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Catherine Milne
Kathryn Scantlebury *Editors*

Material Practice and Materiality: Too Long Ignored in Science Education

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Chapter 1
Introduction: Bringing Matter into Science Education

Kathryn Scantlebury and Catherine Milne

The chapters for this book take as their starting point the notion of culture as fields of material and social practice and worlds of meaning that are weakly bounded, internally contradictory, contested, and subject to constant change (Sewell, 1999). Historically, the research on teaching and learning has mediated social practices through language. The chapters in this book consider how material and social practices are entangled in ways that enrich our understanding of what it means to know and our connections with reality. The authors use a range of philosophies and positions that give prominence to the material in culture.

The chapters span the educational trajectory of science education from early childhood to the professional education of science teachers and discuss matter and materiality in terms of curriculum, classrooms, and technoscience. All chapters of the book share how insights into materiality can inform our understanding of, and practice in, science education.

Science education research has a tendency to ignore material culture focusing instead on social culture through constructivist lenses in which language is used as the arbiter of social practice. The authors of this book's chapters examine the implications of exploring the role of material culture in science education. Often matter and material practices, such as those located in the forms of apparatuses, artifacts, and scientific instruments, are ignored when scholars communicate new knowledge and realities based on their sociocultural examination of the world because language seems so central to what we say and do. Matter is written out of the narrative

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as the human researcher takes center stage. While we do not ignore the role of language in the construction of science and science education, we agree with Karen Barad (2003) that perhaps language has too much power, and, with that power, there seems a concomitant loss of interest in exploring how matter contributes to both ontology and epistemology in science and science education. In this book, the contributors focus on *the material* in science and science education and its role in scientific practice such as those practices that are key to curriculum efforts of science education programs in a number of countries. Building on the notion of cultures as material social practice, these chapters explore the role of apparatus, objects, matter, and materiality as material practice and their role in the learning and teaching of science using a variety of theoretical frameworks.

As a construct, culture owes its existence to the field of anthropology, but fields, like education with an interest in the production of ideas and processes and material social practices, have found the construct of culture to be useful for their purposes also. Although historically culture has been defined variously (Sewell, 1999), the notion of culture as material and social practice is a useful definition for informing our understanding of science in a way that supports researchers to more nuanced explorations of the nature of science and informed and inclusive decisions about the practice of science education. As fields of material social practice and worlds of meaning, cultures are contradictory, contested, and weakly bounded. The powerful (e.g., white, middle-class male in Western cultures) uses power, not to establish uniformity but to organize difference by identifying what is normal or accepted while marginalizing those that diverge from that norm (Sewell, 1999). The notion of culture as material social practices leads researchers to recognize the role of historical context in the development of these practices and associated meanings and to accept that material practice is as important as conceptual development (social practice).

In education and science education, material practices, such as those associated with scientific instruments, are ignored, or instruments are described as merely "inscription devices," that is, devices that are understood to be conduits for language rather than as sources of epistemology and ontology. Davis Baird (2004) argues that "text bias" did not die with the logical positivists and critiques Bruno Latour and Steve Woolgar's study (1979) for not recognizing or acknowledging that scientists share "material other than words" (Baird, 2004, p. 7) when they communicate new knowledge and realities.

This book is an outcome of a discussion about material culture that began during the summer of 2014 when some of this book's contributors were involved in a workshop focused on cultural studies in science education sponsored by the University of Luxembourg. Catherine Milne proposed submitting symposia to the upcoming research conferences, and the book developed after the success of those symposia. Various scholars from across different national contexts (Canada, Denmark, England, New Zealand, Sweden, the United States) explore *the material* in science and science education and its role in scientific practice such as those practices that are key to curriculum focuses of science education programs.

The book begins with different perspectives on materials. Catherine Milne used case studies on the thermometer and ribosome to examine the role of instruments in the construction of phenomena in the intra-action between human and matter, and in doing so, she foregrounds how thinking about the role of instruments and their development can engage science educators in reframing the role of instruments and practice in school science curricula and in national education standards. Her historical analysis shows how objects in science either become absorbed and then taken for granted or marginalized and forgotten. Kathrin Otrel-Cass and Bronwen Cowie distinguish between materials as natural objects in the world and human-made artifacts as they explore the various roles materials and materiality play in shaping, and in turn being shaped by, teachers' classroom practices. The teachers in their study incorporated objects into their teaching to build common knowledge among students, providing opportunities as part of science learning for objects to be made visible, which they found supported both student collaboration and communication.

Kathryn Scantlebury, Anna Danielsson, Anita Hussenius, Annica Gullberg, and Kristine Anderson engage with material feminism and Barad's concept of spacetime mattering to read data about preservice teachers' science perceptions through a "lens of matter." They discuss *intra-activity*, *agential realism*, *phenomena*, *apparatus*, and *material-discursive practices* to identify gendered pedagogical practices, with an assumption that practices are central to material feminist praxis (Barad, 2007, 2014; Taylor, 2013). Through their metalogue, Shakhnoza Kayumova and Jesse Bazzul use new materialisms to explore ethical thinking and action through/for science education. They follow Gilles Deleuze and Felix Guattari (1987) using the key concepts of rhizome, assemblage, territorialization, intra-actions, entities, and multiplicities from new materialism theory to diagram assemblages as a way to engage creative ontologies.

The next group of chapters discuss how considering the material world frames curriculum from a multicultural perspective, for learners from liberal arts students to preschool children. Marc Higgins uses Baradian theory to explore the ethical practices that emerge within the context of multicultural science education when we are responsive to the relationship between epistemology and ontology. He uses this focus to examine ontological questions about traditional ecological knowledge (TEK) and indigenous ways-of-living-with-nature (IWLN) and how they are excluded within Western modern science (WMS). In doing so, he problematizes the nature/culture dichotomy, noting that indigenous peoples have always acknowledged matter's agency. Catherine Milne uses Barad's concept of intra-activity to frame and develop a curriculum for a liberal arts core science course for undergraduate students. She introduces her students to building scientific instruments to facilitate intra-activity and the production of material-discursive practices that engage students' thinking of how instruments and thus matter contribute to the phenomena they observe and their scientific knowledge. In her chapter, Sofie Areljung foregrounds the implications of agentic matter for preschool teachers and their students' learning. She explores children's intra-actions when experiencing phenomena outside of the classroom and how those phenomena change over time and location.

The next set of authors locate their discussions in classrooms. Jesse Bazzul, Sara Tolbert, and Shakhnoza Kayumova explore how interdisciplinarity, urban education, sex/gender, and sexuality and linguistic diversity are influenced through new materialist approaches and the impact of this knowledge on science educators' practices. Jana Haus and Chris Siry examine intra-actions between one human and one nonhuman body within a kindergarten group science activity to gain understandings of how the bodies cause action and in this process *become for one another*. In her chapter, Morabito uses *science in the making* to provide middle and high school teachers with authentic engineering research experiences.

Technoscience is addressed by Shannon Burcks, Marcelle Siegel, Christopher Murakami, and Rose Marra who examine how materiality influenced equitable science education when used asynchronously in non face-to-face learning environments. They conceptualized assessment practices as sociomaterial assemblages that affect learners in technology-enhanced science-learning environments. In their chapters, Shirley Simon and Paul Davis report on studies focused on teachers' professional development. They discuss how the materiality of video and associated website tasks supported teachers' professional development. Through a history of website development, they explore how use by teachers impacted the "being" of the website as teachers asked for material elements, such as "tools" to be central to the design of the website raising the issue of the active relationship between technology and users in professional education settings. And then Simon and Davis explored how the infrastructure provided by a website supported science teachers in their "productive conversations" regarding teachers questioning each other's thinking on the materials, artifacts, and practices to teach argumentation.

Cathrine Hasse uses educational technologies to illustrate "cultural ecologies" as places where humans and nonhumans react to vibrant and frictioned materials. In education settings, technologies reinvent, stabilize, and reinforce cultures in subtle and unpredictable ways. Specifically, Cathrine discusses how tablets became a major force in changing the material constitution of Danish educational habitats.

Jay Lemke (2011) has described science education research as hegemonic and heteronormative. It is ironic that a field such as science education has ignored (or has been silent) about the material in learning science given science's focus on understanding matter and materiality. Through their examination of the phenomena that are generated when agential cuts are implemented, Kathryn Scantlebury, Anna Danielsson, Anita Hussenius, Annica Gullberg, and Kristine Anderson raise questions about practice and problematize science education research. Specifically, they use the example of silence to illustrate how science education research has multiple areas to examine when taking into consideration that matter is agentic, and phenomena that are studied result in the establishment of boundaries which generate unexplored areas – the question that arises is, do these differences matter? The varied interests and theoretical perspectives regarding the role of matter and materiality in science education of the book's contributors provide an opportunity to begin to address this lack of attention to the agency of matter.

