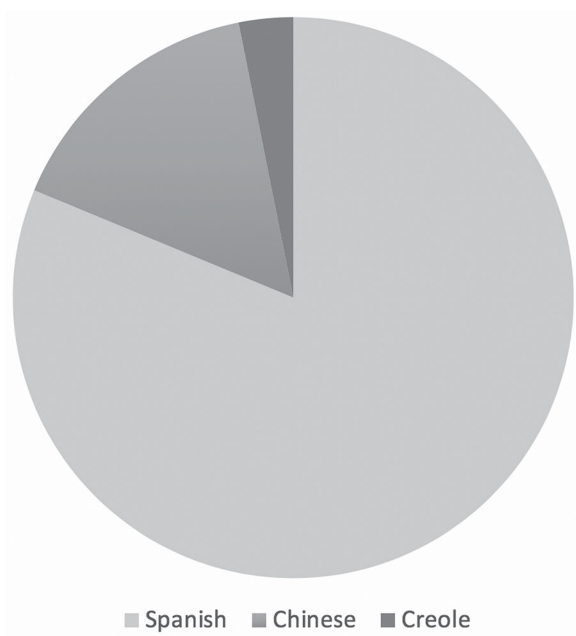

Figure 8. The implied home languages of the language learners in the studies in this review.

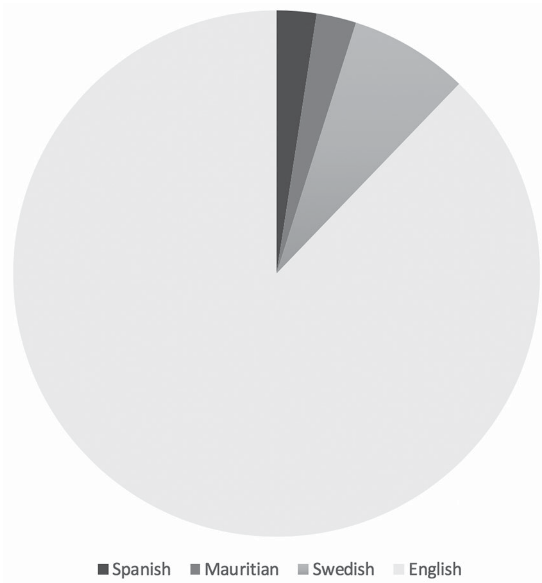

Figure 9. The languages of instruction in the schools within the studies in this review.

General characteristics of the research

Studies came from an eclectic mix of journals (see Figures 5 and 6). The majority of studies included language learners between grades 3 and 7 (Figure 7).

Since most studies (n = 31) were conducted in the United States, the language learners were mostly Hispanics and spoke Spanish, although five studies included students from Haiti who spoke Creole, and one included students from Mexico (see Figure 8). Other studies came from Sweden (n = 3) and one each came from Australia, Hong Kong, Mauritius, Peru and Canada. The majority of research sites across studies were schools that required an English LOI in science (see Figure 9).

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

Limitations

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

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

Figure 10. The different descriptions given to language learners from the studies in this review.

Terminology

There are multiple descriptors for language learners, such as students who learn English as a second language (ESL). Therefore, we reverted to each study's description of language learners, as seen in Figure 10.

Interpretations

Aid science discourse

The first theme focused specifically on the implications of non-linguistic modes for language learners' use of linguistic modes while learning science. Findings showed three distinct patterns (see Figure 11).

Promote the integration of modes and translanguaging

In several studies we inferred that the students' use of communication modes was connected to the type of science experience or space provided. This was probably because in these studies the science experiences and spaces usually included non-linguistic modes, sometimes referred to as 'hands-on activities' (Unsal et al., 2018a). Hands-on experiences enabled participants to make meanings using a tactile mode, by manipulating equipment, and a gestural mode, by pointing out the parts of a model while describing its movement (e.g. Williams et al., 2019). In addition, we found that tactile experiences allowed for translanguaging since students were found using their home language (e.g. Bracey, 2017). Thirteen studies, mostly from grades 3–8, provided evidence for this inference. For example, classroom transcripts in Unsal et al. (2018a) showed that four grade 3 Turkish emergent bilinguals conversed in both Turkish and Swedish when they argued, discussed, explained and generalised during tactile sense-making. In another example, Bracey (2017) discovered college students integrated dynamic and static visualisations with a hybrid of Spanish and English when interpreting the complex phenomenon of galaxy collisions. In a final example, Wu et al. (2019) revealed that grade 8 English language learners (ELLs) (n = 15) increased integration of visual representations, mathematical expressions and manual-technical operations in their science notebooks over time. Final entries showed students were able to demonstrate their understanding of

Table 1. The studies providing evidence for the implications of non-linguistic modes.

