frontiers in Communication

REVIEW
published: 04 February 2022
doi: 10.3389/fcomm.2022.830613

A Metalanguage for Learning: Rebalancing the Cognitive with the Socio-Material

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Technology has enabled new ways of meaning-making in the digital age, incidentally bringing with it inequities in education as a result of the differing access, resources, and experiences of students. These inequities may be rendered invisible if society and schools neither recognize, value nor set out to include in formal education the meaning-making practices from students' lifeworlds. Such neglect can perpetuate the digital divide among students from diverse home backgrounds. The reform agenda of multiliteracies is to bring about educational justice through a pedagogy of access. In this paper, we discuss how this agenda can be operationalized in the frontline of education—the classroom. We propose a pedagogic metalanguage of transpositional grammar for the learning of multimodal literacy. "Transposition" refers to the process of moving between different forms of meaning (text, image, space, object, body, sound and speech), and changes of attention to their functions (reference, agency, structure, context and interest). In particular, we show the value of having a common shared conceptual framework with which to reflect upon and unpack multimodal meaning in terms of its forms and functions. We also describe how a repertoire of knowledge processes, rebalancing the cognitive and the socio-material, affective and embodied, can support teachers in their design for students' multimodal literacy learning. We argue that attention to multimodal literacy in the curriculum, pedagogy, and assessment can be productively supported with a pedagogic metalanguage of transpositional grammar and discuss how this can be a step towards mediating the invisible inequities in education in the digital age.

Keywords: multiliteracies, literacy, pedagogy, multimodality, metalanguage

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Multimodality of Communication, a section of the journal Frontiers in Communication

Received: *07 December 2021*
Accepted: *10 January 2022*
Published: *04 February 2022*

Citation:
Lim FV, Cope B and Kalantzis M (2022) A Metalanguage for Learning: Rebalancing the Cognitive with the Socio-Material. Front. Commun. 7:830613. doi: 10.3389/fcomm.2022.830613

MULTILITERACIES FOR THE DIGITAL AGE

After the COVID-19 crisis, where the role of digital media in education and society has been highlighted, it is timely to reflect on what this new normal should be as well as recognize the social fault lines that have surfaced and need attention (Adami et al., 2020). The saving grace during the pandemic was the advancement of technology made over the years that enabled much of life to continue despite physical lockdowns and social distancing imposed all over the world. Interactions and transactions for work have also been sustained through technological platforms as work-from-home became the main mode of operation for knowledge economy workers, including teachers. Social communication and play shifted mostly online, with social media activities and digital gaming participation and purchases skyrocketing (Nagata et al., 2020). Schooling took the form of online

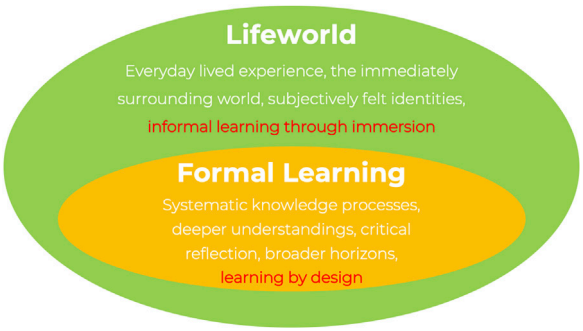

FIGURE 1 | The lifeworld contexts of learning.

learning in many countries (König et al., 2020; Ng 2020). Some might rightly wonder how life would have been if the pandemic had happened just a decade ago when we did not have the quality of digital tools and resources we have today. Those with access to networked digital communications can be grateful for the state-of-the-art technologies we presently enjoy. Indeed, our collective experience during COVID has highlighted a changed perception of technology, from its role as ancillary support to that of an enabler—and during the pandemic, ensuring the continuity of work, play, and learning (Peters et al., 2020).

The incorporation of technology as an integral part of our lives was not a sudden change, but a shift that has been occurring incrementally for some time, only to be accelerated and accentuated by the pandemic. More than 20 years into the 21st century, and almost 40 years after the revolutionary invention of hypertext markup language, the core technology of the World Wide Web, by Tim Berners-Lee in 1989 at CERN in Switzerland, we are now truly in the digital age. The recognition of the fast-changing communication environment is fundamental for educators in considering how best to prepare the young for their future and their active and meaningful social lives. This recognition requires educators to understand and examine the nature of literacy practices, that is the ways of meaning-making that young people are engaged in to ensure the continual relevance of what we are offering in our literacy curriculum. The conviction and courage to reflect on the relevance of and, if necessary, challenge the established philosophies guiding our literacy curriculum, as well as associated in-grained educational practices, will prevent a disconnect between the students' literacy learning in the classroom and what they are experiencing in their lifeworlds (**Figure 1**) (Husserl 1936/1970).

One response to the challenge of connecting the changing dimensions of students' lifeworld experiences with the practices of schooling is a multiliteracies pedagogy proposed by the New London Group (1996). Multiliteracies recognizes the many forms of literacies needed in the digital age, reflecting an "increasing local diversity and global connectedness" (The New London Group 1996, 61). A multiliteracies pedagogy supplements the traditional literacy pedagogy and focuses on modes of meaning-making beyond language. It is focused on meanings in the world in all their inter-related forms, not just language, and their material manifestations, not just their conceptualization. Its analyses seek patterns in these meanings, including the subtle and complex differences that arise in the agency of meaning-makers and their unique contexts. Multiliteracies includes both the diversity of situations and the multiplicity of text forms. The latter we describe as multimodal literacy. Following Jewitt and Kress (2003), we focus on the multimodal meaning-making in multiliteracies learning and use their term "multimodal literacy" (O'Halloran and Lim 2011; van Leeuwen 2017; Mills and Unsworth 2018) to draw attention to the codified set of knowledge and skills as well as a sensitivity to semiotic choices in the interpretation and creation of multimodal artefacts (Lim 2021a).

The agenda for a multiliteracies pedagogy is to engage all our students, not just the privileged few, so they can become "active designers–makers–of social futures" (New London Group 1996, 7). The attention to education justice has been expressed in many of the works on multiliteracies over the last quarter of the century (Unsworth 2001; Macken-Horarik 2009; Zammit 2011; Cope and Kalantzis 2015; Luke 2018; Suwalska 2021). Indeed, the role of the education system as a social leveler and to ensure equitable educational access to social opportunities and resources can also be served when the curriculum requirements, pedagogical practices, and assessment processes value the relevant literacies that reflect the possibilities and practices of the contemporary communicative environment in the digital age. Schools thus must address the new social fault lines caused by differential access and participation using digital technologies and mitigate the inequities resultant from the diverse lifeworld origins of students. For instance, the disparate experiences of students in their access to digital tools, social participation, and the range of literacy practices in their digital learning and play, across different social classes, can be disempowering to marginalized groups. Such inequities can be rendered invisible and the system fails to recognize that the uneven access to multimodal meaning-making can have profound consequences on students' ability to optimize and participate fully in the opportunities that the digital age affords them (Lim et al., 2021a). In this light, educational justice demands that educators recognize the changing landscape of literacy practices in the digital age and include these expanded ways of meaning-making in the curriculum, develop pedagogies for teaching this broader range of literacies by making explicit what is often left tacit, analyzing how they function, and valuing them in assessment practices.