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Part I
Different Perspectives on Materials

Chapter 2
The Materiality of Scientific Instruments and Why It Might Matter to Science Education

Catherine Milne

Three years ago I began to explore the history of how science came to know about the relationship between the boiling point of water and air pressure with the goal of writing an historical narrative for students that highlighted the empirical relationship between these two variables (Milne, 2013). Naively I thought this would be an easy task. With a somewhat meager knowledge of this period of scientific endeavor, I erroneously thought that Blaise Pascal, a French experimental philosopher, had travelled up a mountain and generated the data I wanted. However, my studies showed that I was totally wrong about the questions Pascal was asking and rather than asking about the relationship between air pressure and the boiling point of water his interest was on a question, which absorbed many seventeenth- and eighteenth-century experimental philosophers influenced by Greek philosophy, is there such a thing as a vacuum and, if there is, what is it like? My studies into the historical exploration of air pressure and boiling point of water showed me that understanding this relationship was only possible if one included the development of the thermometer as part of the discussion. This realization about the role of the thermometer led me to realize how much I had taken the humble thermometer for granted in the past. Additionally, I began to think about how historical and cultural studies of science and science education seem to focus so much on conceptual elements of the history of science with an emphasis on theory development rather than exploring the important role of instruments and practice in the historical construction of scientific understanding. I also started to appreciate how a conceptual focus can lead scholars and educators to lose sight of material things, like the humble thermometer, that I think have a significant role in the sociocultural milieu of science and in the learning of science as a form of doing, acting, and making.

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2.1 Thinking Beyond Concepts and Theories in Science Learning

Looking at this issue in greater depth, Albert van Helden and Thomas Hankins (1994) noted that historically the history of science has been about the history of theory, so instruments were considered "reified theories" (p. 2), and the focus on conceptual understanding in contemporary science education represents an extension of this focus. My historical exploration of the relationship between air pressure and the boiling point of water forced me to problematize the instruments needed to support experimental philosophers' exploration of hotness, coldness, and boiling point. It began with the graphic story we developed to show the relationship between air pressure and boiling point for the online simulations we were developing in order to support student learning in chemistry. Beyond the thermometer, we also focused on the instrument that was essential for natural philosophers to explore air pressure experimentally, the air pump. Robert Boyle, a wealthy experimental philosopher, employed a displaced French experimental philosopher, Denis Papin, to help him with his experiments and the refinement of instruments especially the air pump, needed for pumping air out of a space created through the use of a glass globe (see the air pump in Fig. 2.1).

It is clear from Boyle's own descriptions in his book, *New Experiments Physico-mechanical, Touching the Spring of the Air and Its Effects* (1682), that the air pump, which he called the "engine," allowed him and his trustworthy witnesses to observe phenomenon that had not been observed previously:

> That if, when the Receiver is almost empty, a By-stander be desired to lift up the brass Key (formerly described as a stopple in the brass Cover) he will find it a difficult thing to do so, if the Vessel be well exhausted; …he will (I say) find it so difficult to be lifted up, that he will imagine there is some great weight fastned to the bottom of it… it is pleasant to see how men will marvail that so light a Body, filled at most but with Air, should so forcibly

Fig. 2.1 Robert Boyle, light brown hair, and Denis Papin, dark brown hair, discuss the use of the air pump and their roles in its development in our graphic story of the history of the relationship between air pressure and boiling point

draw down their hand as if it were fill'd with some very ponderous thing: Whereas the cause of this pretty *Phaenomenon* seems plainly enough to be only this That the Air in the Receiver, being very much dilated, its Spring must be very much weakn'd, and consequently it can but faintly press up the lower end of the stopple, whereas the Spring of the external Air being no way debilitated, he that a little lifts up the stopple must with his hand support a pressure equal to the disproportion betwixt the force of the internal expanded Air, and that of the Atmosphere incumbent upon the upper part of the same key or stopple. (pp. 21–22)

In this vignette, Boyle first describes how difficult people find it to remove the stopper out of the air pump once a lot of the air has been pumped out of the glass vessel and then explains this "pretty" phenomenon in terms of external air pressure being much greater than the internal air pressure inside the vessel. For me, this comment from Boyle illustrates the argument of Karen Barad (2007) with respect to the agential realism of humans and apparatus who through their entanglement or intra-actions (her term) create phenomena just as Boyle and the air pump created air pressure in his example.

Our narrative also focused on Papin's invention of what he called the "steam digester" (see Fig. 2.2) because of its historical association with the household pressure cooker which is often used in chemistry education as an everyday example of the relationship between pressure and boiling point.

The prominence we gave to instruments such as the air pump and the steam digester in our graphic narrative was based on our desire to communicate to students

Fig. 2.2 Denis Papin invents the steam digester

how this science was made and also the role that instruments played in this making. We were seeking to visually communicate the role of instruments in the evolution of concepts such as air pressure and boiling point. However, Bruno Latour (1987) had noted a different role for instruments when they become such well-understood material objects that they are used unproblematically as a reliable means for eliciting natural phenomena "by separating the phenomena of interest from the noise of the observed world." He called this approach, "black boxing." For example, consider a modern kitchen thermometer, which we take for granted and expect to measure temperature accurately. We are only made conscious of its role if it is damaged in some way and does not actually "work."

Although this black boxing happens in everyday life, it is also what happens in science classrooms when children and youth use instruments for class experiments and the only focus is on the data they obtain from the use of an instrument. Reflecting on how much I had taken the humble thermometer for granted when working with students led me to reflect on how much science education seems to focus on conceptual elements of science, specifically theory development. With that theory focus, science education loses sight of what material things, like the humble thermometer, have contributed to the sociocultural milieu of science and to the learning of science as a form of doing, acting, and making (see also Milne, 2013). I feel almost guilty that through all my many years as both a student and a teacher it was not until I began to explore the history of the relationship between air pressure and boiling point (Milne, 2013) and reread Robert Boyle that I really engaged with the issue of material culture and the role of instruments in that culture.

2.1.1 Instruments as "Inscription Devices"

The other issue associated with my exploration of the history of the thermometer and also of air pressure and the boiling point of water was how sociocultural studies described instruments, such as thermometers, as "inscription devices" (see Latour, 1987), that is, devices for producing external representations that are used for communication through language. While I am not ignoring the role of language in science, Rom Harré (2003) argues that in science studies, there is a tendency to see science in terms of "discourse of scientific communities" (p. 19), that apparatus and instruments are almost invisible, and if any attention is paid to them, it is based on their contribution to the argumentative discourses of science, which is what I see in examples of national curricula. I agree with Karen Barad (2003) that perhaps language has too much power, and with that power, there seems a concomitant loss of interest in exploring how matter and machines (instruments) contribute to both ontology and epistemology in science. Davis Baird (2004) echoes this position arguing that "text bias" did not die with the logical positivists and that scientists share "material other than words" (Baird, 2004, p. 7) raising the question of the role of instruments in coming to know science. However, it is not just in science studies that instruments get no respect. For all their focus on practice, national science education documents, such as the Next Generation Science Standards (NGSS) (Achieve Inc., 2013), tend to ignore, or take for granted, the role of instruments in educational practice and science practice. In the document, *A Framework for K-12 Science Education* (National Research Council, 2011), instruments are mentioned in a description of science as a community but not problematized. Any description of instruments in the NGSS provides no sense of instruments as contributors to the material culture of science. So, I was left with a question, *why there is so little attention given to understanding the role of instruments in the construction of knowledge, especially in science education*? In this chapter, I explore the role of material culture, especially as it is instantiated in the instruments we take for granted, in science teaching and learning.

Additionally, a blinkered focus on theory has other implications for school science because with such a focus we also tend to assign less value to procedural understanding or procedural language. By procedural understanding I mean a strategy for communicating the action or practices of science, which may include developing strategies for exploring claims or questions about the natural and built world, deciding which forms of evidence will allow one to address those actions or claims, how one can generate such evidence through actions of testing and measurement, deciding how to make observations and interpret patterns in the resulting data, and, finally, deciding how to evaluate the quality of the evidence generated. However, I do not want to be thought of as setting up a dichotomy between practices and theory, rather I seek to highlight the lack of attention given to practice and the role of instruments in defining that practice. Indeed, scientific theory can be understood as part of practice, especially if one thinks of theory as practices of modeling and reconciling theoretical models with experimental systems (Rouse, 2002).

Essential to these actions or practices is an appreciation for how instruments allow one to ask different questions and how instruments can help one to explore one's experiences differently. In this respect, in science we are entangled with instruments as apparatus, and through this entanglement, we create phenomena (see Barad, 2007). If science education focuses only on conceptual understanding, then it is always only dealing with finished science. Practice creates a space for learners to see science as something they can do while also providing a space for the development of a more nuanced appreciation for the role of instruments in the building of scientific knowledge and the creation of reality as understood in phenomena. Rather than using them as black boxes with no role in practical or conceptual understanding, thinking of scientific practices as involving complex intra-actions offers a greater opportunity for students to see a role for themselves in science. In science and science education, intra-actions between objects and beings challenge us to understand that what theories describe "is not nature itself but our participation in nature" (Barad, 1998, p. 105). Indeed, Boyle in the quote presented earlier shows how instruments and humans intra-act in a way that creates the phenomenon of external and internal air pressure. This phenomenon can be explained or understood through theories such as Boyle's explanation:

> That our Air either consists of, or at least abounds with, parts of such a nature; that in case they be bent or compress'd by the weight of the incumbent part of the Atmosphere, or by any other Body, they do endeavour, as much as in them lieth, to free themselves from that pressure. (1682, p. 12)

This example provides evidence that practice provides the need for concepts, like *the spring in the air*, to explain the phenomenon that is observed. Hopefully, this introduction has convinced you that instruments are key elements of material-discursive practices, and one way we can start to appreciate the role of instruments in coming to know science is to examine the role of instruments in practical and conceptual scientific understanding.