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

32		X			X					
33	X	X	X							
34		X	X				X			
35	X			X	X	X			X	
36					X	X		X		
37		X	X	X	X	X	X	X		X
38	X								X	
39	X	X	X	X		X				
40					X					

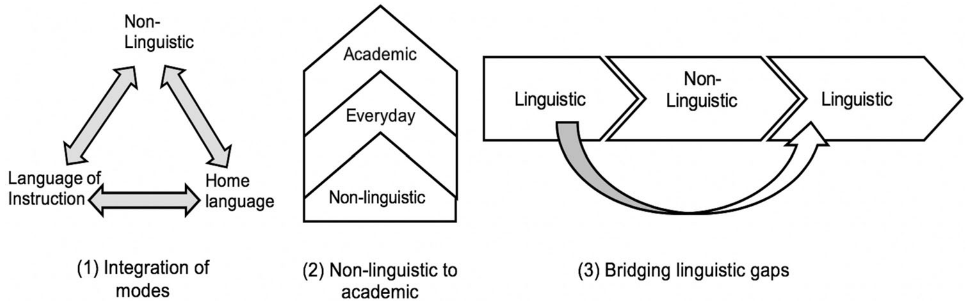

Figure 11. Models showing the processes the language learners used to overcome linguistic restrictions of the langusage of instruction when learning science with non-linguistic modes.

erosion, as they had integrated all modes. This shift also enabled a move from everyday language to academic hybrid language, the subject of the following inference.

Scaffold linguistic meanings

Several studies found non-linguistic modes influenced the use of academic science language (Lee et al., 2008; Robinson, 2005). We included studies where a connection could be made; for example, in one study a teacher reported that while her students built, programmed and tested robots they used words not usually spoken in everyday language, including the names of the materials and the concepts surrounding the Mars landing (Robinson, 2005). In this example we inferred the language developed due to the students participation in the tactile experience. Findings from 13 studies, spanning grades 3–10, revealed that non-linguistic resources had scaffolding properties. In some studies, we inferred a two-step scaffolding process for academic science language. In the first step, findings showed that the use of non-linguistic resources such as visual (e.g. Bracey, 2017) and tactile resources (e.g. Williams et al., 2019) stimulated everyday words. In the second step, participants translated the everyday words into science language. For instance, Jakobson and Axelsson (2017) found multilinguals in Sweden made visual meanings from a connected two-dimensional and thee-dimensional representation of the Earth's rotation around the sun, during which their linguistic meanings evolved from 'move' to 'movement' to 'goes round' (p. 486). Later, the teacher translated the everyday words to the academic word 'rotate'. In other studies, students, as well as teachers, were responsible for translating the everyday words and gestures into academic language (Gibbons, 2003; Unsal et al., 2018b; Williams et al., 2019). This frequently occurred during multimodal discourse in which linguistic gaps were bridged, as is described in the following inference.

Maintain science discourse by bridging linguistic gaps

In many studies, participants used non-linguistic modes (e.g. gestural and tactile) to aid their meanings. The evidence for this came either from concrete examples found in transcripts or from suppositions created from participants' and researchers' descriptions. Several studies revealed that participants drew upon non-linguistic modes to bridge linguistic gaps. A participant could shift from a linguistic to a non-linguistic mode to complete a meaning, or a group of students could shift between modes to co-produce meaning.

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

Accommodate multicultural learning spaces

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

Validate the learner

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

elements (e.g. dirt) transformed in the process. Enquiry settings such as those described appear to provide student interest, which is the subject of our next inference.

Provide the motivation and interest to learn science

For this inference we based our suppositions on findings in studies that made reference to an improvement in student attitude, enjoyment or oral meaning-making. An increase in speech during or following a science experience was interpreted as an increase in student interest. Studies with one or more of these outcomes were included if they attributed the outcomes to the use of non-linguistic modes. For example, if the addition of tactile resources improved learner attitude and increased oral meanings (e.g. Hampton & Rodriguez, 2001) or if the reported lessons, experiments or hands-on tasks increased student enjoyment in science (e.g. Jackson & Ash, 2012). Such outcomes were reported in 16 studies. This relationship was observable in end-of-year teacher questionnaires (e.g. Jackson & Ash, 2012), interview responses (e.g. Zwiep et al., 2011) or statistical results of student engagement (Billings & Mathison, 2012). In other studies, we made inferences from researchers' observations of student behaviour during learning experiences. The evidence includes a study by Zwiep et al. (2011), who delivered a blended science and English language development programme, including contextual hands-on learning experiences, to three Californian elementary schools with large numbers of ELLs. Following the programme launch, the principals and teachers reported an increase in student talk and improvements in attitude. In another study by Jackson and Ash (2012), teacher (n = 24) perspectives from two ethnically diverse Texas public schools were captured during a three-year school-wide intervention. Themes revealed that 22 teachers noted an increase in student enjoyment due to hands-on tasks, while 11 reported that the multi-sensory word-wall (with realia, or real objects, available for exploration) promoted speech in English. Both outcomes were believed to show evidence of student motivation and interest (consecutively) for learning science. It is possible the style of experience promoted student interest. Shared experiences are discussed in the next inference.