Educational justice is the ultimate impetus for the work in multiliteracies (Cope and Kalantzis in review). In this paper, we present a case for designing for educational justice that begins with an introduction of a pedagogic metalanguage of transposition for teaching and learning multimodal literacy. The purpose of this metalanguage is to find terms to describe the processes of meaning-making that are not limited to language, but capable of describing shared meanings between and across text, image, space, object, body, sound and speech. In this way, the same meanings can be expressed in these different forms (or modes), though never in the same ways. This is why we use the terms "multimodal" or "multiform" to describe meaning-making in the digital age, thereby extending and elaborating on the social functions of such forms. We argue that in order to mediate the

invisible inequities caused by privileging specific or single ways of meaning-making in the education system, we must not ignore the diversity in students' lifeworlds and their immersion in multiform meanings, particularly in the digital age. As a consequence, shifts need to be made in the curriculum, pedagogy, and assessment of traditional language-based literacy learning. We argue that a pedagogic metalanguage of transposition for teaching and learning multimodal literacy can serve the foundational purpose of providing teachers and students a shared vocabulary to describe and discuss the meanings made in multimodal discourse (Lim and Tan 2017) and support students' development of broader semiotic awareness (Towndrow et al., 2013).

A PEDAGOGIC METALANGUAGE OF TRANSPOSITION

A metalanguage is a language to describe and represent language itself (Jaworski et al., 2004). Within multimodality, the term "metalanguage" has been used to describe and represent other meaning-making systems, such as images (Kress and van Leeuwen 2021). In the educational context, a *pedagogic* metalanguage is a type of conceptual language that is appropriated and used in the school context as a resource for teachers and students. In this case, the disciplinary knowledge of multimodality has been appropriated or translated into a pedagogic metalanguage that is teachable and relevant for students. While based on the theoretical foundations of various frameworks in the research domain of multimodality (for example, Kress 2010; Kress and van Leeuwen 2021), a pedagogic metalanguage is centrally concerned with issues of teaching and learning. It needs to be "capable of supporting sophisticated critical analysis" of multimodal meaning-making, yet "not make unrealistic demands on teacher and learner knowledge" as well as "not immediately conjure up teachers' accumulated and often justified antipathies towards formalism" (New London Group 1996, 77). As such, a pedagogic metalanguage needs to be both robust and accessible while at the same time motivating its use in multimodal literacy teaching and learning. In other words, a pedagogic metalanguage needs to be theoretically grounded yet practically useful for the classroom. Even as academics continue to improve the conceptual rigor and seek compelling empirical evidence for each conception behind the theoretical frameworks of multimodality (Bateman 2021), teaching and learning cannot wait for "gold standard" and education research must work with "sufficing standards" (Fullan 1994; Hargreaves and Fink 2000; Hung et al., 2015) of what is presently available to inform the urgent pedagogical changes we need to make to address the literacy demands of the digital age.

Additional education-related considerations in the development of a pedagogic metalanguage for teaching and learning multimodal meaning-making include that it has to be rendered age-appropriate across the primary and secondary years of education. Its design and use should also allow for differentiation across ability profiles of students. The terms and definitions used need to be sufficiently stable to be codified in the curriculum documents and adequately reliable to be tested in assessment. Lim and Tan (2017, 181) discuss the importance of a "translational process" from theoretical frameworks to a pedagogic metalanguage and describe the iterative work with teachers to "judiciously identify the necessary descriptions and choice of descriptors that are aligned to what they are already using to teach similar concepts in English language learning". The translational research (Woolf 2008) in developing a pedagogic metalanguage needs to take account of the range of teachers' abilities, readiness and motivation to engage with new knowledge (Albright and Kramer-Dahl 2009; Teo 2014; Macken-Horarik and Horarik 2019; Lim et al., 2021b). It should also be explicitly aligned with other aspects of the literacy curriculum to show clear connection and coherence across the curriculum.

A pedagogic metalanguage needs to be both structured and flexible in its design. It needs to be sufficiently structured to offer a systematic set of tools for discourse analysis and interpretation. Yet, it needs to be flexible to allow for the meanings that continue to shift with new forms of media over time and account for the influence of co-text and contexts which can expand or constrain the meanings made. The New London Group (1996, 77) has maintained that "Flexibility is critical because the relationship between descriptive and analytical categories and actual events is, by its nature, shifting, provisional, unsure, and relative to the contexts and purposes of analysis". Despite the advancements made in multimodal studies over the decades, this principle continues to hold true as empirical findings continue to challenge the prevailing theoretical conceptions we have for a multimodal grammar (Bateman et al., 2017).

The case for a metalanguage for multimodal meaning-making in the classroom has been thoroughly articulated. For example, Unsworth (2006) explains that a metalanguage allows teachers and students to "describe meaning in various realms" (Cope and Kalantzis 2000, 24). Unsworth (2014, 13) also argues that "teachers and students need this kind of metalanguage for talking about language, images, sound, and so forth, and for their meaning-making interactions". A metalanguage organizes students' viewing around the meaning potential in particular multimodal genres to achieve specific purposes—that is, how the textual features fulfill typical functions.

Serafini (2011), 344 argues that a metalanguage allows students to take a "more critical reading position" and interrogate the meanings which creators expressed through the semiotic choices in their artefacts. Researchers have also reported on the positive results of teaching a metalanguage, or a grammar of multimodality, to primary and secondary school students in Australian schools. They explained that the metalanguage could "structure their noticing, offering a fresh view of choices that may have been taken for granted in diegetic reading" (Macken-Horarik et al., 2017, 255). Indeed, the heartening observation was that "The metalanguage was not only "turning up" in their writing and talking but appeared to re-shape their ways of thinking about images and their contribution to higher orders of meaning in multimodal texts" (Macken-Horarik et al., 2017, 259). A central tenet has been to develop in students "a common

terminology to integrate their analyses in an interpretive response in ways acceptable to English teachers" (Macken-Horarik et al., 2017, 19). In other words, the metalanguage offers students tools for semiotic awareness of how meanings are made multimodally.

While it is useful to have a pedagogic metalanguage coded in curriculum documents to encourage motivated and equitable implementation for all stakeholders, it must be emphasized that the metalanguage is neither a set of rules nor standards of correctness. Rather, it is a resource which offers "a common tongue" to support the discussion, analysis, and interpretation of multimodal discourse. In this light, a pedagogic metalanguage of transposition for multimodal literacy learning should ultimately serve teachers' and students' semiotic work. The key principle should be fit for purpose, where teachers and students exercise agency in choosing the most apt tool in the tool kit for the interpretation and creation of multimodal artefacts. As such, it is imperative that a metalanguage can support the identification of similarities and differences across the features in various discourses and relate them to the purpose, the audience as well as context of situation and culture in which the discourse is inextricably embedded.