2.2 What Is an Instrument?

According to the Oxford English Dictionary (OED), the first record of use of the term, instrument, is from the fourteenth century when it was associated with something used by an agent for the performance of an action, sometimes associated with religion as in "God's instrument." However, in general the meaning of the term was diffuse. By the seventeenth century, there was some use of the term as I am thinking of it. For example, according to the OED in 1691, William Petty, natural philosopher and administrator in Ireland, wrote, "Changes in the Air, known by the Instrument call'd the Barrimeter" (p. 48), suggesting a consistency in the English language with the sense that I am using the term, instrument, in the argument I am making in this chapter. In her review essay, Deborah Warner (1990) argues that it was in the seventeenth century, as instruments such as the barometer, air pump, telescope, and microscope were being developed, that people started to group them "as tools of experimental or natural philosophy" (p. 83) to be distinguished from other types of instruments such as those used for music, medicine, and mathematics. Often instrument was used interchangeably with "philosophical apparatus" (p. 83). Nehemiah Grew, considered to be the person who started the field of plant anatomy and the first person to publish observations of the four major finger ridge patterns (see Grew, 1684), in his catalogue of objects belonging to the Royal Society separately identified instruments associated with natural philosophy from those associated with mathematics perhaps demonstrating his appreciation for the power of words to influence perception (Warner, 1990).

2.3 What Instruments Afford and What They Obscure in Science and Science Education

What really struck me as I researched the history of the relationship between air pressure and boiling point of water was how instruments also allowed different and new experimental questions. Once you have an air pump, big science for the time, you can ask questions about the nature of air and about what happens if I put a living thing, like a bird, inside the air pump and then remove as much air as I can (see Carroll-Burke, 2001). In the societies in which they were developed, instruments, like the thermometer and the barometer, were also used for entertainment. Thus some of the qualities of these instruments are that they conferred authority, were used in the conduct of experiments, and entertained (a bit like the seventeenth-century version of The Tonight Show). Carroll-Burke (2001) highlights how a study of “scientific engines” offers the possibility of examining forms of material culture that provide insight into the practices of science. Golinski (2000) provided me with some insights for thinking about why less attention is given to instruments as indicators of material culture, in science education. Something becomes an instrument through a social process by which it attains *taken-for-granted status* from consensus associated with the proper use of the instrument that disciplines users, a standardization of manufacture that ensures the development of uniform scales of measurement and routinized methods of calibration.

I developed greater empathy for thermometers once I began exploring the history of the development of thermometers for measuring hotness and coldness in seventeenth- and eighteenth-century Europe. I realized that although I had trained hundreds, if not thousands, of students to use an alcohol thermometer “correctly,” I had not really challenged the students I taught to consider how thermometers allowed us to ask different questions and their role in the construction of the phenomenon they measured. Golinski (2000) notes that for much of the eighteenth century, the thermometer was considered an “uncertain apparatus,” “its behavior being as much in question as the phenomena it was supposed to reveal” (p. 186). The manufacture and calibration of thermometers “posed a series of challenges on the material level and social resources were mobilized their standardization, replicability, and reliability” (p. 187). Francisco Segredo, a colleague of Galileo’s and an instrument maker, commented that one had to take a leap of faith about its reliability “although our feelings seem to indicate the contrary” (quoted in Golinski, p. 188). As I mentioned previously, in my many years as both a student and a teacher, I had never previously problematized the thermometer I was using beyond thinking about it as an instrument over which each user had control. This meant that my focus in teaching related to effective use by students, exhorting them to focus on the meniscus to get good values or making sure they only immersed the bulb in the liquid for which they were measuring the temperature. The issues that absorbed the builders of thermometers such as *what are we measuring*, *what material should the thermometer be made*, and *what should the expanding material be* were not a focus of consideration in the classroom, and certainly little consideration was given to how thermometers allowed experimental and natural philosophers to explore their world in different ways and how such instruments, the instruments I took for granted, could afford the students I taught similar opportunities.

2.3.1 Historically Speaking, Hotness, Coldness, and Thermometers

The writings of experimental philosophers, like Robert Boyle, who also explored the nature question of *coldness* and *hotness*, suggest that the constructs of hotness and coldness were explored separately during the early development of experimental philosophy. However, by 1772 the development of the thermometer had reached a level of reliability that it allowed for the exploration of both. The term thermometer first appears in English literature in 1626 when Jean Leurechon, writing as Henry van Etten, used the term, *thermometer*, with instructions for making one in his book of mathematical puzzles, *Mathematical Recreations*, first published in French in 1626 (Middleton, 1966; Van Etten and Oughtred, 1653). Unlike thermoscopes, thermometers had a scale (Middleton, 1966). Of course, a scale means that some level of calibration must have taken place. With thermometers today, we take two fixed points (the freezing and boiling point of pure water) for granted, but that was not the case in the seventeenth century. For example, Robert Hooke (1665/2003) suggested one fixed point, the freezing point of water, as his zero point. In 1777, the Royal Society of London accepted the recommendations of a committee they had set up under the leadership of Henry Cavendish, one of which was that the boiling and freezing points of water should be the accepted fixed points for thermometer construction (Chang, 2004). They also confirmed that the boiling point of water was a contentious issue but that is another story (Milne, 2013)!

Although glass seemed to be the material of choice for the making of a thermometer, the question of what the expanding material should be was more vexing with a variety of materials used including air, spirit of wine (a mixture of water and wine), and mercury. One of the early successful thermometer makers was Guillaume Amontons (1663–1705) who experimented air thermometers (Raman, 1973) (see Fig. 2.3).

However, in order to allow a "real" temperature of natural environments to be taken, a barometer was also required (Camuffo, 2002). The Academy of Science and Arts of Bologna when comparing measurements taken with various instruments

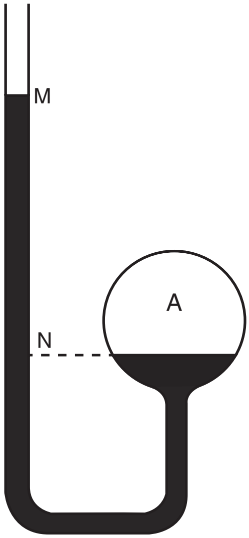

Fig. 2.3 An image of one of Guillaume Amontons' air thermometers. Amontons used mercury to block a bulb of air, which expanded, pushing on the mercury

in the early eighteenth century noted the inconsistent results obtained using Amontons' thermometer. However, they could only speculate on why different bulb sizes, variable moisture content of the air, and the ratio between bulb size and capillary should be included in their efforts to address the inconsistencies in the results. Mercury was attractive as an expanding material because its expansion was more manageable than air and its purity, when compared with "spirit of wine," more reliable.

The issue of whether or not the expanding material expanded uniformly was another question that challenged experimental philosophers, and yet rarely are these issues explored in science classrooms. The development of the thermometer entangled experimental philosophers in new phenomena just as intra-actions of multiple material-discursive apparatuses in the science classroom offer expanded opportunities for scientific practices to be advanced. Unfortunately from an educational perspective, much attention in school education seems to be focused on high-stakes tests or cleaving to the standards rather than exploring the question of how exploration of material-discursive apparatus in science might better support all students to see the study of science as important and interesting to them and an integral element of their identity as learners. It strikes me that if we developed science curriculum around questions such as what are we measuring, of what should that instrument be made, and how will this instrument change what we observe and therefore change the very phenomena we observe, our curriculum could be both richer and more inclusive.

2.4 Instruments and the Construction of the Ribosome

You might think that since thermometers have been around for a long time their black boxing is understandable but wonder about more recent discoveries. Reading Hans-Jörg Rheinberger (1995) as he explored "science in the making" through the identification of ribosomes as discrete organelles in the cell structure provides evidence of the role instruments played in moving scientists through a process by which "research objects acquired material presence and transient stability" (p. 52). Ribosomes, as we now know them, went from being *cancer-inducing agents* to *ultramicroscopic organisms* or microsomes to *ribosomes*. In 1910, Peyton Rous successfully transferred a cancer-causing agent from a sick chicken to a healthy one by injecting the healthy chicken with "cell-free tumor-tissue extract" (p. 54). Arguing that the effect was caused by an ultramicroscopic organism, Rous was not able to replicate this finding with human tumors. Observations that the filtrate could be freeze-dried and water removed and still retain its activity and that the active agent was resistant to UV light led James Murphy, Rous' assistant, to wonder if the active substance might be an *endogenous cellular substance of enzyme-like nature*. The development of ultrahigh-speed centrifugation, which sedimented the agent, provided further evidence of its particulate nature, and chemical analysis indicated that it was 30% lipid, 10–15% ribose nucleic acid, and 50% protein.

