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Orientations to Material Agency in Science Learning

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Abstract: In the absence of adequate conceptual and methodological frameworks to notice how materials contribute to ontological shifts in science learning, it becomes difficult to set up conditions for these shifts to occur. We present our framework of orientations to material agency in order to recognize when materials become more than mediational tools of learning and instead gain a social presence as agentic participants that help build scientific knowledge. We illustrate this framework through examples of interactional experiences of secondary school science teachers, showing how orienting to material agency can begin to move them toward shifts in how they view and value the non-human in science. This in turn demonstrates ways in which working with materials has the potential to become central to culturally rich engagements in science learning.

Introduction

> **Peter:** I remember in each of these, like getting these materials, and it did feel different than when I put a chemical out for my kids for chemistry or whatever else… I do remember when I was trying some different things, I had a little bit of like, "Please let this work or like, like, taste good, please, like do me a good taste right now". And I was almost hoping that the things would gift me a good taste. So that I could be excited about the good taste, like I just wished for a non-neutral. Like I want to discover something exciting.

Much of scientific knowledge is based on experimentation, and working with materials is a foundation of STEM education (Takeuchi et al., 2020). Materials are used to give students better understandings of disciplinary scientific concepts (Phillips et al., 2023), as well as to provide more opportunities for the development of scientific identities (Peppler et al., 2016). In this paper we argue that working with materials can shift ontologies toward greater relational reciprocity between the human and the non-human. Although concepts such as intra-action (Barad, 2007) and sociomateriality (Tietjen et al., 2023) are beginning to gain wider recognition in the learning sciences, learning with materials is still largely viewed through the traditional sociocultural frame of the use of mediational tools that merely respond to human agency (Wertsch, 1991). In the opening vignette, Peter, who is a science teacher at a public high school in Southeastern United States, used the word "gift", which is indicative of a relationship to materials that is ontologically different.

Peter talked about his experience with materials in the context of experiments with taste in the Science Teacher Circles (STCs), a research project that brings together secondary school science teachers and university researchers to imagine science teaching and learning through our own joyful and expansive inquiries. We argue that Peter's description of building a reciprocal relationship with materials shows him *orienting to material agency:* that is, recognizing the dynamic, social, and cultural capacities of materials to shape interactions. When Peter is contrasting his relationship to materials in STCs to the one typical in school science, he is describing an ontological shift – a new way to see materials as *partners* in the process of developing scientific inquiry. Shifts of this kind have been called for in the learning sciences (Vossoughi et al., 2016), but while social theorists of science have developed some conceptualizations of material agency in professional practice (Pickering, 1995), it has been more challenging to account for it in education. This led us to wonder: what are the aspects of engagement with materials in learning spaces that orient participants to new ontological experiences of agency, and what does orienting to material agency look like in interactions?

In this paper we present a conceptual-methodological framework for analyzing orientations to material agency in science learning. We situate this framework in empirical literature in science education and learning sciences on interactions with materials, highlighting the need for approaches that consider materials as *social partners*. We then illustrate the framework in an interaction analysis of secondary science teachers' engagement in scientific inquiry.

Background and conceptual framework

The role that materials play in learning has been of increasing interest in the learning sciences. Typically drawing on sociocultural studies of STEM education, this scholarship highlights the importance of *materials as tools of*

learning. One strand of this literature positions materials as *instruments to strengthen disciplinary learning* (Gravel et al., 2022; Phillips et al., 2023; Nemirovsky et al., 2021; Manz, 2015). Materials can demonstrate concepts, support recall, and engage learners' pre-existing funds of knowledge. Another strand of work on materials, typically in informal learning environments, highlights their aesthetic and emotional appeal. This work positions materials as *joyful playthings to develop STEM identities* (Searle & Kafai, 2015; Kumpulainen & Kajamaa, 2020). Finally, there is a growing strand of scholarship that explores *materials as catalysts to reimagine relationalities* (Barajas-Lòpez & Bang, 2018; Vossoughi et al., 2020; Sheridan et al., 2020; McDaid Barry et al., 2023), informed by critical, Indigenous, and posthumanist frameworks and spurred by the need for *critical onto-epistemological reorientation* of human–non-human relationships in science learning.

As we were thinking with these writings while also beginning to analyze our data of teachers' engagement in STCs, what emerged for us is the need for better integration of these perspectives in order to understand how participants developed an orientation to material agency, such that they recognized and made space for the capacity of materials to dynamically shape the social and cultural space of interactions. We began constructing our framework in order to recognize this presence, as presented in Table 1.