To this end, there has been much work in the development of various sets of metalanguage, as resources to support the investigation of specific semiotic relations, systems of meanings, and discourses for multimodal meaning-making. Unsworth (2004), Unsworth (2006) proposed a framework to map the image-text interactions in picture books for multimodal literacy learning, which was later extended to examine animated movies (Unsworth, 2013; 2014). More recently, Unsworth and Mills (2020) and Mills and others (2020) applied the appraisal framework (Martin and White 2005) from Systemic Functional Theory to teach students the systems of attitudinal meanings and emotions in their digital multimodal composing. Also drawing from Systemic Functional Theory and the work on visual grammar (Kress and van Leeuwen (2021), we have proposed a pedagogic metalanguage for films (Liang and Lim 2020), video games (Toh and Lim 2021), and educational apps (Lim and Toh, 2022).

Building on this work and responding to the call for a metalanguage that is sufficiently sophisticated yet flexible enough to support the interpretation and creation of multimodal artefacts (Macken-Horarik 2009; Macken-Horarik and Horarik 2019), Cope and Kalantzis, 2020; Kalantzis and Cope, 2020; Cope and Kalantzis, 2021; 2022) have proposed the development of a "transpositional grammar". Rather than focusing on specific aspects of multimodal meaning-making, or specific genres, a "transpositional grammar" offers theoretical tools that can be translated into the pedagogic context as ways of thinking with and talking about multimodal meaning-making.

A pedagogic metalanguage of transposition reflects the multimodal nature of meaning-making and accounts for the multiplicities in the forms of literacy practices we can engage with in today's digital age (van Leeuwen 2017). This metalanguage is, in a sense, the grammar of multimodality. It is a grammar, not in the traditional formalist and structuralist sense of prescriptive rules insisting on the correct and standard

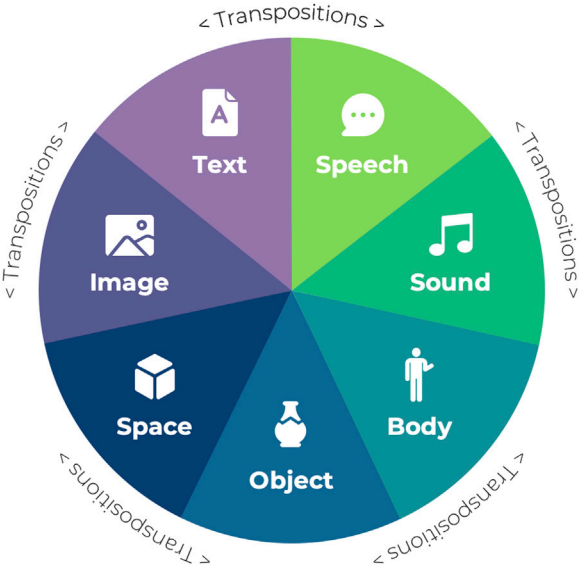

FIGURE 2 | Transpositions between forms of meaning (Cope and Kalantzi, in review).

ways of usage. Rather, it is a grammar in the sense of mapping the patterns in multimodal meaning-making and "a tool kit for working on semiotic activities" with "fuzzy-edged, overlapping concepts" (New London Group 1996, 77). A pedagogic metalanguage of transposition does not assign fixed and context-neutral meanings to forms. Indeed, meanings can never be interpreted independent of context. As such, transposition reflects the shifts in the patterns of meanings—foregrounding the dynamic and fluid nature of multimodal communication, where choices in the semiotic modes are used to instantiate discernible meanings across the time-space continuum in communication (Cope and Kalantzis in review).

The focus on multimodal or multiform meaning presented in a transpositional grammar does not undermine the central role of language in meaning-making. Instead, it recognizes that language is nestled within an ensemble of other semiotic modes (Jewitt 2008) and the orchestration of meanings often involves shifts and movements across these modes. The interaction and interplay of semiotic modes, often described as intersemiosis (Royce, 1998; O'Halloran 2008), result in a multiplication of meanings (Lemke 1998). The intermodal relations, such as image-text relations (Liu and O'Halloran 2009; Unsworth 2001; 2006; 2013), and language-gesture relations (Martinec 2004; Hood 2011; Lim 2021b), and transmediation (Mills 2011; Mills and Brown 2021) have been the topic of study for many scholars working in multimodal studies. Of particular interest is the concept of "transduction" (Kress 2010) and "transmodal transformation" (Newfield 2014) which have been used in multimodal studies to examine shifts or resemiotization (Iedema 2003) in meanings across different modes. Cope and Kalantzis (2020) and Kalantzis and Cope (2020) explain that the notion of transposition is similar in its interest in the reconstitution of meanings. They outline a

metalanguage of transposition in its expression on two dimensions—across meaning forms and across meaning functions. Meaning forms, such as written text, speech, sound, body, object, space, and image, are shaped by the materiality of the media. Meaning functions include the purposes of meaning in relation to what it is about (reference), who is doing it (agency), how it hangs together (structure), when and where it is situated (context), and why it is produced or what it is for (interest).

THINKING AND TALKING ABOUT MULTIMODAL MEANINGS

Forms of Meaning

Cope and Kalantzis (2020) and Kalantzis and Cope (2020) identify seven forms of meaning based on the materiality of their media and the mix of human senses used in their representation and communication. They are written text, speech, sound, body, object, space, and image (**Figure 2**). The first concern of this transpositional grammar lies in the ways in which the material forms allow and constrain the meanings that can be made (Bateman et al., 2017) as well as how they insist in their affordances that certain meaning forms are used (Kress 2010). The second concern is the moveability of meanings from one form to another, and the patterns in the movement. For example, the concept of "love" is expressed as such in written text in the English language and pronounced as /lʌv/in speech, transcribed here using the International Phonetic Alphabet (IPA). While the relations between these forms and meanings may be arbitrary but conventionalized within the discourse community of English language speakers, what may be of greater interest is how the concept of "love" looks like when it is expressed with the body, an image or an object. Can space express love? Perhaps intimacy can be expressed with close proximity. And what are the wonderfully varied ways in which love can be expressed through images with conceptual metaphors? Drawing attention to the transposition in multimodal meaning-making encourages students to develop a rigorous understanding of multimodal literacy as they grow in their semiotic awareness when reflecting on the affordances of each form.

The meanings that can potentially be transposed across material forms are limitless. What may be of greater interest is the question of gains and losses in the movement across forms. For example, Kress (2005) examines the changes in meaning as more scientific representations shift from writing mode to the use of images in secondary school science textbooks over the years. He reflects on how the changes in dominant ways of representation affect the ways in which scientific knowledge is taught and learnt in schools. Similarly, beyond specific concepts to the higher narrative level, a pedagogic metalanguage of multimodality, expressed in terms of transposition, support students in their study of the shifts in meanings when a story, such as *The Fantastic Flying Books of Mr. Morris Lessmore,* is transposed from a picture book to an animated film, and to an interactive educational app (Djonov et al., 2021). The popularity of transmedia narratives (Jenkins 2003) offers rich resources which engage with students' lifeworlds as they reflect on the patterns of meanings that change in each transposition. A transpositional grammar can support the description and discussion of these meaning patterns.