The other instrument available to observe the structure of cells was the light microscope and associated fixation strategies, which by the turn of the twentieth century had led to the identification of a bewildering array of cytoplasmic granules. However, at least light microscopy preserved cells, while ultrahigh-frequency centrifugation destroyed them (see Fig. 2.4).

The question scientists needed to answer was how they could keep cells intact during centrifugation if they wanted to better understand the particles they observed. Enzymatic studies had already shown scientists that what they now called microsomes were different from the mitochondria. The development of the transmission

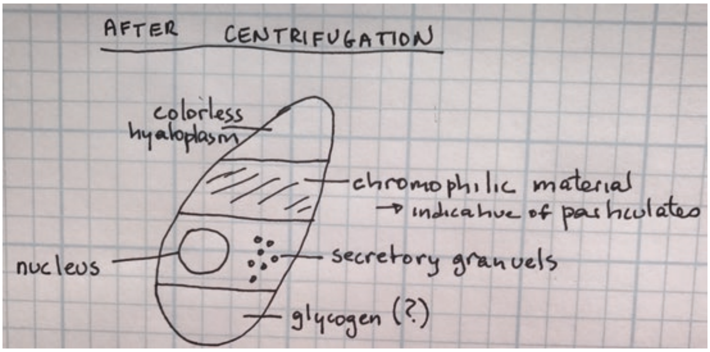

Fig. 2.4 Ultracentrifugation resulted in different differentiated layers, but the internal structure of the cells was destroyed. The "chromophilic material" indicative of particulates was particularly interesting to scientists

electron microscope initially by Max Knoll and Ernst Ruska (Nobel Prize in 1986 for his research on electron optics) initiated scientific endeavors to develop electron microscopes that would allow the study of organic material such as cell structures.

In the mid-1940s Albert Claude and Keith Porter worked on developing biological material that optimized the capacity of the electron microscope. They developed other techniques such as growing cells on glass covered with plastic film so that the film could be peeled off, fixed with osmium tetroxide, transferred to a small metal mesh disc, and dried so that it could be observed through the use of an electron beam in a vacuum. What I want to emphasize with this example is the necessary intra-actions between scientist, electron microscope, and preparation techniques that supported the construction of a new phenomenon of highly magnified cell structures.

However, as Rheinberger (1995) notes if scientists expected to be able to see clear structures embedded in the cytoplasm of normal cells, they were to be disappointed because what they saw instead was points, vesicles, threads, and filaments that were anything but regular. According to Rheinberger, Claude noted in 1948 that in order to construct the phenomenon of highly magnified cell structures, there was a need to make thinner slices, a demand that was beyond their capabilities at that stage. Further developments in ultrahigh-speed centrifugation tools and protein synthesis led to the identification of specific ribonucleoprotein particles, which Howard Dintzis called "ribosomes" (Dintzis, 2006), although there exist other claims to authorship:

> In 1958, the first symposium of the newly formed Biophysical Society was held, and many papers on the particles-until then called nucleoprotein particles-appeared in the proceedings edited by R. B. Roberts (90). At that symposium, Roberts proposed the shortened name "ribosomes" for particles that contained complexes of one-third to one-half RNA and two-thirds to one-half protein, were 10-15 gm in diameter, had sedimentation values in the 100-20S range, were found in all cell types, and seemed somehow to be involved in protein synthesis. (Siekevitz & Zameczik, 1981, p. 55)

This example highlights what typically gets left out of textbook accounts of ribosomes, the role of instruments in the construction of the phenomenon of ribosomes. It was the instruments that supported the reality of phenomena from *cancer-inducing agents* to an *ultramicroscopic organism* or microsome to a *ribosome.* This example also highlights the mattering of both the instruments and human agent, the emergent material-discursive nature of discovering ribosomes, and the entanglement of matter and language. Rheinberger (2000) was interested in these cytoplasm particles as scientific objects that sit at the intersection of disciplines in the life sciences and are framed at the material level. These objects are real but independent enough to manifest themselves in "unthought-of ways in the future" (p. 272). In the case of ribosomes, they went from cancer-inducing agents to microsomes to ribosomes. Yet as soon as they become accepted scientific objects, like the ribosome became, they lost their resilience and recalcitrance and become black-boxed because they were accepted and taken for granted or they became marginalized as unexpected developments in another field as the focus of attention moved elsewhere.

2.5 What Instruments Afford and What They Obscure in Science and Science Education

These two examples from the history of science illustrate that even if instruments are often ignored in the teaching and learning of science, educators might consider giving more attention to scientific instruments and scientific objects. These examples illustrate how the development of instruments allows different and new experimental questions. Take another example and consider Robert Boyle. Once he had an air pump, big science for the time, he could ask new questions about the nature of air and explore those questions through practices (see Carroll-Burke, 2001). In the science classroom, perhaps teachers could challenge students to consider how an instrument affects the questions one can ask illustrating how an instrument can change what counts as scientific practice (Latour, 1994). Additionally, typically, in science classrooms instruments are given greater moral power than the children and youth using them. As Latour (1987) noted, with “black boxing,” specific instruments and objects become such well-understood material objects that teachers and students unproblematically accept them as morally and cognitively reliable for eliciting natural phenomena. Thus, students are disciplined using instruments with the expectation that if an instrument is used correctly, it will produce observations that conform to what is expected or that they will observe the expected phenomenon. Indeed, students are often “disciplined” into calculating “percent error” of their result when compared with anticipated and expected value, thereby placing the burden of “error” on the students’ use of the instrument. However, such authority can be explored and challenged with a greater awareness of the historical development of instruments and the phenomena they produce as a result offering the possibility of examining forms of material culture that provide students with richer insight into the constructed nature of the practices of science.

2.6 Relevance for Science Education

I have long been a proponent for a role for history in the teaching and learning of science, but in this case, thinking about the relationship between the instrument and human in the construction of scientific practices and phenomena really got me thinking about designing courses for scientific literacy. In this thinking I was influenced by feminist philosopher and scientist, Karen Barad. She argues that the relevancy and context approach to developing science curriculum is all wrong because relevancy is undertheorized and often context is constructed in a way that instantiates bias and promotes powerful ideologies about how certain groups respond to science (see Barad, 2000). She argues further there is potential for context-based approaches to reify a nature/culture dualism that seeks simplistic cause and effect relationships between science and culture. She was also critical of courses for students in which entertainment becomes a substitute for learning. Her position is that for the benefit of all science learners, science educators have a responsibility for teaching "science in a way that promotes an understanding of the nature of scientific practices" (Barad, 2000, p. 223) and identifying how we, as educators, understand the nature of scientific practice. She asks:

> If science students do not learn that doing responsible science entails thinking about the connection of scientific practices to other social practices, then what is the justification for our current confidence as a society in the ability of scientists to make socially responsible decisions? (p. 223)

Barad (2000) challenges us to think about developing a curriculum that takes "account of discursive and material constraints on knowledge productions" (p. 223) and inspires a love of science based on recognition of "its strengths and limitations." She argues for science literacy as agential literacy. Barad argues that there is no inherent cut between objects, and agencies of observation and phenomena are constructed through the cuts we make during the experimentation and the measurement process. She argues further that practices exist as the "intra-action of material-discursive apparatuses" (p. 234) that are not simple instruments but formed out of particular practices, so that reality is agential. Unlike Barad, I do not think of instruments as simple but rather as an example of the apparatuses that offer the possibility of affording scientific literacy which in Barad's words is about "learning how to intra-act responsibly within the world" (2000, p. 237).

In their book on multimodal teaching and learning, Gunther Kress et al. (2001) claim there are limitations for classroom research that focuses exclusively on language. They argue for a focus on modes of communication of which language is one not the totality. But I wonder if there is a need to also examine the role of material culture especially as it is instantiated in the instruments we take for granted in science teaching and learning. I wonder if there was a more systematic problematizing of such instruments, we might also be less likely to blame the students for how they use such instruments. I would like to build on the work of scholars such as Mitch Resnick et al. (2000) who conducted case studies of children building scientific instruments because while I see that as one approach to opening the black box of instruments and their use in science education, there may be others that so far I have not considered.

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Chapter 3 The Materiality of Materials and Artefacts Used in Science Classrooms

Kathrin Otrel-Cass and Bronwen Cowie

3.1 Introduction

Classroom teaching and learning in science is anchored around the building of understanding, skills and competencies that are centred on the fabrication of (often) verbal or written academic knowledge. To support such a production, teachers make use of a wide variety of materials and artefacts (Kalthoff & Roehl, 2011). These objects can be as mundane as chalk- or whiteboards or as specific as materials used for scientific experimentation. However because of their ubiquity, these materials are often assumed to be neutral, and for that matter, they are often neglected in terms of their significance to overall teaching and learning outcomes (Roehl, 2012). Teachers or students who want to support their explanations of scientific phenomena make use of objects in very particular ways and not always or necessarily in the everyday use of these items. For instance, an illustration of cell structures qualifies the material 'onion skin' in a particular way when it is viewed under a microscope, and this is different how an onion may be observed and experienced in an everyday situation (unpeeled with other onions, cut for cooking, etc.).

