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Embodied, dramatizing performances in science class: multimodal spaces and places of knowledge and identity construction

Maria Varelas^{id}^a, Amanda R. Diaz^b, Rebecca Kotler^a, Rebecca Woodard^a, Ronan Rock^a, Zachary Sabitt^c, Nathan Phillips^{id}^a, Rachelle Tsachor^d, Marcie Gutierrez^e, Hannah Natividad^e, Derek Threewitt^e and Jaegen Ellison^d

^aDepartment of Curriculum and Instruction, University of Illinois Chicago, Chicago, IL, USA; ^bDepartment of Literacy and Reading Education, University of California, Fullerton, USA; ^cSchool of the Art Institute of Chicago, Chicago, IL, USA; ^dSchool of Theatre and Music, University of Illinois Chicago, Chicago, IL, USA; ^eChicago Public Schools, Chicago, IL, USA

ABSTRACT

We explored the semiotic choices children in grades 1–6 made that nurtured embodied, dramatizing performances in science classes at urban public schools, serving predominantly students of color in a large US city. We studied how such choices in school and home settings (when instruction was remote during the COVID-19 pandemic) were implicated in the children's knowledge and identity construction and related to available resources and positionings. Multimodality and social semiotics, social practice theory, and positioning theory were the three theoretical anchors that guided the study, along with sociocultural and sociopolitical framings of science education. The study took place in the context of the multi-year collaboration STAGE (Science Theatre for Advancing Generative Engagement) among teachers and university educators designing and studying pedagogies of embodiment as part of students' engagement in school science. The ethnographic design of the larger research allowed us to engage over a school year with each class. The focus of this study is on classes of three teachers, who collaborated with a teaching artist, using data from video-recordings, fieldnotes, and conversations with students and teachers. The findings point to the generative nature of embodiments in terms of both the knowledge and identities that the children were constructing and the factors that shaped that generativity. These include (a) the resources available, (b) the children's own particular interests and sources of excitement, and (c) the simultaneous use of multiple semiotic tools that offer different affordances for meaning making. The findings affirm that multimodal embodied performances children design and create in school spaces (classrooms and settings for larger school gatherings, like auditoria) and at home provide opportunities to unsettle expected axiological, ontological, and epistemological norms that often dominate science teaching. The power of dramatizing and of performing arts is facilitating the development of connections, solidarity, and feelings among peoples and materials.

KEYWORDS

Science theatre; dramatizing; materials; meanings; positionings

Science education research has been expanding to interrogate what counts as science, who does science, and who is positioned as a science person, along with how science education in schools maintains or transforms dominant paradigms that have often functioned to exclude particular social groups from participating in science. 'Western philosophical tradition', prevalent in the practices of science and science education, 'has been somatophobic, not only asserting a separation and hierarchy between soul and body but, as feminist theorists have argued, using masculine-feminine difference to produce that distinction and mark its relation of power' (Threadcraft 2016, 208). This somatophobia and the mind/body division have profoundly shaped science and science education as domains (Barbour 2004) and have been implicated in the distancing, alienation, and exclusion of those with less power. Engaging children's whole bodies in science learning can transform science education, especially for those from historically minoritized and marginalized communities, where the body is often under surveillance in and out of schools (Varelas et al. 2022). Activating the whole body and its movement in space affords students' opportunities to bring their full humanity (physical, cognitive, and emotional selves) to exploring science in social worlds and in relation to each other as they make use of embodied, arts-based ways of understanding and impacting the world (Chappell and Varelas 2020; Kolovou and Kim 2020; Kotler et al. 2024; Solomon et al. 2022). Embodying science embraces the feminist perspective that embodiment is political (Threadcraft 2016).

Embodied ways of learning in science settings have included a variety of conceptualizations, from dramatizing (Brandscombe 2019; Braund 2015; Dorion 2009; Ødegaard 2003; Varelas et al. 2010, 2022) to interacting and manipulating physical objects (Convertini and Arcidiacono 2021; Tang et al. 2022) to multimodal thinking that involves gestures, facial expressions, and body orientations, positions, and movement (Goldin-Meadow 2005; Heller 2021; Pozzer-Ardenghi and Roth 2007). Embodiment as dramatizing and role playing, informed by the performing arts and specifically drama and theatre, involves learners taking on characters from the science world or the socio-science world and pretending to be entities that they study, explore, understand, and communicate about. This is the kind of embodiment that we are concerned with in this study.

Ødegaard (2003) noted that three dimensions in which science learning is strengthened when students engage in 'dramatic science' concepts, nature of science and science-society interactions. Varelas et al. (2010) showed how metaxis (being in the real and pretend world at the same time that actors are afforded) offered students in elementary school classrooms opportunities to dig deeper into science concepts, intertwining thinking with emotions. Brandscombe (2019), focusing on tableaux – a process drama tool comprised multiple bodies together creating a still frame as if they are being captured in the midst of an action, demonstrated how such embodiment strengthened understanding of science concepts both for those in the tableau and those in the audience. More recently, Varelas et al. (2022) highlighted how small- and large-scale dramatic performances by elementary and middle school students provided opportunities for collective meaning making of science and socio-science ideas and expansion of science identities.

This learning that has been documented when young people engage in dramatization of ideas related to science, which we consider as always and inextricably embedded in social contexts, has mostly taken place in schools, where particular norms of conduct apply, and particular types of resources are available. However, during the COVID-19

pandemic, as many of the physical spaces of schools in the US remained closed, schooling happened via platforms like Google Classroom, where young people and teachers, in their homes or other spaces with internet access, came together in new and uncharted ways to ‘do school’, explore ideas, develop skills, understand phenomena, and engage in various disciplinary domains, such as science. In learning spaces different from classrooms, where students were not physically together and some norms of school behavior were not imposed, ways of being and acting were shaped – for many children – by home norms (including fewer restrictions on space and movement), and by everyday activities and resources available in home spaces.

Scholars have documented that young people in the US with ethnoracial, cultural, and linguistic identities historically minoritized and marginalized have been labeled as deficient in various ways – in terms of their households and resources in them, and in terms of their wealth of ideas and knowledges – despite the plethora of funds of knowledge they, their families, communities, cultures, and languages hold (Delgado Bernal 2002; Ladson-Billings 2000; Yosso 2005). Aiming to provide counter-narratives to such racist master narratives and positionings, and considering as a given the generativity that dramatizing affords, we focused this empirical study on the factors that enable such generativity when working and learning with children in first through sixth grades attending urban public schools that serve predominantly students of color in a large US city before *and* during the COVID-19 pandemic. As part of a school–university partnership, the children’s teachers facilitated their dramatizing of science ideas, phenomena, and processes, where they engaged in dialogic meaning- and sense-making through role-playing science concepts or people engaged with socio-science ideas. In this way, they engaged in science (expansively defined to include socio-science ideas) through body movement accompanied by other communicative modes (e.g. speech, images, sound, written language, gaze, gestures). Thus, we explored the children’s semiotic choices in their various embodied performances (dramatic enactments of shorter or longer durations, such as dramatizing in groups how rock types are formed or creating a science play for the whole school) in school buildings and at home, and how these choices were related to available resources and positionings within the social practice in which these performances took place.

Theoretical framing

As necessitated by the research goal of this study, multimodality and social semiotics that underpin it, social practice theory, and positioning theory were the three theoretical anchors that guided the study, along with sociocultural and sociopolitical framings of science education. Below, we present our weaving of the constructs that we used from these three theoretical perspectives as pillars to guide our exploration of the cross section of science and theatre that can unfold in schools and at home as part of efforts to transcend various borders including those between everyday culture and the culture of science (Jegede and Aikenhead 1999), and nurture cultural weavings of school and life (Cazden 2006).