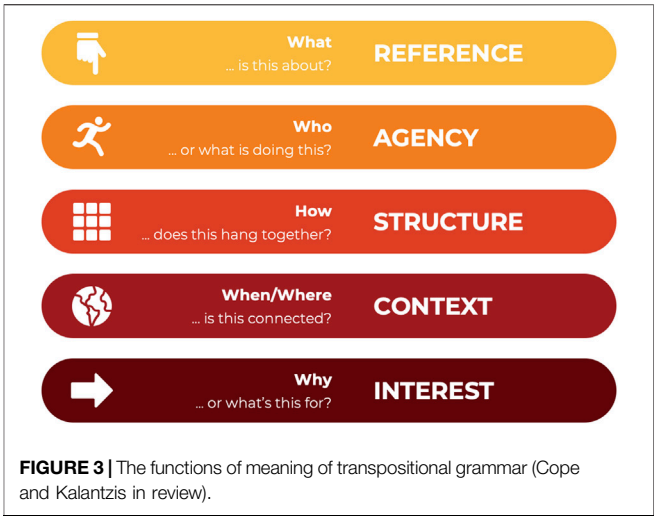

FIGURE 3 | The functions of meaning of transpositional grammar (Cope and Kalantzis in review).

Transpositional grammar is an integrative grammar of multimodal meanings, and not just of a specific genre or the combinational relationships between two or three forms. It offers teachers and students a way to think about how meaning is made and shifted as it is expressed across different forms or modes and discourses and provide them with a common vocabulary to talk about the changes in meaning that occur in each transposition. The focus on the seven forms in this transpositional grammar is a powerful starting point for students to understand and undertake semiotic work. Each of the forms can then be deconstructed into various semiotic modes, that is the "socially shaped and culturally given resources for meaning-making" (Kress 2010, 79). For example, in the written text form, fonts and layout are the semiotic modes where specific selections made are meaningful besides the meaning of the words. Likewise, with the body, gestures and facial expressions are embodied modes of meaning-making (Lim 2021c). Color is a semiotic mode within the image form that can be used to convey both precise denotative and broad connotative meanings (Kress and van Leeuwen 2002; van Leeuwen 2010). While the parsing of the semiotic modes and their meaning potential within each form requires a more sophisticated mapping, which could be gradually introduced, where necessary, in a more detailed curriculum, the pedagogic metalanguage of transposition introduced here focuses on the distinction in material forms and offers a fundamental and interactive approach to learning multimodal literacy.

Functions of Meaning

Complementing the material forms in the pedagogic metalanguage of transposition is the functional dimension. Here, Kalantzis and Cope (2022) propose five functions—reference, agency, structure, context, and interest (**Figure 3**). The development of the five functions and the connection of these terms with concepts from multimodal

FIGURE 4 | Poster from the SG United Website (retrieved from www.sgunited.gov.sg).

studies, including those from a systemic functional theoretical orientation, are discussed in Cope and Kalantzis (2020). Kalantzis and Cope (2020) and Kalantzis and Cope (2022), these five functions are always present in meaning-making regardless of its form or combination of forms. Reference addresses the question of what the discourse is about, or what is represented in the discourse. Agency relates to roles of the meaning-maker as a participant in meaning and the patterns of action in the world to which the meaning refers. Structure is about the coherence of the discourse and how it is organized. Context determines the frames of reference within which the meanings in the discourse can be understood and the scope for interpretation. Interest explains the motivation for meaning-making and alludes to the question of whose interests are served with such representations.

In the classroom setting, teachers can draw attention to the functions of meaning which the discourse serves and guide students to parse these meanings in their analysis and interpretation of the discourse systematically. For example, the pedagogic metalanguage can be used in a discussion of a poster created by SG United, part of the Singapore government effort to support and encourage its citizens during the COVID-19 pandemic. The poster is situated within the SG United website under the Happiness Initiative (https://happinessinitiative.sg/stay-strong-sg/). The form of communication is a digital poster with image and text (**Figure 4**). Of particular interest for discussion could be the semiotic choices made within these two forms, for example, fonts, color, and cartoon emojis.

In terms of Reference, students could discuss what is the message being conveyed in the poster through the use of text and image. In this case, the poster clearly sends an encouragement to the whole nation of Singapore in the form of an imperative text "Stay Strong Singapore". This encouragement is at the same time expressed through the image of a mask-wearing, flag-waving emoji demonstrating its strength by stepping on a coronavirus. In terms of Structure, students may notice that the coherence of the poster is well achieved by the fact that the image and the imperative text help to convey similar meanings of "staying strong". Moreover, the repetition of Singapore as a meaning is multimodally realized by words, by logo and by the national colors of red and white in the poster. In terms of Agency, students might reflect on the use of cartoons to appeal to young people and to bring across the message in a relatable and friendly manner. They might also discuss how the use of bright colors attracts their attention and also note the color contrast of red and white to emphasize the written slogan "Stay Strong Singapore". In terms of Context, students may situate the exhortatory message expressed in the poster in relation to the current pandemic, in particular the stress and psychological toll that the health crisis has imposed on many Singaporeans. Students may also recognize that the message is part of the Government propaganda to foster resilience amongst its people. Crucially, in terms of Interest, students may probe the motivation for the production of such posters in this particular way. They might wish to understand more about the people behind the Happiness Initiative who created the poster and debate on the effectiveness of the poster in communicating the message and in representing the initiative.

In another classroom example from an English Language lesson in a primary school in Singapore, the teacher used the pedagogic metalanguage as a resource to help students explore different ways of representing meanings. After reading a picture book of a story about a conflict between mother and daughter, in the students, in small groups of three to four learn about perspective-taking by role-playing a conflict situation at home and later taking a photo of a freeze-frame from the role-play. Through the role-play, students learn about how the forms of meanings such as speech, sound, object, and space can be used to represent the tension amongst the family members. The transposition of the role-play actions to a freeze-frame image (**Figure 5**) allows the students to discuss and reflect on how a photograph can depict specific meanings by offering one perspective of the conflict situation as well as influence the interpretation of the viewers.

The five functions of meaning can serve as a resource for the students thinking and talking about the meanings they want to express in the role-play of the conflict situation. For example, in terms of Reference, the students decide on the specific issue of conflict to play out, who the participants are, and what they should be doing in relation to Agency. Given that the role-play depicts a certain duration of the conflict, the students would need

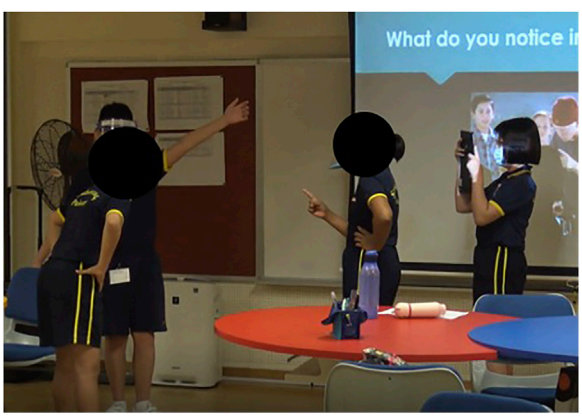

FIGURE 5 | Students' taking a Freeze Frame.