We will begin by discussing the literature on materials and materiality and then consider how materials and artefacts in science classrooms have been studied. We then present an analysis of different materials that were used in New Zealand primary science classrooms to show how teachers considered materiality when they incorporated objects/artefacts into their lessons and activities. We will argue that

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teachers used them to build ‘common knowledge’ (Edwards & Mercer, 1987); to problematize and present departure points for discussion and critical thinking; to make ‘new things visible, or familiar things visible in new ways’ (Wise, 2006); and to show how artefacts were used as an adjunct to talk to examine materials and materiality. Finally, we will summarize the findings and discuss implications and future directions for research.

3.2 Materials, Materiality, Tools and Science

To begin with we distinguish between materials as natural objects and artefacts as made objects (i.e. not occurring naturally) (Ingold, 2011). Typically, artefacts ‘are for something’ and this means that they have a function.

We recognize that materials and materiality are of course connected, but we are left with the question of how exactly material is different from materiality. By drawing on Tim Ingold’s (2011) thinking, we deduce that materials are the natural objects in the world that are made from substances that have particular properties. For instance, a stone’s properties may include that it is hard (sometimes), it is resistant to fire or water (some better than others) or it may feel hard, rough, dry, heavy or smooth depending on its constituents—the type of stone it is.

The properties of materials are not fixed attributes but are also ‘processual and relational’, or to put this another way, they are ‘practically experienced’ in activities that draw intentionally or not on their different qualities (Ingold, 2007, p. 17). Ingold uses the example of observing a stone when its surface is wet and slowly dries. But a stone could be experienced also by scratching it with a nail to identify how hard it is or it may be evaluated as to being the right shape for skipping on water. These illustrations provide examples for the processual and relational attributes of materials. Also, many materials or artefacts that we use and/or experience are composed of different parts and ingredients from different sources and with different properties, but when assembled, these individual properties are not easily or immediately apparent. For example, a kitchen knife has a blade and a handle. The blade is often made from special steel with perhaps wooden handles fastened together with rivets, or the blade may be melted on to the handle. The blade’s steel is frequently an alloy of carbon and iron or sometimes an alloy of iron, chromium, nickel, molybdenum and only very little carbon. But when a kitchen knife is touched and used, the individual properties of those components are not easily evident.

The materiality of an object is not the same as the properties of its materials. Materiality is not something that can be ‘touched’, but it is what makes things ‘thingly’ (Ingold, 2011, p. 9). It is when we come in contact or interact with the ‘surfaces’ of materials that we experience their materiality. Ingold uses the example of a smooth river stone that is made wet and dries. Its properties have not changed, but it has a particular materiality through the connection we establish with changes in its surface as it dries. Materiality then is about how we see things around us in their entirety, because we do not necessarily see the dematerialized components with their individual properties and nor, at any one time, do we see them in isolation from our earlier experiences with them. As Ingold (2007) explains, the properties of materials can be likened to their histories and to describe the properties means telling their stories. Another example is a bucket that we see as a watertight cylinder that has an open top and a flat bottom and a handle. We do not necessarily see it for its components, being made of galvanized steel, for example, and so these material properties can stay seemingly hidden while they are in fact always there and contribute to how we think to use an object like a bucket.

Educational researchers with an interest in material objects have often focused on examining material objects as ‘tools’. For instance, some have explored the role of symbolic or material artefacts as tools that mediate learning (Cobb, 2002). These ideas are based on Vygotskian sociocultural activity theory and describe that in a classroom artefacts can complement, anchor and/or scaffold student interaction and learning by providing ‘vehicles of thought’ to the extent that they are ‘integral and inseparable components’ of these activities as socio-material practices (Engeström, 1999, p. 29). As Wertsch (1991) points out, material artefacts and phenomena have no intrinsic meaning: ‘Only by being part of action do meditational means come into being and play their role. They have no magical power in and of themselves’ (p. 119). Material objects have to be actively enacted as an educational object. They shape and are shaped by classroom practice through the way they selectively present science and science lessons as a particular kind of social situation. The persistence of material objects allows them to become a focus of joint activity, and their conceptual or symbolic aspects allow them to contribute to students’ progressive attempts to increase their understanding of the phenomena under investigation with these aspects interacting to afford and constrain the forms of action that are likely to ‘emerge’ in a setting (Wells, 2003).

However, tool use is also connected with storytelling because ‘to name a tool invokes a story’ (Ingold, 2011, p. 56). To talk about a hammer, for example, means to think about the action of using a hammer to pound a nail into the wall. It evokes body memories of holding, swinging and hammering. It tells stories about the different materials that are being hammered in and against. Adopting this way of thinking about tools allows us to bring in the circumstances that account for the change of conditions under which activities that involve tools and materials occur. This means that to think and talk about tools requires careful consideration of the circumstance (social and material circumstances), the purpose and the objectives of using tools.

The aim of this chapter is to bring the ideas that were discussed above together and explain how significant it is for science education to consider materials and the history of their properties (their materiality) and the storytelling that shapes how materials are used as tools.

3.3 Materials and Artefacts in Science Education

The materials that make up and can be found in late modern science classrooms form, and inform, what teachers and students discuss and talk about in the classroom (Cowie, Moreland, & Otrel-Cass, 2013). They provide a backdrop within which expression of meaning (both verbal and non-verbal), interaction and emotional experience in classrooms occurs. In large part, the meanings, interactions and emotions that can be witnessed in school settings are situated in a material world. However, science education research has paid little attention to how materials shape these aspects (Roehl, 2012) despite the significant role material objects play in producing scientific understanding. Science studies emphasize that science has a material and a social dimension (Anderson, 2007); new knowledge develops as a consensus explanation of natural phenomena, with this mediated significantly through materials and instruments used. For instance, an example of scientific knowledge generation could be to find the boiling or freezing point of water and observing what may happen when salt is added. While the materials water and salt are in the foreground, vessels, cooling and heating devices are not necessarily foregrounded and yet are instrumental in shaping the processes and practices involved.

Talk has dominated research on classroom learning in science (Lemke, 2000). Less attention has been paid to what Pea (2004) terms the 'technological' aspect or the role of designed and material artefacts in the classroom. The ubiquity of artefacts in the classroom is perhaps what explains their comparative invisibility in analysis of classroom interactions. Nonetheless, natural materials and made artefacts (Ingold, 2011) are integral to and inseparable from human endeavour and functioning (Engeström, 1999). Pea, for example, (1993, p. 50) notes, while it is people who are in activity, artefacts commonly provide resources for its guidance and augmentation. Material artefacts and objects both enable and constrain what is possible. In the context of the classroom, it is important to remember that artefacts carry the intentions and norms of cognition and form a part of the agency of the activity, where this includes serving as a constraint (Miettenen, 2001). Understood this way, resources or artefacts already contain within them human wisdom which blurs the distinction between human and non-human intelligence (Lee, 2014). As Roehl (2012) explains it, material artefacts carry multiple qualities and 'have to be turned into epistemic objects by various means before they can become part of (educationally relevant) human–object relations' (p. 66). Teachers need to introduce and talk them into social action for them to support the goals they are seeking to achieve with and through the use of particular material artefacts.

In some of his early work, Wolff-Michael Roth explicated some of the roles artefacts can play as part of an ensemble of influences. These include the chalkboard as a site for the public display of materials and artefacts that are visible to all that can afford the coordination of conversation over space and multiple participants in whole class settings (Roth, 1996). With colleagues, he has elaborated on how artefacts operate to provide scenarios and resources for action and for unfolding conversations (Roth, McGinn, Woszczyna, & Boutonne, 1999). In the study of a simple machines unit, Roth and his colleagues distinguish between teacher- and student-produced artefacts, where these could be material objects or inscriptions. Roth noted that, as the teacher, he designed tasks and supporting artefacts to focus student thinking on topics considered important by him. The objects he designed ordered activity and interaction in terms of topic, physical space and temporal development. Typically, in a whole class setting, students near the 'focal artefact' had better access to artefacts to support and anchor their talk. Roth and his colleagues concluded that in the classroom, artefacts are influential but have to be evaluated in terms of how they support and scaffold students' participation in scientific discourse and practices. A study by Maria Varelas et al. (2008) illustrates the role that an ambiguous object can play in prompting students to refine and articulate their ideas in both small group and whole class settings. In their example, the students sorted several everyday objects into groups of solids, liquids and gases and recorded their decisions on a three-column chart. They then discussed their reasons in a whole class setting to produce a whole class chart. This inclusion of ambiguous objects ensured there was considerable debate amongst the children as part of negotiating what would be taken as shared common and legitimate knowledge.

Research on teaching with objects that offers a direct, tactile experience for students has clearly established that hands-on learning is a rewarding, essential experience for most learners, one that can help them achieve better understanding of topics and sometimes offer them a leadership role amongst their peers and should be part of good science teaching (e.g. hands-on learning; see Cobern et al., 2012).