Provide shared experiences

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

and difficult to observe in nature (Whittier & Robinson, 2007). A further study showed cosmology visualisations connected a familiar movement with an unfamiliar concept (Bracey, 2017). From these findings, we deduce that shared experiences with tactile materials that help students to reconcile the abstract unobservable or unfamiliar phenomena and science concepts could potentially bridge the cultural divide for language learners.

Afford multicultural science discourse

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

Ensure equitable learning for diverse science communities

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

Enhance science understandings and processes

Many studies in this review attributed learning gains to the use of multiple modes. Evidence for these gains varied, yet the majority were noticeable. For this inference, we included studies that credited the use of non-linguistic modes with student advances in science learning. For instance, Fradd et al. (2001) suggested that drawings, charts, tables, graphs and computer-developed simulations enhanced learning by reducing the language (i.e. linguistic) load for ELLs, thus making it easier for them to participate. In another example, Billings and Mathison (2012), who found a significant interaction effect between group assignment, language status and total score, revealed that ELLs

performed better with hand-held mobile devices. In addition, Ryoo and Bedell (2017) found that dynamic visualisations enabled ELLs to make more frequent connections between visual and textual science information. Altogether 24 studies recorded learning gains which related in part to the use of non-linguistic modes. Several studies also offered suggestions as to why non-linguistic modes used in combination with other modes benefited language learners. Bravo and Cervetti (2014) suggested that multimodal experiences gave ELLs multiple entry points into understanding and processing science. Haneda and Wells (2010) suspected the movement between multiple modes allowed ELLs to process information in smaller chunks and reflect on results and explanations. A final study (Williams et al., 2019) suggested the re-representation of meanings in different modes deepened ELLs' understandings because modes harboured diverse affordances. These affordances ensured details of science concepts accumulated.

Facilitate the nature of science

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

Offer authentic assessment opportunities

Our final inference recognised the potential of non-linguistic modes for teachers of language learners. In the studies in this review, we discovered multiple indicators that showed non-linguistic modes supported the assessment of language learners. This appeared beneficial at overcoming limitations caused if the teacher and students did not share a language. For example, in Zwiep et al. (2011) non-linguistic forms (e.g. graphic organisers, pictures and the manipulation of materials) were added to obtain more details of language learners' understandings after the sentence frames used provided insufficient information. Indicators in other studies revealed that images had been used by teachers to gain a better

understanding of what language learners were describing and thinking (e.g. Martinez-Alvarez, 2017). In five studies we deduced connections between the teaching pedagogy, science experience and assessment. For example, in a study conducted by Hampton and Rodriguez (2001), bilingual practicing teachers delivered a hands-on enquiry curriculum in both English and Spanish. Results suggested that the enquiry-based, hands-on learning allowed the teachers opportunities to observe (or assess) the students during the science investigations throughout the lesson. In contrast, one culminating English discussion appeared to prevent ELLs from communicating. Similar findings emerged in a study by Robinson (2005) that compared three different student groups from grade 8 physics, including ESL, majority ELLs and an afterschool mathematics, engineering and science group. Results showed that the use of a tactile resource, Robolab, enabled assessment transparency for all groups. This was because students consistently measured their knowledge during tasks, revealing their understandings without requiring linguistic modes. The following section will address the research questions.

Summary

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

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

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

Discussion

A large amount of research to support language learners in science education have used linguistic initiatives (e.g. Bravo & Cervetti, 2014; Cervetti et al., 2015; Lo et al., 2018; Rupley & Slough, 2010; Santau et al., 2011; Tong et al., 2014). Following the reconceptualisation of findings from studies through a twenty-first century lens, we demonstrated the diversity of outcomes non-linguistic modes offered to language learners in science. While several outcomes confirmed our hypothesis, others were unanticipated. We attributed the

broad range of outcomes to the inclusion of multiple theories which served to illuminate new perspectives, validate language learners and ensured that the outcomes of numerous non-linguistic modes were contemplated.

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

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

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

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

learners to address the bi/multilingual world. Transdisciplinary research is necessary to expand our understandings further.

Acknowledgements

This paper is part of the first author's Ph.D. dissertation with Curtin University, Australia. We express gratitude to the anonymous reviewers and Dr. Nicola Johnson for their advice.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

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Appendices

Appendix A

The Concepts Used in the Database Searches

Table A1. The concepts used in the database searches.

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

Appendix B

Reference List of Reviewed Studies

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