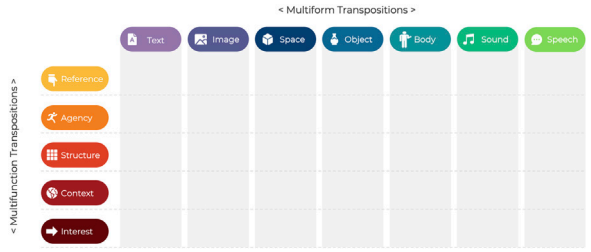

FIGURE 6 | Form meets function in the matrix of transpositional grammar (Cope and Kalantzis in review).

to discuss the Structure and decide how the specific scene works coherently. The Context also offers important consideration for the students to situate the scene they are acting within the broader situation and culture. The students have to make decisions based on the Interest and reflect on the purpose of the role-play as a pedagogic activity, such as being mindful of how the activity can help them appreciate multimodal meaning-making and learn about perspective taking.

As illustrated through a example of artefact analysis and interpretation as well as a representing activity in the classroom, a pedagogic metalanguage of transposition can be useful as a resource to support the thinking and talking about multimodal meaning-making. **Figure 6** below shows how the form and function dimensions of transposition can come together in a matrix to be used as a toolkit for teaching and learning.

PEDAGOGICAL DESIGNS FOR MULTIMODAL LITERACY LEARNING

Refining and elaborating upon the pedagogy of multiliteracies (New London Group 1996), Cope and Kalantzis (2015) outline a repertoire of knowledge processes to guide the learning of multimodal literacy in the classroom. The four knowledge processes are experiencing, conceptualizing, analyzing and applying. **Figure 7** shows how each of these processes is grounded in established pedagogical practices. In drawing from all major traditions of pedagogical practice, the knowledge processes reflect a balanced repertoire of pedagogical moves (Cope and Kalantzis in review) in line with a "principled eclecticism" (Cazden 2006) in literacies pedagogies.

The knowledge processes suggest that teachers design strategic moves between one knowledge process and another, though in no necessary order. For example, a typical learning experience design could have students engage with multimodal resources from their lifeworlds through the knowledge process of experiencing, acquire the pedagogic metalanguage to discuss the discourse though conceptualizing, explore the meanings of the discourse collaboratively through analyzing, and creating multimodal artefacts through applying.

Matthiessen (2019) describes the swings in educational paradigms between teacher-centered learning and student-centered learning. Responding to the dominance of the thesis of teacher-centeredness in the educational paradigm of didactic pedagogy is the swing to the antithesis of student-centeredness of progressive pedagogy. Matthiessen (2019) argues, however, for the value of a synthesis in relationship-centered learning. The repertoire of knowledge processes expresses that synthesis and balance. For example, in conceptualizing, teachers can be didactic in guiding students to notice how meanings are made in multimodal discourse and introducing to them a pedagogic metalanguage of transposition. In analyzing, teachers can also apply an inductive approach to learning, where students explore various multimodal artefacts amongst themselves and elicit the principles of multimodal meaning-making on their own, before the teacher consolidates their understanding. The use of an inductive approach engenders greater engagement and ownership in students as they embark on epistemological work for themselves, and, while more time-consuming, it has been regarded as being more effective for learning (Haight et al., 2008; Qi and Lai 2017). The blend of explicit teaching and inductive teaching is thus an expression of a "reflexive pedagogy" (Cope and Kalantzis 2015). Through a "reflexive pedagogy" of blending both inquiry-based learning and didactic teaching, teachers can design for students' multimodal literacy learning.

Formal education has long been biased towards the cognitive domain of learning, frequently at the expense of what we call the "socio-material domain". This latter domain is closely connected with the materiality of lifeworld experience, as opposed to the cognitive domain which is frequently abstracted away from the everyday in its formal educational practices. The socio-material is intrinsically sociable, contrasted with the cognitive orientation of conventional schooling where knowledge is mostly framed through learning activities and testing, narrowly focused on the capacities for memory and procedural operations of individual, separated brains. Cognition is oriented to objectivity and formalized reasoning, contrasted with experiential lifeworld knowledge which is motivated by emotion, feeling and embodied subjectivity. Of course, the cognitive and the socio-material can never be separated, so we are talking about orientations to learning, where we are

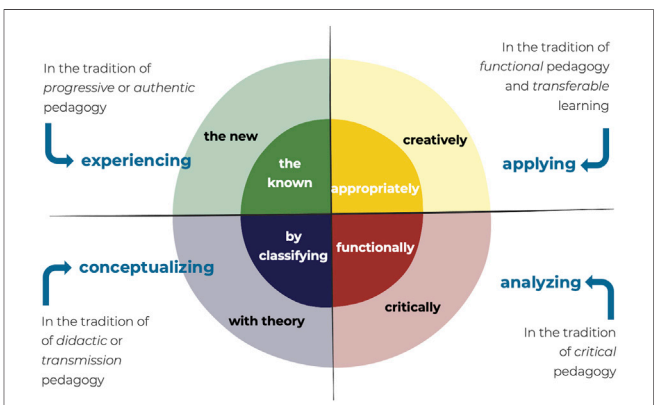

FIGURE 7 | Multiliteracies pedagogy: recruiting and supplementing traditions of educational practice (Cope and Kalantzis in review).

advocating a re-balancing of the two perspectives, socio-material and cognitive. With the engagement of their lifeworlds and the valuing of their emotions and embodied subjectivity, we argue that teachers and students can learn to recognize the influence of the pedagogies of self-reflection and their choices in meaning-making.

Here is a historical aside, symptomatic of the longstanding bias towards the cognitive in education: Benjamin Bloom and colleagues began in 1949 the enormously ambitious task of developing a taxonomy of educational goals in order to assess comparable outcomes across subject domains and educational institutions. The taxonomy they created involved a wide range of leading educational leaders. It has since become the pre-eminent framework for setting high-level educational objectives.

The *Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I, Cognitive Domain,* was presented as an "educational-logical-psychological classification system" (Bloom et al., 1956, 6). Although the complete taxonomy was intended to cover three major domains—cognitive, affective, and psychomotor—by the time of its publication in 1956 the group had only managed to address the first, the cognitive domain. For this, they developed a series of six hierarchically ordered classes (Bloom et al., 1956, 17–20). Running from the lower to the higher order, these were: 1) knowledge, such as facts, terminology and theories; then a series of increasingly complex skills and abilities: 2) comprehension; 3) application; 4) analysis; 5) synthesis and 6) evaluation (Bloom et al., 1956).

The original group never did complete these other parts of their project on the affective and psychomotor. Eventually, in 1964, a research assistant on the original project, David Krathwohl, led a new team to add the affective domain: *Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook II, Affective Domain.* Krathwohl's affective domain was ordered in the form of a hierarchy of internalization, starting with 1) receiving or attention, followed by 2) responding or reacting in a meaningful way, 3) valuing or attributing worth, 4) organizing into a value system, and 5) characterization by a value system or a characteristic lifestyle (Krathwohl. et al., 1964).