Multimodality & social semiotics

'The simultaneous use of diverse semiotic resources ... is pervasive in the organization of endogenous human action' (Streeck, Goodwin, and LeBaron 2011, 4), and, thus, multimodal moves are an important unit of analysis of social action, interaction, and transaction (Enfield 2011). Various semiotic resources and the communicative modes they compose have different epistemological affordances, and coupled with the inherent 'multiness' of human perception and expression – what Cope and Kalantzis (2009a) called synaesthesia, the 'overlay of sensory-cognitive modes' (p. 363) – provide different potential for meaning making. When people engage with representational systems, they do not just reproduce the meaning potentials of the signs in these systems, but they imbue them with their meanings. As meaning makers, they make and remake signs and their meanings while guided by the familiar, patterned resources of the representational systems they use (Cope and Kalantzis 2009b). In this way, the familiar is used to imagine the unfamiliar, creating connections among ideas. As people, learners of all ages, conceptualize through multiple modes, they may engage with ideas functionally, focusing on reasoning, or critically, focusing on evaluating how relationships of power exist and manifest in particular perspectives (Fairclough 1992; Kalantzis and Cope 2005). Different semiotic resources and representational systems or modes offer different opportunities for engaging with ideas functionally and/or critically, which is why dramatizing, an ensemble of multiple modes, is considered so rich in meaning making potential in educational settings.

Social practice

As people interact with each other to develop and communicate understandings within a social practice, including a teaching-learning context, three elements are important to focus on and track shifts in – materials, competencies, and meanings (Shove, Pantzar, and Watson 2012). Materials include tools, objects, or infrastructures; competencies include both knowledge and skills that may be both tacit and explicit to various degrees; meanings include social conventions, norms, expectations, and other socially shared understandings. In social practice theory, the focus is on the practice as a collective enterprise rather than on individuals and their performances at specific times. It is the collective actions, then, that create the histories and trajectories of social practices. As Giddens (1984) noted, in social practices, which 'exhibit "structural properties", structure exists, as time – space presence, only in its instantiations in such practices and as memory traces orienting the conduct of knowledgeable human agents' (p. 17). Social practices are located in space and time and as individuals act within systems of social practices, they also bring in their past experiences of reality and ways of being, seeing, and acting, and their bodies and habits shape their engagement. Thus, both structure and agency and their dialectical relationship are important to consider as we engage in and study social practice (Varelas, Settlage, and Mensah 2015). Moreover, modern conceptions of social practice theory, based on Latour, emphasize non-human materiality – objects and things. The material world 'necessarily participate[s] in social practices just as human beings do. These things are "interpreted" by the human agents in

certain ways, but at the same time they are applied, used, and must be handled within their materiality' (Reckwitz 2002, 208). Thus, materials are not only elements or resources of structures but also 'active agents and participants in practice' (Reckwitz 2002, 196).

Positioning

In social practices, as people use and create signs to construct and communicate ideas in multimodal discourse acts, they continuously position themselves and are positioned by others. Thus, positioning theory (Davies and Harré 1990) constructs, as intertwined in composing identities-in-practice (Holland et al. 1998), offer insights with which to understand how the meanings of self and others and the meanings of ideas explored are constructed in social practice. People's positioning (self and others') is shaped by norms, expectations, rights, and duties, which in turn are shaped by and shape social forces within particular storylines that govern the social practice (McVee et al. 2021). As Warren and Moghaddam (2018) noted, 'social reality is the product of negotiations between storylines' (p. 321), which are 'constantly challenged, negotiated, and transformed in social interactions' (p. 319). In any multimodal discourse act, the storyline that is constructed in the moment links the present with both the past and the future (Slocum and van Langenhove 2003) and, thus, becomes the evolving narrative where reproduction and/or transformation of norms, expectations, rights, and duties reside. In science classes where the social practice is grounded on respecting and honoring students' ways of being in the world, considering their brilliance and wisdom as a given, centering their bodies along with their minds, their hearts, and the materials that surround them in the process of meaning making, and protecting their rights to meaningful learning, storylines of engaging in science will be constructed differently than in classes where power tends to reside in the teacher and the disciplinary domain of western science. In the original positioning theory, identities, although essential elements, are not explicitly noted in the positioning triangle – actions/acts, positions, and storylines (Davies and Harré 1990) but subsumed in positions. However, the positioning diamond (Slocum-Bradley 2009), as an expansion of the triangle, made identities visible entities and in interaction with storylines, social forces, and rights and duties. Thus, positioning theory provides us with a frame to attend to the construct of identity and identity construction within a social practice. Defining identities from a sociological viewpoint as 'meanings one has as a group member, as a role-holder, or as a person' (Stets and Burke 2003, 132) and 'internalized positional designation[s]' (Stryker 1980, 60) fits with the overall framing of this study.

Methods

Design & participants

The research question that we focused on in this study is: How did the semiotic choices elementary school children made in science classes while engaging in multimodal, embodied, dramatizing performances in school and home settings relate to available resources and positionings within the social practice in which these performances took place?

The study took place in the context of a multi-year collaboration (project STAGE – Science Theatre for Advancing Generative Engagement) among urban-public-school teachers and university educators designing and studying pedagogies of embodiment as part of students’ engagement in school science. The teachers all taught at the public district of one of the largest cities in the United States – see more details in Varelas et al. (2022). The focus of this ethnographic study is on classes of three teachers and co-authors (Gutierrez, Ms. G; Threewitt, Mr. T; and Natividad, Ms. N) who taught at two different schools in the district and collaborated with a teaching artist and co-author (Ellison, Mr. E). The specific classes and years chosen, which will be presented in more detail below, were selected so that we explore young peoples’ semiotic choices and enactments in embodied performances in a range of instructional settings and modalities by students of a range of ages and ethnoracial, linguistic, and cultural backgrounds, engaging in a range of embodied performances and including various types of material artefacts to construct and represent a range of science ideas. The ethnographic design of the research allowed us to engage with each class over a school year, being immersed in the teaching and learning unfolding in each class from different perspectives (i.e. that of the teacher collaborator who was orchestrating teaching throughout the year, of the teaching artist who collaborated with and supported two of the teachers in the year of the study and of the university-based educators who were participant observers and supporters of the school-based educators and their students).

Ms. G’s combined 1st/2nd grade class and Mr. T’s combined 4th/5th grade class were in the same school, a predominantly African American neighborhood school that also served some Latinx students, and where both teachers have taught for many years. Ms. G, who self-identifies as a Mexican American woman and had been part of the project since its inception, collaborated with the teaching artist Mr. E, who self-identifies as a Black man, during the in-person year of this study. Mr. T, who self-identifies as a White male teacher and whose first year with the project was during the pandemic, got his introduction to embodiment in science over a week-long workshop offered remotely and led by project members, including Ms. G and other collaborators. The ideas resonated with him as he later shared: ‘Wow! How come I haven’t been getting my kids to embody these topics?’ Like Ms. G, Mr. T also collaborated with the teaching artist Mr. E, who visited classrooms roughly once per week per class co-leading embodied science lessons with the teacher that they had planned jointly. Data for this study come from Ms. G’s in-person class and Mr. T’s remote class. Ms. G’s in-person embodiments often happened on the classroom rug, which was transformed into a place of movement and performance as the class was studying states of matter, earth materials and their properties focusing on rocks, and plant life cycles, using the FOSS (Full Option Science System) school curriculum as a guide. During online school sessions with students at home during the pandemic, Mr. T created performance spaces for the students over Google Meet sessions, collectively by gallery view where every class member was on one screen square, and individually by pinning the camera of a student performing to draw attention, as the class was studying food webs, photosynthesis, fossil fuels, renewable energy, and the rock cycle.