Building on these studies, we propose that it is important to analyse how materials and artefacts are being incorporated into activities, not as neutral objects but as materials with histories and established/accepted ways to experience aspects of their materiality.

3.4 Materials and Artefacts in Science Classrooms: Our Examples

Next we present examples from New Zealand primary school science classrooms to illustrate how teachers deployed material objects and artefacts by identifying their materiality to provide scenarios and resources for interaction. They furnished resources within and for 'hands-on' learning activities in various ways:

(a) Collections of objects to build 'common knowledge' (Edwards & Mercer, 1987)
(b) Objects that problematize (Varelas et al., 2008)
(c) Artefacts to make 'new things visible, or familiar things visible in new ways' (Wise, 2006)
(d) Artefacts as an adjunct to talk.

For this purpose we draw on data generated within two projects: the Classroom Interactions in Science and Technology Education [InSiTE] project, which was a 3-year study of teacher-student interactions around science and technology ideas (Cowie, Moreland, Jones, & Otrel-Cass, 2008), and the Science Classroom Investigations of the Affordances in Teaching with ICT [SCIAnTICT] project (Otrel-Cass, Cowie, & Khoo, 2011). Both projects were funded through the Teaching and Learning Research Initiative (TLRI) New Zealand. The Classroom InSiTE project aimed to investigate formative assessment interactions in primary science and technology classrooms as well as the nature and contribution of teacher pedagogical content knowledge to these interactions. This research was framed within a sociocultural view of learning (Roth, 2005). The research team interpreted this orientation as requiring explicit attention to who was involved in an interaction (individuals, groups, the whole class), what was talked about and how this talk was supported by artefacts and material and gestural resources. The SCIAnTICT project investigated what it looks like when teachers and students use ICTs in science classrooms (Otrel-Cass et al., 2011). This meant that the research team investigated possible sources of disruption, innovation, change and development in the ways ICT affected student engagement and attainment of science ideas (Hennessy, Ruthven, & Brindley, 2005). In both projects, data were collected via video and audio recordings from classroom observations together with field notes and records from interviews as well as teaching materials produced by teachers and students. The focus was on the ways material objects and artefacts were introduced and mediated dialogue and on how they could be used to scaffold students towards more independent ways of working. The project also investigated the role artefacts played in making student learning visible and public. Next we will focus on the three themes identified earlier.

3.4.1 Objects to Build 'Common Knowledge'

In today's classrooms, which tend to be characterized by diversity in student backgrounds, students' classroom experiences with material objects can help to develop what Edwards and Mercer (1987) described as 'common knowledge', or shared understandings between teachers and students and amongst students. Common knowledge is an important classroom resource that, when activated, can provide a shared contextual frame of reference for interaction and meaning making (Cowie, Moreland, & Otrel-Cass, 2013).

Early in a teaching sequence, a number of our teachers in the InSiTE study used guided examination of a collection of objects as a strategy to ensure all students had some knowledge and experience of an object/phenomena. The InSiTE study investigated the nature of formative assessment interactions from within a sociocultural frame (Wenger, 1998). We followed the teachers into their classrooms when they were teaching primary science and technology lessons. Most straightforwardly, when Jane, a teacher in the study, noticed that not all of her Year 1 students (aged

5 years) knew what a seed was, she set up a 'nature table' to which students contributed seeds from home. Each day for a week, she guided the class in a review of the seed characteristics—for example, shape—or likely means of dispersal and so on. Brenda, a Year 4 teacher in the same study, began a unit focused on students developing a modified cheese with a class brainstorm of all the students who knew about cheese. They then conducted a product analysis of three different types of cheeses and recorded their views on a teacher-constructed worksheet. The use of real cheeses proved to be an exciting experience for some students who obviously had not tasted strongly flavoured cheese before. For students who had experience of eating various cheeses, the activity allowed them the opportunity to share their knowledge and show a degree of expertise. Brenda carefully chose the cheeses to accentuate the criteria the students needed to take into account when developing a cheese of their own design—aroma, appearance, texture and flavour. This experience provided the students with a common basis comparison in subsequent discussion and testing. It helped them understand the task criteria and helped eliminate any potential to blurring of the distinction between them.

In some cases the desired outcome of an examination of a set of objects was student understanding of the 'thingness' of the set. In one instance of this, Lois, also a teacher in the InSiTE study, provided her young students, aged 5 years, with a collection of fossils. She asked them to think about what could be a fossil and how they thought fossils might form. What was interesting was that many students were not convinced that living things that were still around now could become fossils because the set of fossils did not include an example of a lifeform that was still around today. In another example, Glenys collected a set of different tongs (fire tongs, sugar tongs) and asked her students aged 7 and 8 years to develop a description of 'tongness'. Glenys planned this activity to help students think about how to design tongs to retrieve an object that was inaccessible by hand.

Tina (a teacher of Year 7 and 8, children aged 11 and 12 years in the SCIAnTICT project) planned a number of material encounters for her students as part of them learning about the water cycle. The development of common knowledge in her classroom took a different path. She taught the water cycle during the winter months, and one morning, after a clear night, she sent the students out to collect blades of grass that were frozen. As soon as the children brought the grass inside the heated classroom, the grass defrosted. Tina decided at that moment that it was important to observe more closely the changes in the frozen dew. She asked the children to cut some grass carefully and put it on a plate, not in their hands, bring it quickly back to the classroom and put it immediately under the video microscope. Tina recorded the defrosting of the grass magnified x60 under the microscope and projected the image onto an interactive whiteboard [IWB]. Students were able to see the detail of the ice on the grass as it melted and transformed to water. Tina directed the students to note down their observations from watching the x60 magnification. By using the IWB, Tina was able to ensure that the class as a whole had easy visual access to the level of detail they required to identify the material changes occurring. Tina's talk mediated students' observation and collective analysis of the frozen dew on the grass blade. The observation and magnification were also recorded on video so that

Tina and the class could refer back to as point of shared reference. Tina who was also a teacher in the InSiTE project used a video microscope to project a magnified image of the mould on bread on an IWB to the same effect (Ryan & Cowie, 2009). The students observed the mould using their naked eye, a microscope and the video microscope. The detail of the spores became apparent at high magnification; all the students were able to view and identify the different structural features of mould. There were exclamations of amazement at the detail the students could see in the greatly magnified image.

3.4.2 *Objects That Problematize*

Artefacts can be used to challenge student thinking, particularly those that are ambiguous with respect to the target construct (Varelas et al., 2008). As part of our InSiTE study, Jane also designed a unit focused on physical change. For one of the introductory activities, she asked the children to sort a set of biscuit ingredients into wet and dry (flour, egg, baking powder); the recipe required these to be combined separately and then mixed. She then asked the children to sort the ingredients into solids and liquids. The children were intrigued and debated whether to place the raw egg in the wet or dry column and in the liquid or solid column. The students held, felt and gently shook the 'material' egg to make a decision. In the end they compromised and made a category that spanned the two on the basis that the shell was solid and the inside was liquid.

In this activity the students discovered the materiality of the egg using their hands, their eyes and ears (looking and listening). The eggshell, the surface against which eggness 'stands out', was here the focus to problematize liquids and solids. The teacher deliberately included this activity and provided samples that the students could touch. For the egg the feeling of its surface using fingers and palm of the hand combined with a gentle shake differed from and extended thinking about the materiality of an egg. Touching to understand, also called haptic perception, depends on contact with materials or artefacts, through the whole body (e.g. Merleau-Ponty, 1968), through the feet (Ingold, 2004) or through the hands (Hatwell, Streri, & Gentaz, 2003). With touch-based interaction being a key feature of digital learning environments (Crescenzi, Jewitt, & Price, 2014), the role of touch is gaining significance as a mode of exploration.

3.4.3 *Making New Things Visible*

Reducing our perceptions of the world to seeing things only using our eyes can leave new things unopened (Wise, 2006). Yet science has perfected the art of seeing, at different scales and through different means. Wise explains that 'making things visible is to make them real' (p. 81); visualizations shape knowledge production in science and become part of particular ways of thinking and operating in the field. As Wise puts it, it is not about the production of illustrations but rather about the production of arguments through the use of visualizations. The previous examples of melting ice and examining mould relied on the projection of a highly magnified image that allowed new ways of seeing and explaining what the properties of water and the fungi 'mould' are.

Carol discussed with her Year 7 class physical and chemical changes. The main point that Carol wanted to make was that in a physical change the substance itself doesn't change, while a chemical change involves a chemical reaction and is not reversible. Carol was aiming to make conceptual ideas visible around physical and chemical change. She asked her class to follow through a number of steps and reflect after each step:

Carol: Fill your cup halfway with water.
Now let's pour in orange juice.
How is it going to change it?
Child: If you add the orange juice you can't really take it out.
Carol: Is it going to taste the same?
Child: No.
Carol: So you are going to change the taste and the…
Child: …colour!
Carol: What will happen if we add baking soda and sugar?
Child1: It will make bubbles.
Child2: Maybe it gets thicker…
Child1: No

The class experiments with the juice and baking soda.
Later Carol reflected:

> I started with hands on activities to get the students thinking in a tactile way. They could see the changes they were making and although it lead to some confusion at times. I used the example of the drink because the children were familiar with it, they knew how it looked and tasted. Using the drinks as a learning experience allowed the kids also to use their senses to find out things. Of course when they added the baking soda and sugar the drinks started fizzing. I built on this new information, the visual evidence they collected to discuss and build on what they already knew and it allowed them now to make predictions based on their new experiences.