None of the original group got around to working on the missing third of the taxonomy, the psychomotor domain, a domain that we would today call "embodiment". However, with a grant from the US government in 1965, a colleague of Krathwohl, Elizabeth Simpson, did (Simpson, 1966). Her *Classification of Educational Objectives, Psychomotor Domain,* adopted the same methodology as the other parts of the taxonomy project: literature review, consultations with leaders in the field, a conference that attracted national experts, and checking the objectives to exemplify them against a range of curricula (Krathwohl et al., 1964).

Today, only the cognitive part of Bloom's taxonomy is used, as if that could serve as a comprehensive set of educational objectives. The revised 2001 edition of the taxonomy is single-mindedly cognitivist as if other major learning domains did not exist (Anderson and Krathwohl 2001). In our terms, the taxonomy is individualistic and mentalistic, without balance of

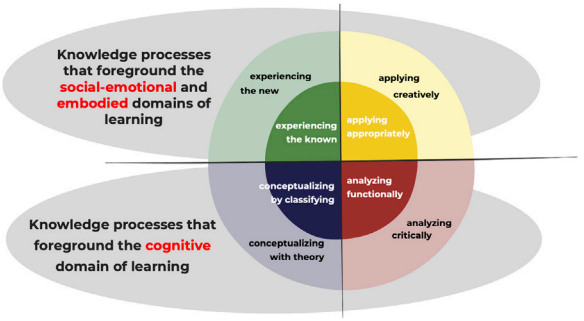

FIGURE 8 | Socio-material and cognitive orientations to learning.

crucial socio-material, embodied, or emotional aspects of learning.

This, we have tried to rectify in the knowledge process pedagogy which moves backwards and forwards between a cognitive and a socio-material orientation. In this pedagogy, the knowledge processes of experiencing and applying are socio-material in their primary orientation, and those of conceptualizing and analysing are more cognitive in their orientation (**Figure 8**). We use the word "orientation" because there can never be socio-material activity without cognition, and never cognition that is disembodied or isolated away from the social. We are speaking here of the foci of pedagogical attention. These always beg refocusing; the cognitive begs refocusing on the socio-material and the socio-material on the cognitive. Pedagogy is thus a matter of moving backwards and forwards across these different kinds of focus. This is another example of the process of transposition, now focused specifically on the processes of learning and teaching.

We have mapped the knowledge process pedagogy onto the full taxonomy by Bloom, Krathwohl and Simpson in the **Supplementary Appendix SA1**.

The knowledge process framework for educational objectives covers the full range of the Bloom et al. taxonomy, recovering crucial socio-material, embodied and emotional aspects that have been long neglected, not only in the taxonomy but education generally. However, there is one important respect in which the knowledge process framework differs from the Bloom taxonomy—these capacities cannot and should not be ordered into a hierarchy. All are important; all are equally challenging for learners. There is no developmental hierarchy and there is no necessary order of delivery. The knowledge processes present a repertoire of pedagogical alternatives. Any good learning activity should have a mix of at least some and potentially all knowledge processes, or at least a justifiable explanation for a certain emphasis on some knowledge processes ahead of others. The art of teaching is the apt orchestration of moves across processes—another transposition in other words.

Table 1 shows a newly elaborated overview of the knowledge processes.

In this way, the knowledge processes perform the role of a pedagogical grammar, calling out different kinds of learning activity. This is not only for teachers—to map the range of

TABLE 1 | Elaboration of knowledge processes.

Knowledge processes	Learning domain	Description	Some marker words
Experiencing > the Known	Socio-material, affective and embodied	Activity: knowledge making that is closely connected with a person's immediate background and familiar lifeworld, expressions of self- and social- awareness and identity. Situated, grounded and personal experience. Prior knowledge and understanding, revisited. Describing personal perspectives and interests. Tracing the roots of subjectivity, the sources of one's opinions beliefs and values. Expressing personal preferences and articulating affect. Self-consciousness based on recognition of the influences of the lifeworld Material Practices: speaking aloud, diarizing and writing self-reflective texts, autobiography, re-enactments, picturing immediately accessible realities via realistic or abstract imagery, storyboards Disciplinary Practices: metacognition, self-awareness, conscious self-reflection, the autobiographical self, self-regulation, making explicit knowledge and understanding that may previously have been tacit, unconscious, or the result of informal learning Social Practices: knowledge and expression of self in relation to social situation, articulating identity shared with others, expressing personal intuitions and feelings, explaining stances, justifying convictions, reflecting on motivations, explaining commitments Emotions: feeling at home, belonging, nostalgia, sentimental, comfortable, identity, happiness/sadness, trust, love, pride, desire, valuing, cherishing, liking, admiring Pedagogy: restating lifeworld experience and knowledge in a formal education setting, self-inquiry and exploration of personal experience and context, authentic and immersion learning, within the zone of current development without necessarily pushing into the zone of proximal development	Background Belief Experience Familiarity Feelings Identity Motivation Opinion Perspective Preferences
Experiencing > the New	Socio-material, affective and embodied	Activity: knowledge making during an encounter with an unfamiliar reality. Immersion in media, information, facts, data, text, a place, images, or a social situation. Noticing the new and remarking the unfamiliar. Inductive reasoning and cautious interpretation Material Practices: watching a video on a novel topic, visiting an unfamiliar place, reading text describing a different part of the social or natural world, viewing images of realities with which one has previously been unacquainted, participating as a newcomer in a social situation. Activities which represent the new situation and assist with its understanding: recording, measuring describing, testing, experimenting, interviewing, surveying Social Practices: intercultural and cross-contextual encounters, setting aside personal opinion Disciplinary Practices: observing empirical realities, objectivity, working with evidence, identifying facts and their sources, piecing together information, examining data, describing experiences Emotions: setting aside self and opinions during new encounters, and/or visceral or corporeal feelings of strangeness, open-ness to the new, willingness to take on board new experience, amazement, surprise, acceptance, struggle to make sense, inquisitiveness, empathy or antipathy, respect Pedagogy: investigatory, exploratory and inquiry learning, moving out into the zone of proximal development, immersion in a zone that is only partially understandable at first	Data Describing Documenting Encountering Experiment Exploration Fact Immersion Information Inquiring Investigation Measuring Observation Recording Testing
Conceptualizing > by Classifying	Cognitive	Activity: knowledge making by classifying things in ways that are more closely specified than vernacular lifeworld meanings. Making fine semantic distinctions. Developing the technical terminology of specialized knowledge systems (e.g. science, history, literary analysis, mathematics). Making distinctions, by identifying differences and similarities with other concepts Material Practices: using concept words, applying icons, and identifying symbolic spaces, totemic objects, or repeatable gestures. Sorting and grouping. Labelling and tagging Social Practices: dialogues of clarification and collaboration in refining distinctions. Reliance on expert definitions Disciplinary Practices: writing definitions, illustration with examples. Categorizing and grouping texts, images, objects, spaces, and gestures, by identifying their defining features Emotions: this is mainly a cognitive process, but secondary satisfaction may arise from the discovery of ideas, the deeper meanings of concepts, sometimes after periods of disorientation and confusion Pedagogy: Vygotsky's notion of concept, didactic teaching introducing concept by providing definitions, constructivist notions of assimilation of new concepts and taking this on board by accommodation	Category Classification Concept Definition Distinction Grouping Idea Labelling Technical term

(Continued on following page)

TABLE 1 | (*Continued*) Elaboration of knowledge processes.