The third focal classroom is that of co-author Natividad (Ms. N) who taught three 6th grade science classes (totaling about 90 students each year) for several years at a fine and performing arts cluster school with about half of the student population being Latinx and

a quarter Asian, and more than half of the students being bilingual. Ms. N who self-identifies as a Southeastern Asian Filipina and has a background in theatre and dance along with science had been part of the project since its inception. The focus of this study for Ms. N's class is on what was becoming a school tradition – an annual 6th-grade science play. During the in-person year of the study, the curricular focus that students brought to their science play was pollution (air, water, and land), a science topic that they were exploring in their science class, informed by the environmental-justice perspective that Ms. N had been emphasizing. As they were studying science ideas, the students in each class constructed and shared group embodiments, with and without narration, to capture some ideas and develop them further. Then, for several weeks, each of Ms. N's science classes was responsible to script and stage acts of their science play, which could include lyrical adaptations to popular songs, dances, embodiments, and narration. The students in each class formed committees based on their interests and excitement to participate in either script writing, acting, music and sound effects, visual images, lighting, or costume/prop-making for their roughly 45-minute science play which they entitled *Pollution and Its Impact on Communities*. They performed this play several times on one day for their whole-school community including families. On the following day, they brought the play to the university's theatre where other project members' elementary and middle school classes were their audience.

Data sources and analysis

The data for this study came from (a) video-recorded embodied performances that took place in school classrooms, the school auditorium, or the children's own homes when they were engaged in remote instruction due to the pandemic, (b) fieldnotes of university-based educators/researchers, and (c) conversations with the teacher collaborators. For each of the three teachers, the number of video-recorded lessons varied. For Ms. G, there were 57, for Mr. T, 39, and for Ms. N, 74.

To analyze the data, first, we watched all the video-recorded lessons, along with reading the fieldnotes on these lessons, and notes on other lessons that the teacher collaborators have shared with the university-based collaborators. For each class, we then created a 'storyline' capturing (a) science ideas and how they were developed, (b) students and how they were engaged and contributing to this development, (c) positionings that were created during this process, and (d) representational systems employed and ways in which their semiotic resources were put in action. Afterwards, each storyline guided the selection of a subset of lessons in each class for which we conducted further analyses. Five lessons per year were selected from each class to offer us a range of science ideas, forms of enactment, instructional activity genres, and forms of generative science learning across the year. For these lessons, we used multimodal critical discourse analysis (Fairclough 1992, 1995; Kress and van Leeuwen 2001) to explore how students engaged with ideas and with people (peers and teachers, including the teaching artist when present) and movement analysis based on the Laban-Bartenieff Movement System, LBMS (Fernandes 2014; Studd and Cox 2019), to explore how the ways in which students' movements in space and time, and in relation to others, communicated science understandings and involved other materials and representational systems. As presented in Varelas et al. (2022), the four LBMS dimensions of movement we focused on are: Body

(what is moving); Effort (how it moves and the dynamic qualities of the movement); Space (where it moves in the physical environment); and Shape (why and how it moves in relation to body parts, others, and the environment). The goal of both analytical techniques was to examine the ways in which features of the students' embodiments were made possible due to the physical spaces in which they were performed and how these performances became both spaces of exploration and places for belonging for actors and audience. This micro-analysis was then overlaid with teaching artists' notes on the lessons they had participated in, notes on conversations among university-based collaborators and the teaching artists, and other project meeting notes taken during meetings with all collaborators and various subsets of them to derive themes.

Findings

The study findings point to three factors that shaped the generative nature of dramatizing embodiments that the students planned and performed in terms of both the knowledge and identities that they were constructing. These include: (a) the resources available; (b) the children's own particular interests and sources of excitement; and (c) the simultaneous use of multiple semiotic tools that offer different affordances for meaning making. The children's generative engagement during the embodiments included opportunities to explore ideas by experiencing them in imaginative ways. It also provided opportunities to advance their thinking while exploring movements with partners, and opportunities for audiences to explore ideas as they watched and discussed their peers' multimodal embodied performances. While they were exploring, the children chose, alone or with partners, to engage in what felt good and made sense to them.

We elaborate on the factors that afforded the generativity, creativity, and vibrancy of the children's engagement in embodied performances by focusing on the three classrooms noted in the Methods section and on specific moments that illuminate the meanings of our findings. In each of the following three vignettes, we focus primarily on one factor, while simultaneously showing how all factors are intertwined and shape each other. The presentation of the findings as narratives of the children's engagement in dramatizing is intentional and aligns with the focus we stated in the introduction, namely to contribute to the anthology of counter-narratives resisting still dominant narratives and ideologies about science learning of students of color in the US (Solarzano and Yosso, 2002).

Vignette 1: Flor's enactments on food chains & energy resources during remote instruction

During remote instruction, Flor, a young Latina in Mr. T's class, was always committed to embodied learning and performances in multiple ways that allowed her to deeply engage in meaning making. Often Flor relied on materials in her home, including objects, drawings, and other living organisms (i.e. her dog) to engage in idea exploration and functional reasoning in ways that the materials were active agents (Reckwitz 2002).

During a unit on food chains, Mr. T starts the class with a review of what students have learned about the topic. Flor uses this opportunity to engage with the relationship

between food chains and food webs, as well as what distinguishes them from one another (i.e. a food chain is a direct relationship and a food web is composed of multiple chains). As she talks, she uses her hands to represent different organisms involved in a food chain or web, such as using a hand to represent one organism and the other to represent its predator. Mr. T then directs students to a wondering they had the day before, when they contemplated the possibility of a wolf eating an eagle. Mr. T asks students to consider what they know about eagles and what they know about wolves, continuing to privilege their knowledges consistent with this science class's storyline of engaging with science. A student notes that eagles can fly, but wolves cannot. In response, Mr. T asks students to consider 'how would that look? If a wolf was going to eat an eagle, and a wolf can't fly, how would that look?' Another student answers that a wolf cannot catch an eagle because it cannot fly. Flor is quick to respond that it is possible, 'when the eagle goes down [to the ground] and they find some mice and they eat it, the wolf is going to wait until the eagle doesn't see and then is going to try and pounce on it and eat it'. While the discussion on a wolf eating an eagle gets suspended for a few moments and while the class starts talking about a hawk catching and eating a bat, Flor is moving around in her house, crying out as a hawk (Figure 1, panel 1). To one particularly loud call, the teaching artist Mr. E, who is present, responds, 'it sounds like somebody caught one' positioning Flor's act as an important one within the embodiment-nurturing science class. Flor responds, puts a marker in her mouth and leans into the camera to show her catch (Figure 1, panel 2), saying 'I caught a bat'. She then takes the marker out of her mouth, holds it up, says 'look at the bat' and then returns it to her mouth with a giggle, mimicking chewing on it. The marker was needed for Flor to be the hawk that she was, which was eating a bat, and it led the development of meaning of what it means that one animal captures and eats another. The familiar 'animal', her human body and its actions relative to food intake became the site of Flor's functional reasoning.

As the class returned to the idea of a wolf hunting an eagle, Mr. T asks that each student takes a moment to practice, and Flor and another classmate volunteer to go first. Flor is selected to share her enactment first, further recognizing her engagement and her commitment to embodiment as a way to make sense and communicate science to her peers. She places her camera on the floor and holds up a small stuffed dog. She notes that the dog is the eagle she is trying to catch, and she places it on the floor in front of the camera with its head facing the camera. She moves behind it on her hands and knees (Figure 2, panel 1) and narrates 'right now [the eagle] is eating a rat'. Then, Flor, crouching low, crawls up behind the dog/eagle sign as she narrates 'I'm sneaking, closely. He doesn't

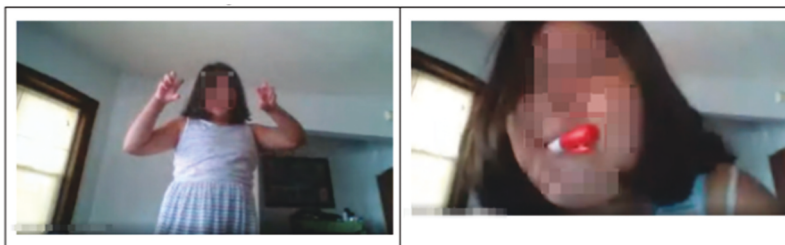


Figure 1. Flor enacts a hawk catching a bat.