When the children were asked about chemical change, they remembered that they were able to see changes of colour and taste the watered-down orange juice, but they also smelled the juice bubbling after they added the baking soda. They saw and learned new things including that you couldn't change the mixed materials back.

3.4.4 Materials and Artefacts as an Adjunct to Talk

In science classrooms it is not uncommon for students to present their ideas. Presentation of ideas supported by a self-produced material artefact shifts the authority/power to the student(s), and the ownership of the artefact was linked with ownership of ideas. When students used artefacts they had developed themselves in whole class presentations, they spoke with authority and confidence about their science and technology ideas. The artefact anchored and/or augmented their interactions with peers, providing a focus for their explanations and peer questions. It served as a source of continuity between whole class and small group settings. What students chose to record and bring to the whole class setting provided evidence of student understanding and learning.

When student talk was not supported or initiated by the relevant artefact, they experienced more difficulties in the communication of their ideas. For example, in a digital classroom, Tina had asked students to create an animation of the life cycle of mould. Each student stood by the digital whiteboard as the teacher brought up their animation for presenting to the whole class. During the animation the student explained what was happening as the animation unfolded. Several of the students became aware during the presentation process that they had omitted either a phase or label from the life cycle which they had not been aware of before verbalizing their life cycle. Tina asked questions and prompted the students to unpack omissions and to help the children expand on their animation. Three comments made by Tina were:

What could he do to improve this animation?
Some graphics are quite good, but not so powerful without the words.
You should focus on getting the graphics done before doing fancy headings.

Tina reflected that when students had not been able to complete the animation, perhaps because of technical difficulties or time factors, they struggled to explain the stages in the mould life cycle. This illustrates the important supportive role that a student-generated artefact can play in anchoring ideas about materials.

3.5 Discussion

In this chapter we discussed how unfolding the materiality of materials and artefacts can be used in science classrooms. Through our examples we have shown how materials can guide and mediate class interaction in ways that contribute to student learning. Materials were used by teachers to capture and focus student attention and interest, to introduce new ideas and procedures, to cue and access student knowledge, to support the construction of new knowledge and provide continuity and connection. Materials and artefacts supported rich whole class cumulative discussion when teachers made them available over time; they provided scenarios and resources for thinking. The examples shared showed that meanings were socially constructed but also that students needed support to identify salient conceptual and physical features; otherwise these can be ambiguous to them. Put another way, teachers need to explain the form and function of an artefact and the interaction of these in order for students to appreciate the relevance of these aspects to the task at hand. Teachers also need to consider the role of the artefact in the overall flow of activity. When students do not clearly understand the teacher-intended function of an artefact, they use their own experiences to interpret its meaning.

Teaching with materials and artefacts is a powerful way to facilitate learning and levels of reasoning (Hatcher, 2012). It offers a range of accessible ways to anchor and focus on what is to be learned. It can also stimulate student interest. Materials possess materiality that can be used in class to explore the properties of their components (Ingold, 2007). Teaching with materials and artefacts can enhance students' ability to connect with and communicate what can be deduced through sight, touch, hearing, smell and even taste; it can 'invoke a story' that draws on and integrates a range of experiences (Ingold, 2011, p. 56).

Materials and artefacts are often overlooked as a mechanism for agency within an activity. They can serve as an evolving record of the salient points of what is taken as shared and as a reference of thinking and as a means of bringing back ideas into play to support for meaning making. The teachers in our examples looked for material encounters that could be linked with students' everyday experiences while providing opportunities to explore the properties of these materials. Materials and artefacts act as resources to reduce the need for the full articulation of ideas as students are grappling to make and communicate meaning. In our view, the role materials, artefacts and their materiality can play as a focus of and meditational means for productive conversations in class, is worthy of our ongoing attention.

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Chapter 4
Using Spacetimemattering to Engage Science Education with Matter and Material Feminism

Kathryn Scantlebury, Anna T. Danielsson, Anita Hussénius, Annica Gullberg, and Kristina Andersson

4.1 Introduction

Material feminism is producing new knowledge about humans' engagement with the natural and physical world, the agentic nature of matter and the sociocultural context, and the entanglement of the material, such as bodies and learning spaces and time (Barad, 2007). Susan Hekman (2010) outlines the movement in material feminism[1] to reclaim matter into a feminist discussion and a shift from epistemology to ontology and the rejection of "the fixed ontology of modernity and the linguistic construction of the postmodernism" (p. 89). According to Hekman, the production of the subjects is not only connected to social and discursive practices, but also it is entangled with material entities that occupy spaces such as politics, religion, and/or education.

Material feminism offers a unique theoretical framework for science educators because it moves theorizing and analysis from the postmodern that focused solely on language/discourse critique to reengaging with matter/material (Barad, 2003). However, we also acknowledge a challenge of introducing and incorporating a

[1] There is a discussion as to whether this is material feminism, new materialisms, or new feminist materialism (see Lykke, 2010). For the purpose of this chapter, we use the term material feminism.

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theory into science education research that has emerged from discussions about the limitations of epistemology given the characterization of science education research as primarily focused on knowledge production in teaching and learning (Hussénius, Scantlebury, Andersson, & Gullberg, 2013), as masculine and politically conservative (Lemke, 2011), and as having sporadic engagements with poststructuralist theories (Bazzul, 2012).

While discourse contributes to the construction of reality, it is not alone or the sole entity to impact that reality, and that matter along with other factors need consideration (Hekman, 2014). When considering those other factors, Barad (2007) introduces the concept of entanglement to note that "matter and meaning are not separate elements" (p. 3) in her argument that matter matters. But entanglement in Baradian theory is not a description of separate entities entwined with each other "to lack an independent, self-contained existence" (p. 3) but rather that entities come into being through the intra-actions between them; those intra-actions produce material-discursive practices.

This chapter will utilize Barad's concept of *spacetimemattering* to reintroduce matter/materiality into science education by "reading data with and through a materialist lens" (Mazzei, 2013, p. 777). *Spacetimemattering* are forces in producing material-cultural worlds through the intra-actions between human and nonhuman (matter) that also recognizes that time is entangled with space and matter (Barad, 2007). We will introduce *spacetimemattering* by "cutting together-apart" a preservice teacher's account of learning science, and in doing so, our intention is to describe and use key Baradian concepts of *intra-activity*, *agential realism*, *phenomena*, *apparatus*, and *material-discursive* practices to identify if there are gendered pedagogical practices, with an assumption that practices are central to material feminist praxis (Barad, 2007, 2014; Taylor, 2013).

4.2 Entanglement of Space, Time, and Matter: Spacetimemattering

> In lower secondary school, science immediately became more boring. In biology class, we would just sit indoors and watch the stuffed birds and listen to recorded birdcalls instead of going out to look and listen. Often the teacher just stood at the blackboard and wrote, and we would copy what he wrote. [...] In upper secondary school, it became even harder and even more boring. Then we were also just sitting still. We never got to be outside and look at things, instead the teacher followed the text book to the letter, because it was what was going to be on the test, instead of teaching us what we ought to know for the test by being out to observe and discover for ourselves.

Matter is agentic and intra-acts with the human to produce phenomena that are co-constituted and emergent (Taylor & Ivinson, 2013). The uniqueness of entanglements (i.e., material culture, time, space, human, matter) is that the entities involved are not just intra-acting with each other; instead the entanglement produces something that is “greater than the sum of its parts.” However, to understand how space, time, and matter are intra-actively engaged, we foreground each concept individually in the quote from the student before examining the resultant “sum of parts.” The quote illustrates the entanglement of space (indoors, outdoors), time (lower secondary school, upper secondary school), and matter (stuffed birds, recorded birdcalls, blackboard, textbook). Making agential cuts “entangles us ontologically with/in and as the phenomena produced by the cut we make” (Taylor, 2013, p. 692). However, what are agential realism and an agential cut? A phenomenon? And what does it mean that space, time, and matter are intra-actively engaged? We will discuss these core concepts in the next section.

Agential realism forms the basis of Barad’s theory which proposes that matter is agentic and “scientific practices are intra-actions of multiple *material-discursive apparatuses*” (Barad, 2000, p. 2). *Intra-actions* position matter as agentic which challenges the heretofore dominant assumption that knowledge is uniquely a social construction (Hekman, 2010). The engagement of matter through *intra-actions* generates *material-discursive practices* and produces *phenomena*. In Baradian theory, subjects do not have individual agency but generate agency through intra-action. The student describes an occurrence of how the material-discursive practices of the intra-action between the nonhuman (recorded birdcalls) and human (herself, other students) are enacted as boredom in the students. In the classroom space, where the intent was for students to learn biology, they instead copied notes. This intra-action between the student, a pen, and paper produces a different set of material-discursive practices. But we should halt the analysis at this point and acknowledge that by selecting a particular text for discussion, we have used an “agential cut” which produced a phenomenon that is momentary and unique. Furthermore, as researchers, we are not “apart” from the data but are entangled.