Table 1
Orientations to Material Agency Framework

Strand of Framework	Description	Examples
Openings of possibility	Materials open possibilities for the participants to experience different ways of knowing when experiments take unexpected turns and proceed in directions that were not planned in advance. Experiments with materials become generative environments when new questions get asked and new paths toward answers are constructed.	When Gravel et al. (2022) explored STEM concepts with teachers through iterative, playful, small-scale design projects, materials helped open possibilities for many creative transdisciplinary connections. In Manz' (2015) work with elementary school science students, materials opened possibilities for the kids to ask big questions about life and nature.
Interactional role	Orienting to material agency means both the human and the material have the potential to control which way the events of the interaction will unfold and to direct the details of this unfolding. In the moment of interaction, this is recognizable as a construction of a social relationship through various moves (language, body positioning, etc.)	Positioning of materials as partners in inquiry is sometimes described as having "conversations with materials" (Schön & Wiggins, 1992). These conversations help learners pay attention to "transient qualities accompanying a puzzling event" (Nemirovsky et al., 2021, p. 182) in their process of meaning-making.
Knowledge construction	Recognizing material agency in building knowledge means attuning to the process of resistance and accommodation (Pickering, 1995): humans make conjectures about what will happen, and the materials either accommodate or resist them. Though this process is dialectic, its development is not always straightforward, and building new knowledge with materials is often emergent rather than sequential, thus attention to complexities is crucial.	Searle & Kafai's (2015) use of e-textiles (conductive thread which can be used to create electronic circuits with sew-on LED lights and a programmable power source, such as Arduino Lilypad) in workshops that combined craft and programming showed how students developed both conceptual knowledge and practical skills in these domains by constantly testing out approaches, discarding solutions that didn't work, and refining the ones that did.
Cultural presence	Orienting to material agency understands that materials and humans are connected through histories, traditions, and ways of knowing and being. Materials have cultural presence	Acknowledging the cultural presence of materials needs to be central to learning designs and analyses of engagements that seek to produce ontological shifts (Vossoughi et al., 2016). This was

	when their connections to history and culture are explicit in the interaction and, more specifically, when these connections influence the ways in which interactions unfold.	evident in McDaid Barry et al.'s (2023) work with Indigenous students on exploring plant personhood in a STEAM summer program.
Conditions of arrival	Orienting to material agency needs to emphasize the ways in which historical power relations become part of all interactions, including human-to-material. S. Ahmed (2010) tells us that when we look at objects as simply "there", we do not account for how they acquired their physical properties together with social and relational meanings. This compels us to question whether certain materials are really equally accessible to all and calls for sensitivity and care around selections of materials for exploration.	In the literature we reviewed, the materials' conditions of arrival were not addressed. Including them in our framework speaks to the multiple ways in which power dictates which humans and what materials get to participate in science.

As we seek to build science education that takes historical systems of power into account, we must attune to how these systems of power present themselves in the materials through both their physical properties and discursive associations. We propose that in order to create the desired ontological shifts toward greater relationalities in science education, we must recognize the complexity of roads that lead both humans and materials to interactional spaces and the emergent and non-linear nature by which materials acquire a social presence in them.

Data and methods

STCs are monthly meet-ups with local secondary science teachers to engage in joyful scientific explorations and reflective conversations about teaching (https://www.scienceteachercircles.org). Drawing on the framework of teacher solidarity co-design (Philip et al., 2022), teachers and university researchers developed a shared vision for the community to re-imagine science teaching, celebrate cultural diversity in understanding the natural world, and reflect on our pedagogical practice, while also creating a safe and empowering space for teachers. The data corpus analyzed for this project comes from our first co-design year of STCs in which we piloted our scientific explorations using open-ended questions to invite expansive connections to phenomena.

To illustrate our framework, we present an episode from the group's exploration of the question, "Why do salt, fat, acid, and heat make food taste good?" (Nosrat, 2017). After a discussion that elicited connections to human biology, cooking, cultural practices, and geology, at the following month's meeting STC members worked in two small groups to investigate the phenomena with materials. After reviewing video data, we chose episodes where the social presence of materials felt especially strong to the members of our research team and that were memorable to the participants. We then transcribed a number of these episodes multimodally (Jewitt, 2009), which, in addition to focusing on discourse and non-verbal communication, allowed us to pay attention to the movements of materials and humans. We engaged in repeated viewing of the focal episodes, using methods grounded in interaction analysis (Jordan & Henderson, 1997; Derry et al., 2010) as well as ethnographic microanalysis of video data (Erickson, 1992), to look at these episodes in detail; and we returned to them often as we were constructing our framework. Our data also includes artifacts such as the notes that participants took during the interactions and interviews conducted several months later.