Figure 2. Flor is a wolf hunting an eagle.

know’ (Figure 2, panel 2). Once she is right behind her prey, she lets out a primal shriek and pounces (Figure 2, panel 3). She momentarily wrestles the prey in her mouth while grunting, she then lifts her head towards the camera, and we see the dog/eagle securely in her mouth (Figure 2, panel 4). Flor then drops the dog/eagle saying ‘Don’t look at me eating my food’ and ends her scene. The dog, like the marker, became both structural elements of the scene Flor was constructing but also active agents of Flor’s meaning making.

On another day, as part of a unit on energy resources, the class focused on the formation and extraction of fossil fuels. Mr. T reviews with students what they have discussed fossil fuels. Flor shares that ‘fossil fuels [are] made out of dead animals and plants’. She also shares a drawing she created of the process and reasons that ‘plants, they die and the pressure from the water goes on top to create oil, then we turn it into gas and that gas goes into our car’. Then, Mr. E works with the children to assign various roles for the fossil fuel enactment (i.e. pressure, coal miners/diggers, oil field pumpers, coal, oil) and supports them while figuring out how to represent each role through movement. Throughout this planning, Flor is actively participating in offering ideas and her own understanding and volunteers to act out all of them, stating that she wants ‘to do all of them [the roles] in one body’. Ultimately, she settles representing pressure, along with another classmate.

However, once the enactment starts, Flor deviates from the plan and acts out her own one-person show, while her classmates work together in the virtual space around her. With her microphone muted, Flor moves at her own pace to enact the entire process of creating fossil fuels, using the chat box to narrate her enactment. First, she lifts her arms

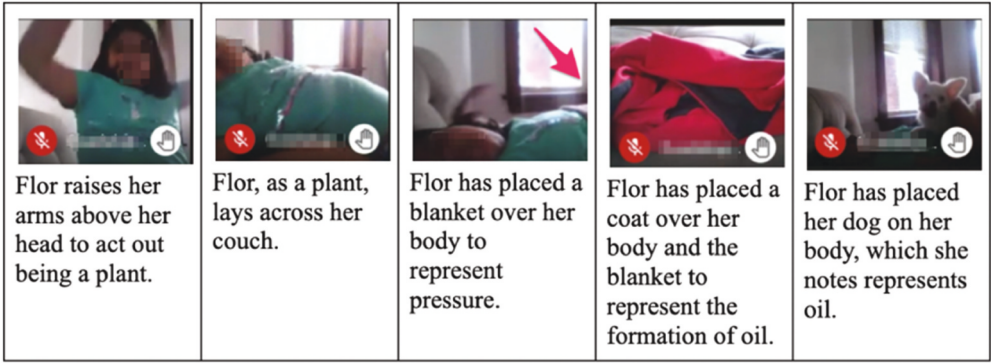


Figure 3. Flor’s first fossil fuel enactment.

above her head (Figure 3, panel 1), and writes in the chat 'i am the plant'. She then lays on across her couch as the 'organic material' spreading flat at the bottom (Figure 3, panel 2). Next, Flor lays a pink blanket over her body (Figure 3, panel 3). In the chat, she writes 'my pink thing is pressure'. She then adds a red coat over her body (Figure 3, panel 4), writing in the chat 'red is oil'. Her class continues with their enactment, and Flor adds '1,000,000 years later' to the chat before grabbing her alive house pet dog. She lays down on her couch and places her dog on top of her body and lays still (Figure 3, panel 5). She then returns to the chat to write 'dog is oil to [sic]'. For Flor, the couch where she lays horizontally, the blanket, the coat, and her pet dog are all agents in her meaning making around the idea that both plants and animals contribute to the creation of fossil fuels, which involves pressure and compacting of organic matter over time and deep inside the earth.

Once the class enactment comes to an end, Mr. E leads students in a debriefing session. New roles are assigned, but Flor interjects that she 'wants to be pressure again'. She is encouraged to take on a new role and asks to be a 'digger'. Flor picks up her house pet dog and holds him in the air in front of her face, gently moving him back and forth as if she has just discovered him (Figure 4). She then brings the dog to her lap and points him towards the camera. Mr. T asks her to 'please put the dog down'. Flor complies, but then immediately adds to the classroom chat 'the dog was the bones i found'. For Mr. T, her pet dog was first seen as a distraction and something that should not be attended to during class time, but for Flor, her living house pet dog did not need care at that time or was offering her an opportunity to cuddle or play, but was rather a semiotic agent of meaning making of the science ideas she was exploring and constructing.

The class begins the enactment for a second time. Flor, who is a digger, immediately begins acting out her role as she mimics shovelling and picking away at coal (Figure 5). She also writes in the chat 'i am mining coal'. After this run through, Mr. E leads the children in a debrief of the enactment. Students talk about how their bodies felt during the enactment and Flor writes in the chat 'ow my arm hurts owwww'. As they continue to debrief Flor explains that during the enactment she 'got a pick ax [sic] and I was using my hand as a shovel and every time I was digging I was mining til I found coal and ... [I]

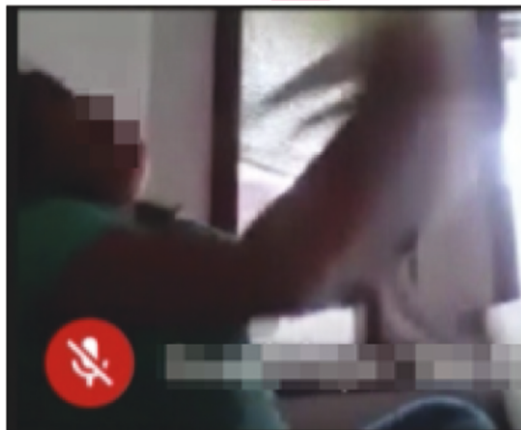


Figure 4. Flor discovers bones represented by her dog that she lifts up.



Figure 5. Flor is a digger.

grabbed it with my hand and put it in the cart'. Although, Flor was not physically experiencing the movement of a real shovel filled with material, the intensity of her mimicking with her arms the act of shoveling gave her the grounding for the discomfort/pain involved in extracting coal.

Vignette 2: Diane & Elena's classroom enactment of rock types

Midyear in Ms. G's classroom the children were exploring rocks, and the various rock types – igneous, sedimentary, and metamorphic – creating enactments independently and as a whole class. In one class period, students were placed in pairs, and were tasked with choosing a rock type, planning an enactment that represents how the rock type is formed and its features, and sharing it with the class. Students were given time in class to plan before they present their enactments. Two girls, Diane who is Black, and Elena who is Latina, helped us see how students' desire to incorporate a particular move (which for this pair was rising from the floor into a backbend) shaped the students' enactments and their thinking on which types of rocks to enact and how.

After the students are paired up, they move with their partners throughout the classroom to begin planning. Diane and Elena move to the other side of the room where they are away from their teacher and peers. When a university-based researcher, who is observing and recording the lesson, approaches the girls, Diane is in a backbend, and Elena is squatting next to her. The researcher asks the children which rock they have selected, and they answer that they have not decided yet. What seemed to be salient in their minds at that moment was incorporating a backbend – a move was driving their enactment. The researcher then asks if the girls plan to use the backbend in their enactment, and Diane explains, 'We wanted to do a backbend rock because some rocks are in that', which indicates that the students may have had in their minds images of rocks of that shape and that may have led them to consider the backbend as a potentially useful and relevant semiotic resource.