Knowledge processes	Learning domain	Description	Some marker words
Conceptualizing > with Theory	Cognitive	Activity: knowledge making that pulls concepts together into broader and deeper frameworks of meaning. Concepts tied together into relations of connectedness, cause-effect, or contrast-similarity. Generalizing and creating abstractions. Making mental models and developing conceptually coherent interpretive frameworks. Developing propositions from premises and principles. Organizing knowledge into frameworks. Understanding paradigms. Deductive reasoning, drawing inferences, making logical connections, hypothesizing and predicting. Achieving greater depth and breadth of explanatory scope than everyday lifeworld knowledge or informal learning Material Practices: concept mapping, diagramming, creating schemas, modelling, think-alouds, brainstorming ideas Social Practices: collaborative reasoning, understanding and working with socially acquired interpretive and disciplinary frameworks Disciplinary Practices: encounters with theories and theorists, building models Emotions: mainly a cognitive process, but secondary intellectual pleasures—"aha" moments, the pleasures of finding meaning in the connected world, thoughtfulness, awe, astonishment at deeper and broader meanings. Appreciation of elegance, parsimony, profundity Pedagogy: schema theory in cognitive psychology	Deduction Framework Generalization Hypothesis Logic Model Paradigm Prediction Principle Proposition Reason Schema Theory
Analyzing > Functionally	Cognitive	Activity: knowledge making that focuses on the workings of the social and natural worlds. Examining how phenomena are organized. Deconstructing parts, analysing relations, finding internal consistencies, explaining workings, tracing cause and effect, understanding functions. Practical reasoning, creating functional explanations, operationalizing procedures. Looking for repeated patterns, practices, behaviours, conventions or styles. Examining rules and laws Material Practices: logic models, plans, 3D simulations, models, walk-throughs, written outlines, oral explanations Social Practices: think-aloud about workings, brainstorming functional analysis Disciplinary Practices: deconstruction, functional analysis, explanation Emotions: mainly a cognitive process, secondarily the aesthetics of patterned order Pedagogy: functional, pragmatic	Analysis Connections Convention Deconstruction Explanation Function Law Operation Organization Pattern Rule Working
Analyzing > Critically	Cognitive	Activity: knowledge making that interrogates explicit or underlying interests, intent and purposes. Reflection on points of view, perspectives, values and agendas. Analysing conscious or unconscious impacts of knowledge and action, their proximate and collateral effects and consequences, and the contextual validity of assertions. Evaluating alternative perspectives, claims against counter-claims, and propositions against their potential rebuttal. Interrogating facts for the validity of their sources or things that have been neglected or overlooked. Uncovering doubtful empirical untruths and ignorance of fact or accepted theory. Exposing logical fallacies. Looking for inconsistencies in argument and practice. Critically reviewing ethical stances Material Practices: seeking supporting evidence, tracing sources, reframing and re-interpreting claims, imagining and portraying alternative worlds, reality checks Social Practices: dialogue around alternative perspectives, argument, rebuttals of arguments, questioning, exploring implications Disciplinary Practices: critique, contrasting paradigms, statements of limitations in evidence and perspective Emotions: primarily a cognitive process, by secondarily, senses of agreement/disagreement, affinity/aversion, pleasure/anger, approval/disgust, approval/disapproval, pleased/dismay, satisfaction/disturbed, liking/disliking Pedagogy: critical	Claim Counter-claim Criticism Critique Disagreement Disapproval Doubt Ethics Fallacy Ignorance Ignorance Interest Limitation Misunderstanding Neglect Overlooking Perspective Purpose Intent Rebuttal Refutation Untruth

(Continued on following page)

TABLE 1 | (*Continued*) Elaboration of knowledge processes.

Knowledge processes	Learning domain	Description	Some marker words
Applying > Appropriately	Socio-material, affective and embodied	Activity: knowledge applied in a predictable or typical way and appropriate for a context. Replication of a procedure to produce an expected effect or answer. A habituated response, validated with a reality check. Transfer of learning into a practical context where the situation is similar to available examples. Turning plans into practice, following steps in "how to" instructions Material Practices: applying intellectual and media conventions real-world or simulated context in ways similar to available examples and models. A re-enactment of conventional patterns of meaning-making with minimal transformation. Implementing with fidelity clearly articulated plans instructions. Design processes where the redesigned is more or less as expected. Proof-of-concept Social Practices: mimesis, re-enactment, demonstration, repetition, replication Disciplinary Practices: implementation processes, evaluation of outcomes against plans, verification and confirmation of results against expectations Emotions: fit, belonging to a community of practice, satisfaction in task achievement Pedagogy: functional, pragmatic, transferable, competency-oriented learning	Application Competence Confirmation Confirmation Demonstration Fidelity Implementation Mimesis Practice Proof Repetition Replication Solution Transfer Transfer Verification
Applying > Creatively	Socio-material, affective and embodied	Activity: knowledge making that is inventive, innovative, risky. Novel applications of concepts or practices to immediate contexts, or successful transfer to unexpected contexts. Applicability measured by contextual cogency, relevance, and effectiveness. Internal coherence as an expression of a worldview or realization of a change agenda. Design that is transformative Material Practices: hybrid and inventive combinations of different media Social Practices: collaborative action, change agency, politics Emotions: intrinsic motivation, imagination, optimism, the edginess of risk, hope, excitement, eagerness, confidence, a sense of responsibility for outcomes Disciplinary Practices: interdisciplinarity Pedagogy: a design orientation, creativity	Change Creativity Hybridity Imagination Innovation Interdisciplinarity Inventiveness Originality Risk Transformation Vision

learning activities they are planning for their curriculum, suggesting perhaps that they adopt a wider repertoire of activity types. This pedagogical metalanguage can also be translated into explicit, age-appropriate markers for learners. In classroom interventions documented in a number of research projects, teachers have applied learner-friendly versions of these knowledge processes (Neville 2010; Arvanitis and Vitsilaki 2015; Cope and Kalantzis 2015; van Haren 2015; Zapata 2018).

Following are several examples of the knowledge process pedagogy at work. **Experiencing the known** involves students sharing the artefacts from their lifeworlds in the classroom. A common way to do this is to invite students to bring artefacts or tell stories from their daily lives as rich resources for discussion. For instance, in a lesson on understanding how persuasion works in multimodal texts, the teacher could have students take a photo or save an image of an interesting advertisement which they have come across and have them discuss with their peers how semiotic choices were made in the advertisement to appeal to them.

Experiencing the new, the teacher creates for learners an encounter that engages the socio-material domain of learning. The focus here is to encourage students to respond to the multimodal artefacts. It could be an intuitive response, such as seeing a burger depicted in the print makes me feel hungry and want to buy the food or a banal response that the discourse bores me. It could also be more sophisticated such as the film makes me feel nostalgia with a sense of poignancy, loss, and disquiet at the urban changes happening in my once familiar neighborhood as a result of gentrification.