Findings

The focal group is composed of two teachers and two researchers. The teachers, Maria and Stacey (pseudonyms), work at the same school, which serves children ages 10-14 in an urban district in the Southeastern United States and enrolls a large population of English language learners. The researchers are the second and third authors: Jess (PI) and Yeung, her doctoral advisee. Each participant in this small but diverse group came from very different geopolitical, professional, and cultural backgrounds, which they drew on throughout the STCs. First author, who did not participate in the focal episode, is a doctoral student and another research assistant.

The experiment that Maria, Stacey, and Yeung were conducting had been primarily guided by Maria and Stacey. A variety of materials was brought in by Jess and Yeung, their choices inspired by ideas from the participants' brainstorming in the previous meeting, advice from cooking magazines, and general culinary observations. Unseasoned sauteed mushrooms were chosen as a neutral base for adding additional flavors. The focal flavoring agent was the bitter melon juice (BMJ), selected in part for its less familiar flavor, but also for its prominence in Southeast Asian cuisine. Though Jess was the one who decided to bring it in, Yeung talked about the use of bitter melon (or gourd) in traditional cuisine of Hong Kong. For Maria and Stacey, this would be the first time trying it. Initially, they planned to taste a little bit of different flavored liquids with the mushrooms (such as vinegar, lemon juice, etc.), using unflavored mushrooms as control. However, the actual tasting of BMJ with mushrooms produced an unexpected phenomenon: the anticipated bitterness wasn't there. Jess then suggested that others experience BMJ by itself "at some point"; however, Maria decided that even though they initially didn't set out to taste each flavor by itself, BMJ did something different and therefore required further investigation outside of established parameters. Once she confirmed that BMJ tasted differently by itself, she compelled Stacey to try it too; and when she did, Stacey agreed: "I did not taste that with the mushrooms". Then Jess, who hadn't tried BMJ with the mushrooms before, decided to do so. Subsequently, she joined this group's tasting experiment.

From the traditional sociocultural view of tool mediation, Maria and Stacey's questions about the origin and traditional uses of BMJ would be seen as "off-task" to their planned experiment. Through our framework we see that cultures, histories, and BMJ's conditions of arrival were interconnected with the ways knowledge was constructed, interactions unfolded, and new questions posed. Maria's inquiry began as an orientation to the BMJ's *conditions of arrival*: she asked questions about what kind of container it came in ("…does it come from a bottle? Is the bottle clear?"). Prior to tasting, both Stacey and Maria examined BMJ's original container, with Stacey reading BMJ's full name out loud ("First pressed virgin juice, bitter gourd"); this led Jess to wonder out loud where this specific BMJ came from and to read the answer to the group ("India!"). Thus, the whole group was oriented to this material's conditions of arrival. Maria and Stacey directed questions about BMJ to Yeung due to his positioning as the source of cultural knowledge about this ingredient; and he shared his experience as well as questions that he was also interested in exploring within this experiment, since they hadn't come up before in this particular way. The participants' language, movement, and gestures showed that this social interest in the material as a new partner in inquiry was part of an integrated process of making meaning (Goodwin, 2000).

Our framework also points to the ways that BMJ had *cultural presence*, for instance in prompting Maria, Stacey, and Yeung to share their culinary backgrounds, likes and dislikes. The participants also treated BMJ as an *interactional partner*, listening to it speak through its "fascinating" and unexpected tastes. By providing an unanticipated phenomenon, BMJ participated in the *construction of knowledge* in this experiment, thus *opening possibilities* for inquiries to unfold differently than anticipated, both in terms of activities that were created on the spot to answer specific questions, and also in terms of shifting participation frameworks, as when Jess switched her role from observer to participant. Importantly, building a relationship with BMJ via *orienting to its agency* through all of these dimensions led to further conversations in STCs on the ontological implications of scientific experiments and the ways in which materials get positioned within them.

Discussion and implications

Our framework of orientations to material agency contributes to the growing body of work that centers the importance of learning with and through thoughtful and exploratory interactions with materials. It brings together diverse literature on the use of materials in science learning by highlighting the various ways in which the materials themselves had agentic presence in the data that was described. At the same time, grounding our framework in interactional experiences of secondary school science teachers shows how orienting to material agency can begin to move how they view and value the non-human in science.

As a conceptual-methodological tool, the framework of orientations to material agency shows how working with materials can become central to culturally rich engagements in science learning. Instead of materials being considered purely as a mediational tool, it shows that they can shape interactions as they participate in them as agentic, social partners. Thus, attuning to the conditions of arrival, cultural presence, knowledge construction, interactional role, and openings of possibility in interactions with materials can become a way to design expansive and connective spaces for science teaching and learning. This, in turn, has the potential to create new relationalities and inspire ontological shifts.

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