The girls continue discussing which rock type they will enact for the class. When the researcher checks back with the girls approximately five minutes later, they have decided to enact what Diane calls 'a metamorphic' rock, which she describes as the rock where 'layers are getting on top of the rock' as she moves her arms across the front of her body to gesture layering. Although it is sedimentary rocks that have layers, at this time Diane calls them metamorphic and Elena does not react to that, as Diane seems to be a more dominant discourse member. Diane and Elena then demonstrate for the researcher what

they have come up with for their enactment. Diane crouches into the fetal position, with the front of her body facing the floor. Elena gets on her hands and knees with her body curving over Diane's, so their bodies form the shape of a 3D X. Elena then instructs Diane to 'try and get up'. Diane tries to push herself up but Elena's body resists Diane's force. Diane explains that the rock layers 'make it heavier'. The girls then tell the researcher their original enactments were different and show the researcher by both moving their bodies into backbend positions. Diane explains that they had to change their enactment, so they could embody a 'metamorphic' rock. The girls adapted their original semiotic choices to capture a particular type of rock they ended up choosing to represent.

Ms. G then calls students to the carpet where they form a circle. Pairs of students take turns performing their enactments in the middle of the circle, while their peers watch. Ms. G and Mr. E who are present during that lesson pose questions for both the performers and the audience about embodiments and what they convey about various rock types. When it is their turn, Diane and Elena tell Ms. G they have two enactments to share as they move to the center of the circle. They start showing the first one by laying on the floor side-by-side (Figure 6, panel 1). Each girl slowly moves their legs from a resting position into a bend with their feet flat on the floor (Figure 6, panel 2). They then take their arms from next to their bodies to bent positions above their heads with palms touching the ground (Figure 6, panel 3). The girls then raise their bodies into the air and move into backbend positions (Figure 6, panel 4). These double backbends, which were the original movements they had told the researcher that they had to adapt, are now one of the enactments they show the class. This enactment draws a reaction from Casey, another student and a Black girl, who comments 'Oooh backbend!' Casey nods and provides an affirming 'okay!' that communicates her admiration and envy for such a move as she crouches down closer to observe the enactment (Figure 6, panel 5). The girls move out of the position and sit in the center of the circle. As their classmates have to guess which rock they just enacted, they ask the performers what the backbend represents. Diane explains they were an igneous rock, and the backbend is 'for when you come up'. Ms. G elaborates on Diane's 'come up': 'For when the igneous rock comes out of the crust of the earth?' The girls nod their heads and Diane gives an 'mm-hh'. Although during practice it felt like they had abandoned that enactment for its adaptation, the girls had managed to make sense of a move they wanted to do, a backbend, in relation to the science formation of an igneous rock. The desired move was driving the meaning making and storylines of girls who can do backbends and who can do science.

The girls then perform their second enactment, the one they showed the researcher as the one they had chosen to do. Now Elena is in the fetal position on the ground, and Diane bends her body over Elena's, so they overlay, and Elena pushes up against Diane (Figure 7). Another student guesses that they are a metamorphic rock, but whereas Diane



Figure 6. Diane and Elena enact the formation of an igneous rock.



Figure 7. Diane and Elena enact the layering in a sedimentary rock.

nods in agreement, Elena shakes her head indicating disagreement. Mr. E asks Diane what she represents and she responds, 'I was layers'. When Mr. E follows Diane's answer with, 'Is that metamorphic?' Diane changes and quickly answers 'no' sensing that Mr. E is asking her probably because her original answer was wrong, while she has also seen Elena disagreeing with her. Ms. G continues the conversation asking the class which rock type has layers to which the class chorally responds with 'sedimentary'. Diane and Elena take a bow and leave the carpet. The sharing of Diane and Elena's enactment of sedimentary rocks showed not only how an originally desired move came to be transformed offering opportunities to both performers and audience to engage with functional thinking, but it also offered Elena an opportunity to position herself as someone who had power to shape the meaning making for her partner and her peers.

Vignette 3: Ms. N's class performs a scene on air pollution in their science play

One of Ms. N's in-person classes created an act for the science play that focused on air pollution. This class decided to write the script as a series of questions and answers between time-travelers and scientists about various pollutants, including smog, tropospheric ozone, and VOCs. For this vignette, we focus on the final production of this scene. The lights come up on two time-travelers from the future who had just 'arrived' in the 1990s to learn about air pollution from a team of EPA scientists in lab coats holding clipboards, echoing a prevalent storyline of what scientists wear and do. While the questions and answers are verbalized, students taking on roles of toxic chemicals fill the theatre space. Holding cardboard signs with 'Nitrogen Oxide' and 'VOCs' painted on them, they embody the toxic compounds by moving, swaying, and circling around the actor holding a large representation of the sun made of cardboard and painted in bright yellow and orange (Figure 8). As the scientists explain to the time-travelers that 'ozone is produced in the atmosphere when pollutants from cars and industries are exposed to sunlight', vehicles that the prop committee created by cutting out large pieces of available cardboard in the shape of cars are carried out to the stage and move amongst the



Figure 8. Toxins invade the air.

swirling toxins. There is simultaneous use of several multimodal representations that theatre affords – ominous music and lighting, flowing movements of toxic pollutants, troubling projected images one after the other of cityscapes encapsulated with smokestacks and smog, lab coat costumes worn by the scientists, colorful props for pollutants, and a science-rich narrative. All these representations created meaning potential that any one or two modes alone could not. On stage multiple ideas across time, space, and scale unfolded at once, offering opportunities for performers and audience to explore the sense of mayhem that humans are creating on the earth as well as experience the intensity and emotionality of these ideas.

The children's interest in, and excitement for, the different modes and resources simultaneously employed was particularly evident in what came next in the act. One of the time travelers asks 'how do these pollutants impact our health?' to which an EPA scientist responds 'Let me show you. Let's go to the microscopic level'. At this very moment, a sound effect, referred to in the script as the 'Shrink Sound Effect', is played as children raising large cut-outs of a set of human lungs start to enter the stage and take their positions, each on a chair on the stage framed with spotlighting, making the set of pink lungs (with detailed blood vessels painted on each) appear even more prominently (Figure 9a).

After the shrink sound, the music is changed (indicated in the script as the 'Inside the Lungs' track), signaling to the audience the scale change from the macro- to the meso-level, and its echoey, synthesized effect sounds like the inside of something cavernous, making it especially fitting for taking a view from inside the body. The children then represent the micro-scale of the 'toxic chemicals' that 'break through your lungs protective barriers . . . penetrat[ing] those defenses lodging toxic compounds even deeper' while on the projector screen a human face in profile is shown where toxins enter through the nose, passing into the lungs. Two actors playing toxins floating in the air, wearing signs that read 'Particulate Matter', now enact infiltrating the lungs by making crawling and creeping motions with their fingers coming out from behind each lung (Figure 9b). The various material resources the children decided to use, the signs, the lungs, the gloved