Moving between the knowledge processes of **analyzing functionally** and **conceptualizing by classifying** and **conceptualizing with theory,** the teacher draws on the knowledge of the transpositional grammar described earlier. The focus here is on having students identify and offer textual evidence in support of the thoughts and feelings they have towards the artefact. Students operate within the cognitive domain and perform a close reading of the discourse to identify the specific semiotic choices that lead to their preliminary thoughts. Their analysis and interpretation of the artefact enable them to surface textual evidence to explain their response. For example, younger students in primary schools could identify the villain's facial features and expression to explain why they were positioned to feel antipathy towards him. Older students in secondary schools could identify the use of minor keys in the musical score of a video to generate suspense.

Analyzing critically entails activities often highly prized as critical thinking and reading in schools. Here, students are encouraged to evaluate critically the composition both in terms of how successfully it has been created and whether the

embedded values have been appropriately and effectively conveyed in the work. In other words, students adopt a critical inquiry stance in their engagement with the discourse and question the ideas represented in the artefact. Even as they recognize the discourse offers a single perspective which it advocates, they are encouraged to consider other possible perspectives that are absent, suppressed, or ignored. For example, primary school students could explore alternative endings of a fairytale or experiment with what might have happened if the gender roles were reversed. Secondary school students could identify sexism present in a discourse where women's bodies are being commodified.

Applying appropriately is important in reinforcing the inextricable connection between the viewing and representing of multimodal artefacts (Lim et al., 2021a). Beyond responding, understanding and interpreting multimodal discourse, students must be given opportunities to create multimodal artefacts. Studies have highlighted the value of multimodal composing (e.g., Nelson 2008; Anderson 2017; Thibault and Curwood 2018; Smith et al., 2021) in students' learning of multimodal literacy as well as in other aspects such as empathy (Jiang and Gao 2020).

Pushing at times in the direction of innovative or hybrid expressions of meaning, **applying creatively** offers students wider opportunities to be active and agentive designers of meaning. Such creative work could also be done in groups where students engage in collaborative meaning-making and negotiation of meanings with one another. For example, primary school students could be guided in the creation of a deck of presentation slides for their show-and-tell. Secondary school students could be given a theme with choices in topics for them to explore bending genre conventions in their multimodal composing as an expression of their creativity. In this aspect of multimodal representation, digital technology offers powerful tools such as sophisticated images or video editing and production tools, which were once available to professionals only, but are now mediated by simple interfaces and freely accessible to students in many countries.

Mediating Invisible Inequities in the Digital Age

In relation to the outcomes of schools, Cope and Kalantzis (in review) describe "epistemic capital" as the capacity to meld the ideal of conscious meaning with the materials of its media. Following Bourdieu, (1986) theory of cultural capital, epistemic capital reflects the knowledge and skills from learning, enabling students to act effectively, share meanings with others and to interpret, value, and work with the differences in others. Importantly, epistemic capital is not just cognitive; it is also socio-material, including the practical, embodied activities of meaning-making, with their affective or socio-emotional underpinnings and effects.

In this paper, we have described a pedagogic metalanguage of transposition to account for the processes of multimodal or multiform meaning-making, as well as a grammar of learning itself in the theory and practice of multiliteracies pedagogy and its taxonomy of knowledge processes. The idea of a pedagogic metalanguage has been applied to inform the design of learning all over the world (Purcell-Gates 2007; Hilton et al., 2010; Pahl and Roswell 2012). In Singapore, for example, some of the concepts discussed in this paper has been used to guide the design of lesson packages on multiliteracies for primary and secondary school students in a design-based research project to develop pedagogies for multiliteracies (Lim and Tan-Chia, 2018).

We argue that incorporating multimodal literacy in the curriculum, offering teachers and students a metalanguage as a resource for all students to engage in multimodal meaning-making, and supporting teachers to design the learning experiences based on knowledge processes that rebalances both the socio-material and the cognitive, will contribute to educational justice. Multiliteracies is the meaning-making essence of this epistemic capital and its pedagogy of access. Education is the pathway to epistemic capital and educational justice holds us accountable towards a more equitable distribution of resources, not just financial, but also attentional, in our schools today. Educational justice begins by valuing the diversity in students' lifeworlds and recognizing the need to provide opportunities in schools that both legitimize and harness the new ways of meaning-making that young people are engaged with in the digital age. More crucially, a program of educational justice sets out to provide every child, regardless of their background, the tools and resources for thinking and talking about meaning-making to support their interpretation and creation of multimodal artefacts. In this paper, we have proposed that a pedagogic metalanguage of transposition can serve as a step towards this endeavor. Having a codified set of knowledge and skills to develop multimodal literacy in students provides a common set of resources that can inform the development of curriculum requirements and explicate learning outcomes in concrete terms. More importantly, as discussed in this paper, a pedagogic metalanguage of transposition can offer a framework for teachers in the design for students' multimodal literacy learning. For example, the repertoire of knowledge processes can guide teachers in their pedagogical practice. A pedagogic metalanguage of transposition can also be appropriated as a set of criteria in the design of assessment for multimodal literacy. Teachers' concerns over what to assess and how to measure the multimodal literacy of students can now be addressed by what is the knowledge and skills that have been introduced to the students.

While language will remain fundamental in the literacy classroom, the incorporation of multimodal literacy contributes to educational justice to ensure that the literacies needed for young people to participate agentively and fully in the digital age are not ignored in formal learning. Schools are powerful in shaping the future society through privileging a particular configuration of knowledge and skills to be learnt in the curriculum, determining the emphases and ways these knowledge and skills are to be learnt, and shaping the agenda of what is ultimately to be valued in the assessment.

The multiliteracies agenda has highlighted the centrality of multimodal meaning-making both as a reflection of the students' present lifeworlds and a necessity as part of their future work competencies (New London Group 1996; Cope and Kalantzis 2000; The). Neglecting the learning of multimodal literacy in schools is to do injustice to students. While some students, because of their socio-economic backgrounds, access to resources, and richer experiences, may be more ready to engage in multimodal meaning-making, there are students who will appreciate the opportunities that school can provide in lieu of the distance between their home experience and the characteristic epistemologies of schooling.

Given the diversity of students, some may require further support and guidance from their teachers in the development of multimodal literacy. Attention to multimodal literacy paves the way toward educational justice in making explicit to some students what may be intuitive and tacit for others. The pedagogic metalanguage of transposition levels the playing field by offering a common shared set of vocabulary, with concepts, as tools for students to think and talk about multimodal meaning-making explicitly with teachers and amongst themselves. Demystifying multimodal meaning-making challenges the flawed assumption that multimodal interpretation and creation belongs to those naturally gifted with the intelligence and sensitivity to perceive nuances in meaning. As such, we posit that the teaching of multimodal literacy in schools will mediate the invisible inequities that may incidentally accompany the digital age. Such recognition, supported by proactive intervention, will contribute to the project of educational justice advanced by the advocates of multiliteracies.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

This study was funded by Singapore Ministry of Education (MOE) under the Education Research Funding Programme (DEV 01/18 VL) and administered by National Institute of Education (NIE), Nanyang Technological University, Singapore. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Singapore MOE and NIE. This research has received clearance from the NTU-Institutional Review Board (IRB-2019-2-038).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2022.830613/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.