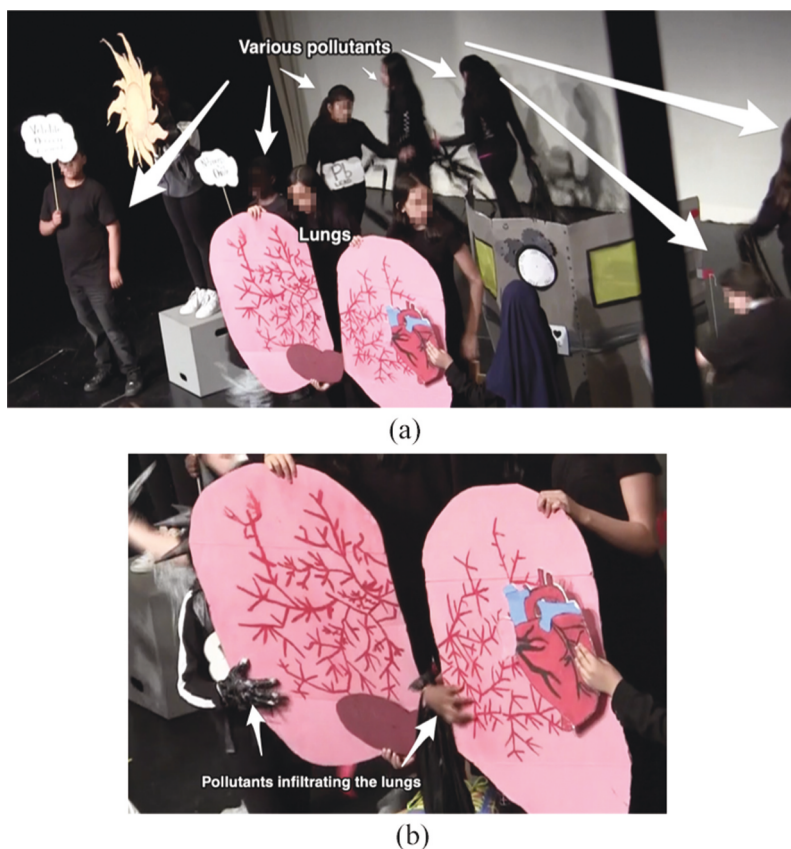


Figure 9. (a) Pollutants surround a pair of lungs. (b) Pollutants infiltrate the lungs.

hands creeping, the lab coats the narrators wore, the projected images, and the music that was playing, all worked together, creating meaning potentials that could not be possible without the available resources being used to create layers of meanings within different scales. Such layering of meanings and scales, which the theatre space and resources afford, let performers and audience imagine connections among ideas in ways difficult to achieve in written and oral text that is inherently sequential.

At this point, a narrator shares that the toxins 'weave clots that can be deadly blockers of blood flow to your heart or brain ... even causing a stroke', as an actor playing the blood clot, jumps in front of the giant lungs making a blocking gesture with his arms spread across the set of lungs, and a beep-beep-beep sound effect is played continuously. The children's ingenuity came alive with the double meaning of this sound. The writers indicated in the script to play the BEEP track after the line 'even causing a stroke' and to 'let music play for a few seconds', while the lungs are carried off the stage. The beep sound indicated the stroke that the toxins caused at the micro level, but it also served as an alarm going off at the nearby EPA headquarters at the macro level.

One of the scientists then explains to the time-travelers that the sound means that 'the nitrogen oxide levels have gone up', and, reacting to the dangerous levels, the scientists

form a line and turn away from the audience. All is still and silent when one of the scientists asks the others 'are you ready?' The silence on stage feels ominous and a sense of anticipation is building in the quiet stillness. Kayla goes on to say 'Hit it!' as the whole line turns toward the audience wearing sunglasses. In this moment, a steady and familiar beat begins, and the EPA scientists become singers of a lyrical adaptation they wrote about air pollution to the tune of the top chart song in that year, 'Old Town Road' by Little Nas-X. Thus, the beep sound shifted the action to the meso-level where a group of people need to take action after the alarm at an institutional macro structure was sounded indicating a dangerous level of a chemical.

The scientists sing their adaptation, while the instrumental track is played. Performers move upstage while holding toxin signs adorned with blue and grey plastic strips swayed up and down to represent air pollution. Cardboard cut-outs of vehicles simultaneously move back and forth across the stage. With the lyrics projected on the screen, the scientists, led by Kayla's cue, weave together a storyline of scientists who know the science that leads them to be concerned about people's health with a storyline of pop artists who share an emotional plea with the audience, singing about the gruesome correlation of air pollution and lung cancer:

I got the gases in the back
Lung cancer attached
Phlegm is matte black
Got the lungs that's black to match

They then declare that they have 'woken up' now and no one can change their minds about the situation that they are describing:

Breathing all this air
You can't change my mind
I been in the coma
I haven't woken up until now

Here, being in a state 'coma' could have two meaning potentials, denoting both the serious consequences to health that 'breathing all this [polluted] air' causes *and* the state of people's (and their own) knowledge and understanding so far regarding the impact of air pollution. The children now uncovered the truth about air pollution, and they won't continue to accept anything else but the truth. Thus, for their next verse, they kept the original lyrics of the song:

Can't nobody tell me nothin'
You can't tell me nothin'

There is no turning back to accepting lies and excuses now that they had gained critical knowledge about the polluted air that people inhale and that is wreaking havoc on their lungs. They now know what polluted air consists of, where it comes from, and what it does to human health.

Ridin on a tractor
Smelled NITROGEN OXIDE
From fuel combustion
Now the SMOG has formed
My lungs are in danger

from carbon monoxide,
Particulate matter,
VOCS and sulfur oxides

The children's adaptation of a popular song (i.e. lyrics filled with science ideas and the act of singing to the tune of popular music that was part of their everyday lives), which came after the children had enacted the way in which pollutants invade the human body, encapsulated connections between form and function of air pollution. The lyrical adaptation was their way of taking the familiar representational system of a tune well known to them, and using it to make meaning of what was unfamiliar before they created this play. The multiple intersecting modes that constituted the science play gave us glimpses of the children's knowledge and identity construction. The synaesthesia that was produced in the play was the result of the children's use of the familiar to imagine the unfamiliar and to coherently present this unfamiliar story of pollutants, both functionally and critically, to their audience. Positioning themselves as both learners and teachers, they traversed micro-, meso-, and macro-spaces using a variety of modes to story ideas through theatre.

Discussion

Recent calls for reimagining and rethinking learning, especially as the COVID-19 pandemic forced schools to educate students in out-of-school settings, encourage us to consider new pathways for working towards making school spaces places of belonging and thriving for minoritized students who are still too often seen from a deficit perspective (Delgado Bernal 2002; Ladson-Billings 2000; Yosso 2005), so we can disrupt 'inequality, oppression, and marginalization' (Nasir et al. 2021, 562). The findings of this study showed us how children, Black and Brown children in public school classrooms and in their homes in a large US city and an urban social ecological system make their own the various resources they are surrounded by and have access to.

Guided by their own interests, curiosities, and ingenuity, and the freedom and encouragement to consider their bodies and minds and any semiotic resources they would like, the children showed us what they valued, how they made sense of ideas and each other's participation in the learning spaces, and how they orchestrated semiotic tools they wanted to create and communicate meaning with in generative ways that both strengthen their conceptual knowledge and expand their science identities (Ødegaard 2003; Varelas et al. 2022). Thus, the study findings affirm that dramatizing performances children design and enact in school spaces (classrooms and settings for larger school gatherings, like auditoria) and at home provide opportunities to desettle expected axiological, ontological, and epistemological norms that often dominate science teaching. This further supports Brandscombe's (2019) emphasis on Merleau-Ponty's (1968) construct of 'chiasm' and its importance in learning, namely the significance of valuing and working towards an 'integrated existence, reconciling humans with the material world, with each other, and most significantly with themselves by dismantling a mind/body binary' (p. 5).

The study further articulated that children, and particularly minoritized children who are often mischaracterized and mislabeled in and out of schools, transformed everyday materials together with their bodies, into learning tools that supported their own and others' meaning making. The resources they found around, their own interests and ways

of being, and multiplicity of modes of communication they wanted (and were allowed, and in fact encouraged) to use, all came together under their ingenuity and each other's and their teachers' support, even when the support was temporarily compromised due to pervasiveness of master narratives about schooling and learning.

The children in the three vignettes did not restrict their bodies and body movements in usual ways that are imposed in school spaces whether they were 'doing school' in classrooms or their homes. They did not limit themselves to using materials in ways that they are often used in science class to do hands-on activities. They pushed back when the purpose of their actions and behaviors was not understood in the way they intended. They had to depend on others and on materials around them to develop their ideas and share them. In these ways, integrating dramatizing and performing-arts-based practices in science classes and considering their home environments as generative spaces for participating in science provided important opportunities for building on children's imaginative and creative selves to nurture and sustain their playful and cultural ways of knowing and being in the physical and semiotic worlds (Woodard, Diaz, et al. 2023; Woodard, Kotler, et al. 2023).

Repositioning students of color and other historically marginalized students as knowledge creators, who accomplish that by both performing themselves and being the audience of others' performances, has the potential to not only dismantle inequities and injustices in schools but also build community and collectivist orientations towards knowledge, identity, and action. In this way, we see this work aligning with those who seek to 'critique, re-imagine, strategize, design, and re-make' (Curnow and Jurow 2021, 14) what it means to engage in science learning with implications for both practice and policy. Creating classroom opportunities for young people to engage through multiple communicative modes with ideas and with each other makes space for their agency to shine through their choices of body movements, words, images, and sounds, and transforms traditional schooling structures. Blacks in the US consider that white power structures that have permitted them to gain renown and respect were more associated with performances, primarily the arts and athletics, whereas the sciences and engineering were ranked at the opposite end of the spectrum (Pew Research Center 2022). Thus, leveraging the arts to create such possible spaces and places in science education settings has the potential to both transform unjust structures and augment Blacks' and other people's of color, identifications with science.

Embodied, dramatizing performances can be liberating at various levels, championing and sustaining the multiplicity, horizontality, and dialogicality necessary in educational structures (B. Warren et al. 2020). Bakhtin (1986) argued that all meaning is contextual and it flourishes as multiple voices play out in dialogue with exchanges, negotiations, and possibilities. 'Contextual meaning is potentially infinite, but it can only be actualized when accompanied by another (other's) meaning ... There can be no contextual meaning in and of itself' – it exists only for another contextual meaning, that is, it exists only in conjunction with it' (p. 145). Considering 'voices' in a more expansive way than only as linguistic utterances, but as multimodal expressions where the whole body and its multiple forms of expression interact with other bodies and objects to create meaning, drama-based embodied performances cultivate dialogicality and multiplicity in ways that support horizontality. Peers ideas are valued, built upon, negotiated, and become part of the embodied ensemble children create as we saw in the vignettes that are presented in the

findings as counter-narratives of what students of color can do and do. As they negotiate body positions, movements, and attire, materials that become a part of what they do, speech, and sometimes images they create or find, children shape and claim the 'stage' to different degrees at different times building on their cultural contexts and life experiences. The axiological commitment of the performing arts to relational becoming of characters leads performers and audience to become contributors to the joint meanings created across varied space-times implicated in a performance.

Wilmes (2021) builds on Turner's (1969) concept of 'communitas' to engage with the notion of 'collective joy' in classrooms that arises in joint experience via collective action and emotion and was compromised by the COVID-19 pandemic's impact on collective life. Our study showed that the embodied performances children chose to create and enact mediated the development of communities and collective joy whether the children were in the physical classroom/school spaces with their peers or at their homes surrounded with the objects that were part of their everyday life and interacting with their peers remotely. Such may be the power of dramatizing and of performing arts: facilitating the development of connections, solidarity, and feelings among peoples and materials.

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ORCID

Maria Varelas  <http://orcid.org/0000-0001-8212-2674>

Nathan Phillips  <http://orcid.org/0000-0003-1571-5503>

References

- Bakhtin, M. M. 1986. *Speech Genres and Other Late Essays*. Edited by V. McGee, C. Translated by Emerson & M. Holquist. University of Texas Press.
- Barbour, K. 2004. "Embodied Ways of Knowing." *Waikato Journal of Education* 10 (1): 227–238. <https://doi.org/10.15663/wje.v10i1.342>.
- Brandscombe, M. 2019. *Teaching Through Embodied Learning: Dramatizing Key Concepts from Informational Texts*. Routledge.

- Braund, M. 2015. "Drama and Learning Science: An Empty Space?" *British Educational Research Journal* 41 (1): 102–121. <https://doi.org/10.1002/berj.3130>.
- Cazden, C. 2006. "Connected Learning: "Weaving" in Classroom Lessons." In *Pedagogy in Practice 2006 Conference*. University of Newcastle. <http://www.newcastle.edu.au/Resources/Schools/Education/Pedagogy/2006/PIP-2006-keynote.pdf>.
- Chappell, M., and M. Varelas. 2020. "Ethnodance and Identity: Black Students Representing Science Identities in the Making." *Science Education* 104 (2): 193–221. <https://doi.org/10.1002/sce.21558>.
- Convertini, J., and F. Arcidiacono. 2021. "Embodied Argumentation in Young Children in Kindergarten." *Education Sciences* 11 (9): 514. <https://doi.org/10.3390/educsci11090514>.
- Cope, B., and M. Kalantzis. 2009a. "A Grammar of Multimodality." *International Journal of Learning* 16 (2): 361–425. <https://doi.org/10.18848/1447-9494/CGP/v16i02/46137>.
- Cope, B., and M. Kalantzis. 2009b. "'Multiliteracies': New Literacies, New Learning." *Pedagogies: An International Journal* 4 (3): 164–195. <https://doi.org/10.1080/15544800903076044>.
- Curnow, J., and A. S. Jurow. 2021. "Learning in and for Collective Action." *Journal of the Learning Sciences* 30 (1): 14–26. <https://doi.org/10.1080/10508406.2021.1880189>.
- Davies, B., and R. Harré. 1990. "Positioning: The Social Construction of Selves." *Journal for the Theory of Social Behaviour* 20 (1): 43–63. <https://doi.org/10.1111/j.1468-5914.1990.tb00174.x>.
- Delgado Bernal, D. 2002. "Critical Race Theory, Latino Critical Theory, and Critical Raced-Gendered Epistemologies: Recognizing Students of Color as Holders and Creators of Knowledge." *Qualitative Inquiry* 8 (1): 105–126. <https://doi.org/10.1177/107780040200800107>.
- Dorion, K. R. 2009. "Science Through Drama: A Multiple Case Exploration of the Characteristics of Drama Activities Used in Secondary Science Lessons." *International Journal of Science Education* 31 (16): 2247–2270. <https://doi.org/10.1080/09500690802712699>.
- Enfield, N. J. 2011. "Elements of Formulation." In *Embodied Interaction: Language and Body in the Material World*, Edited by J. Streeck, C. Goodwin, and C.D. LeBaron, 59–66, Cambridge University Press.
- Fairclough, N. 1992. *Discourse and Social Change*. Polity Press.
- Fairclough, N. 1995. *Critical Discourse Analysis*. Longman.
- Fernandes, C. 2014. *The Moving Researcher: Laban/Bartenieff Movement Analysis in Performing Arts Education and Creative Arts Therapies*. Jessica Kingsley Publishers.
- Giddens, A. 1984. *The Constitution of Society: Outline of the Theory of Structuration*. University of California Press.
- Goldin-Meadow, S. 2005. *Hearing Gesture: How Our Hands Help Us Think*. Harvard University Press.
- Heller, V. 2021. "Embodied Displays of "Doing thinking." Epistemic and Interactive Functions of Thinking Displays in Children's Argumentative Activities." *Frontiers in Psychology* 12 (Article 636671): 1–21. <https://doi.org/10.3389/fpsyg.2021.636671>.
- Holland, D., W. Lachiocotte, D. Skinner, and C. Cain. 1998. *Identity and Agency in Cultural Worlds*. Harvard University Press.
- Jegede, O., and G. Aikenhead. 1999. "Transcending Cultural Borders: Implications for Science Teaching." *Journal for Science & Technology Education* 17 (1): 45–66. <https://doi.org/10.1080/0263514990170104>.
- Kalantzis, M., and B. Cope. 2005. *Learning by Design*. Common Ground.
- Kolovou, M., and N. J. Kim. 2020. "Effects of Implementing an Integrative Drama-Inquiry Learning Model in a Science Classroom." *The Journal of Educational Research* 113 (3): 191–203. <https://doi.org/10.1080/00220671.2020.1771673>.
- Kotler, R. T., M. Rosario, M. Varelas, N. C. Phillips, R. Tsachor, and R. Woodard. 2024. *Latinx Students Embodying Justice-Centered Science: Agency Through Imagining via the Performing Arts*. Science Education.
- Kress, G., and T. J. van Leeuwen. 2001. *Multimodal Discourse: The Modes and Media of Contemporary Communication*. Arnold.
- Ladson-Billings, G. 2000. "Racialized Discourses and Ethnic Epistemologies." In *The SAGE Handbook of Qualitative Research*, edited by N. Denzin and Y. Lincoln, 257–277, Sage.
- McVee, M. B., K. N. Silvestri, K. A. Schucker, and A. Cun. 2021. "Positioning Theory, Embodiment, and the Moral Orders of Objects in Social Dynamics: How Positioning Theory Has Neglected the Body

- and Artifactual Knowing." *Journal of the Theory of Social Behavior* 51 (2): 192–214. <https://doi.org/10.1111/jtsb.12289>.
- Merleau-Ponty, M. 1968. *The Visible and the Invisible*. Northwestern University Press.
- Nasir, N. S., C. D. Lee, R. Pea, and M. McKinney de Royston. 2021. "Rethinking Learning: What the Interdisciplinary Science Tells Us." *Educational Researcher* 50 (8): 557–565. <https://doi.org/10.3102/0013189X211047251>.
- Ødegaard, M. 2003. "Dramatic Science: A Critical Review of Drama in Science Education." *Studies in Science Education* 39 (1): 75–101. <https://doi.org/10.1080/03057260308560196>.
- Pew Research Center. 2022, April. *Black Americans' Views of and Engagement with Science*. United States.
- Pozzer-Ardenghi, L., and W. M. Roth. 2007. "On Performing Concepts During Science Lectures." *Science Education* 91 (1): 96–114. <https://doi.org/10.1002/sce.20172>.
- Reckwitz, A. 2002. "The Status of the 'Material' in Theories of Culture: From 'Social structure' to 'Artefacts.'" *Journal for the Theory of Social Behaviour* 32 (2): 195–217. <https://doi.org/10.1111/1468-5914.00183>.
- Shove, E., M. Pantzar, and M. Watson. 2012. *The Dynamics of Social Practice: Everyday Life and How It Changes*. Sage.
- Slocum-Bradley, N. 2009. "The Positioning Diamond: A Trans-Disciplinary Framework for Discourse Analysis." *Journal for the Theory of Social Behaviour* 40 (1): 79–107. <https://doi.org/10.1111/j.1468-5914.2009.00418.x>.
- Slocum, N., and L. van Langenhove. 2003. "Integration Speak: Introducing Positioning Theory in Regional Integration Studies." In *The Self and Others: Positioning Individuals and Groups in Personal, Political, and Cultural Contexts*, edited by R. Harré, F. M. Moghaddam, and F. Moghaddam, 219–234, Greenwood Publishing Group.
- Solomon, S., D. Champion, M. Steele, and T. Wright. 2022. "Embodied Physics: Utilizing Dance Resources for Learning and Engagement in STEM." *Journal of the Learning Sciences* 31 (1): 73–106. <https://doi.org/10.1080/10508406.2021.2023543>.
- Solorzano, D. G., and T. J. Yosso. 2002. "Critical Race Methodology: Counter-Storytelling as an Analytical Framework for Educational Research." *Qualitative Inquiry* 8 (1): 23–44. <https://doi.org/10.1177/1077800402008001003>.
- Stets, J. E., and P. J. Burke. 2003. "A Sociological Approach to Self and Identity." In *Handbook of Self and Identity*, edited by M. R. Leary and J. P. Tangney, 128–152, Guilford Publications Inc.
- Streeck, J., C. Goodwin, and C. D. LeBaron. 2011. "Embodied Interaction in the Material World: An Introduction." In *Embodied Interaction: Language and Body in the Material World*, edited by J. Streeck, C. Goodwin, and C.D. LeBaron, 1–28, Cambridge University Press.
- Stryker, S. 1980. *Symbolic Interactionism: A Social Structural Version*. Benjamin-Cummings.
- Studd, K., and L. Cox. 2019. *Everybody is a Body*. Dog Ear Publishing.
- Tang, K. S., J. Jeppsson, K. Danielsson, and E. B. Nestlog. 2022. "Affordances of Physical Objects as a Material Mode of Representation: A Social Semiotics Perspective of Hands-On Meaning-Making." *International Journal of Science Education* 44 (2): 179–200. <https://doi.org/10.1080/09500693.2021.2021313>.
- Threadcraft, S. 2016. "Embodiment." In *The Oxford Handbook of Feminist Theory*, edited by L. Disch and M. Hawkesworth, 207–226, Oxford University Press.
- Turner, V. 1969. *The Ritual Process: Structure and Anti-Structure*. New York: De Gruyter.
- Varelas, M., R. Kotler, H. Natividad, N. Phillips, R. Tsachor, R. Woodard, M. Gutierrez, M. Melchor, and M. Rosario. 2022. "'Science Theatre Makes You Good at science': Affordances of Embodied Performances in Urban Elementary Science Classrooms." *Journal of Research in Science Teaching* 59 (4): 493–528. <https://doi.org/10.1002/tea.21735>.
- Varelas, M., C. C. Pappas, E. Tucker-Raymond, J. Kane, J. Hankes, I. Ortiz, and N. Keblawe-Shamah. 2010. "Drama Activities as Ideational Resources for Primary-Grade Children in Urban Science Classrooms." *Journal of Research in Science Teaching* 47 (3): 302–325. <https://doi.org/10.1002/tea.20336>.

- Varelas, M., J. Settlage, and F. M. Mensah. 2015. "Explorations of the Structure-Agency Dialectic as a Tool for Framing Equity in Science Education." *Journal of Research in Science Teaching* 52 (4): 439–447. <https://doi.org/10.1002/tea.21230>.
- Warren, Z., and F. M. Moghaddam. 2018. "Positioning Theory and Social Justice." In *The Oxford Handbook of Social Psychology and Social Justice*, edited by P. Hammack, 319–330, Oxford University Press.
- Warren, B., S. Vossoughi, A. S. Rosebery, M. Bang, and E. V. Taylor. 2020. "Multiple Ways of Knowing: Re-Imagining Disciplinary Learning." In *Handbook of the Cultural Foundations of Learning*, edited by N.S. Nasir, C.D. Lee, R. Pea, and M. McKinney de Royston, 277–294, Routledge.
- Wilmes, S. E. D. 2021. "Interaction Rituals, Emotions, and Early Childhood Science: Digital Microscopes and Collective Joy in a Multilingual Classroom." *Cultural Studies of Science Education* 16 (2): 373–385. <https://doi.org/10.1007/s11422-021-10056-6>.
- Woodard, R., A. R. Diaz, N. C. Phillips, M. Varelas, R. Kotler, R. P. Tsachor, R. Rock, and M. Melchor. 2023. "'I. Am. A. Star.': Exploring Moments of Muchness in Children's Digital Compositional Play and Embodied Science Learning." *English Teaching: Practice & Critique* 22 (2): 163–176. <https://doi.org/10.1108/ETPC-08-2022-0101>.
- Woodard, R., R. Kotler, M. Varelas, R. P. Tsachor, N. C. Phillips, and M. Gutierrez. 2023. "Playful Disciplinary Learning: Using Drama to Move Along with Reading, Writing, Drawing, and Talking." *Literacy Today* 40 (4): 28–30.
- Yosso, T. J. 2005. "Whose Culture Has Capital? A Critical Race Theory Discussion of Community Cultural Wealth." *Race Ethnicity and Education* 8 (1): 69–91. <https://doi.org/10.1080/1361332052000341006>.