Agential cuts make temporary boundaries and generate phenomena. When the boundary is made, a “measurement” has occurred. Within Baradian theory, the concept of *apparatus* extends beyond physical equipment (such as instruments). *Apparatus* emerges from the specific material-discursive practices and can construct researcher subject and the object of the research. Consider the scientific material-discursive practices the student has learned through engaging with recorded birdcalls and stuffed animals, compared to “being out and observing and discovering for ourselves.” The teacher used an agential cut in teaching the students about birdcalls through recordings rather than their engagement with birds in a natural setting. The preservice teacher noted how this pedagogical choice evoked feelings of boredom and disengagement with the subject matter and that going outside to hear birdcalls would have provided an opportunity to “discover for themselves.” The preservice teacher’s feelings are a part of the material-discursive science practices that emerged through their entanglement with matter; possibly those emotions may have been positive if the preservice teachers were listening to in situ, rather than recorded birdcalls.

4.2.1 Unentangling "Material Moments"

Taylor (2013) identified "material moments," when utilizing Barad's diffractive methodology to examine matter's agency, bodily practices, and how they intra-act in classrooms. In contrast to reflexivity, or critical reflection that promote "mirroring and sameness," diffraction examines "heterogeneous history, not about originals" (Haraway, 1997). As a methodology, diffraction generates different patterns and thus leads researchers to new knowledge and considers the material consequences and the consequences of the material in framing and analyzing the research (Lykke, 2010). To illustrate the use of diffraction as an analytical tool (or in Baradian terms – *apparatus*), in this next section, we examine what differences, if any, emerge from first considering space and then time and matter by paying attention to the material-discursive practices that emerge through the different agential cuts and the phenomena that emerge. We summarize through a discussion of how the enfolding of *spacetimemattering* will always provide opportunities for the production of new material-discursive practices that may generate positive responses from students to science experiences and learning.

4.2.2 "Material Moments": Space

> Spatiality is intractively produced. It is an ongoing process of the material (re)configuring of boundaries-an iterative (re) structuring of spatial relations. Hence spatiality is defined not only in terms of boundaries but also in terms of exclusions. (Barad, 2007, p. 181)

Elsewhere we have described the importance of place in students' emotional responses to science, nature, and learning (Danielsson, Andersson, Gullberg, Hussenius, & Scantlebury, 2015). In this section, the issue of space is foregrounded when examining the phenomena that are produced through students' (dis) engagement with science. We have used diffraction on the preservice teacher's quote to examine the material-discursive practices when making an agential cut focused on space. The bolded text indicates where the preservice teacher refers to space:

> In lower secondary school, science immediately became more boring. In biology class, we would just sit **indoors** and watch the stuffed birds and listen to recorded bird calls instead of **going out** to look and listen. Often, the teacher just stood **at the blackboard** and wrote, and we would copy what he wrote. [...] In upper secondary school, it became even harder and even more boring. Then we were also just sitting still. We never got to be **outside** and look at things, instead the teacher followed the text book to the letter, because it was what was going to be on the test, instead of teaching us what we ought to know for the test **by being out** to observe and discover for ourselves.

The student comments that "by being out," she and her peers would "observe and discover for ourselves" knowledge regarding birds which she views are more authentic, valuable, and interesting than sitting "indoors" listening to recorded birdcalls (Danielsson et al., 2015). Engagement with learning science by sitting in a classroom has generated a phenomenon with specific material-discursive practices.

The teacher's location of standing at the blackboard "prompts a reconceptualisation of things, bodies and pedagogic space as an assemblage of intra-active, ongoing and productive happenings entailing multiple agencies" (Taylor, 2013, p. 692). What are the implications for entanglement of the teacher located near the blackboard and the space that this intra-action unfolds? The boundary that is established by the student's description that the teacher was "at the blackboard" implies the other space within the classroom is excluded from science instruction. When an agential cut is made, it generates a phenomenon that is within the boundary and also exclusions to that phenomena. Thus the space where the student was located, along with her peers, was not part of the phenomena "teaching birdcalls space."

The teacher's choice in standing next to the board, distant and distinct from the students, is part of a learning code in the classroom (Ivinson, 2012). The question is always posed when using a diffraction method: do the exclusions "matter"? And in this example, it clearly does: the student has been excluded from the teaching space. Another possibility in how space could change the student's attitude and interest in learning science, is to make science "not boring"? Would the students become more engaged in a lesson if the teacher moved around the room while teaching about birdcalls rather than excluding students from the teaching space? Thereby changing the teaching space from the blackboard location to one that is utilizing the classroom as a whole includes the students into the phenomena. From the text we can infer that being outdoors to listen to birdcalls would generate a different phenomenon, one where she potentially could develop material-discursive practices that would we might label "scientific."

The teacher may have good reasons for choosing to remain indoors to teach birdcalls. Arrangements to move students from a classroom to an outside location may be problematic. The transition into a different space could also generate management problems for the teacher in terms of his responsibilities regarding students' safety and supervision. However, there are also cultural inferences inscribed in the student's recollection of this learning experience. There is a strong ethos in Swedes' cultural identity of connecting to nature. Government policies provide people a right of access to public and privately owned forests (Danielsson et al., 2015). The student could have had experiences of hearing birdcalls in a natural setting which may have evoked positive connection to nature and science learning.

4.2.3 "Material Moments": Time

> As a result of the iterative practices that constitute phenomena, the 'past' and the 'the future' are iteratively reconfigured and enfolded through one another: phenomena cannot be located in space and time; rather, phenomena are material entanglements that 'extend' across different spaces and times. Neither the past nor the future is ever closed. (Barad, 2007, p. 383)

Time is not a linear entity within Baradian theory but rather "intra-actions themselves matter to the making/marking of space and time" (p. 180). In the following vignette, we have bolded the text where the student references time with the intent of establishing an agential cut that establishes a boundary between time and other categories:

> In **lower secondary school, science immediately** became more boring. In biology class, we would just sit indoors and watch the stuffed birds and listen to **recorded** bird calls instead of going out to look and listen. Often the teacher just stood at the blackboard and wrote, and we would copy what he wrote. [...] **In upper secondary school**, it became even harder and even more boring. Then we were also just sitting still. We never got to be outside and look at things, instead the teacher followed the text book to the letter, because it was what was going to be on the test, instead of teaching us what we ought to know for the test by being out to observe and discover for ourselves.

The time frames referred to in the quote – school years – generate sedimentated history that have different patterns of mattering (Barad, 2007). The question is how do students' schooling history, such as the progression through grades, mark time on students? And what series of different material-discursive practices, produced within the expectation and assumption that in upper secondary school, students would "sit still" generate different body-space-time phenomena.

Using recorded birdcalls allowed the teacher to "manage" time. He decided when students would hear the birdcalls' audio. Because time is "never closed," the student's recollection of her science experiences has the possibility for different interpretations and understanding. For example, after she has begun teaching, the student may rethink her narrative about her science experiences and interpret the teacher's use of recorded birdcalls as one to ensure that all students heard the "right" sound and thus would be in a position to identify birdcalls when outdoors. This could produce different phenomena between matter, space, and time for the student.

Barad's conception of time enfolding offers science educators new possibilities for encouraging students into science. While a student may have a negative science experience, they could reenter that experience with a different set of material-discursive practices, producing positive recollections about learning science.

4.2.4 "Material Moments": Spacetime

In this section we rerun, that is, go back and "turn over" the text again by using diffraction to cut together-apart spacetime:

> In lower secondary school, science **immediately** became more boring. In biology class, we would just sit **indoors** and watch the stuffed birds and listen to recorded bird calls instead of **going out** to look and listen. Often the teacher just stood at the blackboard and wrote, and we would copy what he wrote. [...] In upper secondary school, it became even harder and even more boring. Then we were also just **sitting** still. We never got to be outside and look at things, instead the teacher followed the text book to the letter, because it was what was going to be on the test, instead of teaching us what we ought to know for the test by being out to observe and discover for ourselves.

Spacetimemattering examines not only the agency of space, time, and matter but the intra-actions between those entities and material social practices that generate "bodies-in-the-making and contingent spatiotemporalities" (Haraway, 1997, p. 294). *Spacetime* generates a set of material-discursive practices that change the student's science experiences. The time, that is, the changing grade level, with the move into lower secondary school meant science, even though the concepts were related to fauna and birds' behavior, (i.e., singing), was taught in a classroom. For the student, time and space are entangled, which is illustrated by the student's comment that science is boring and hard describes "upper secondary school," where the student tells of the expectation that they are "sitting still," and our inference is that this refers to the chairs and desk in a "typical" Western classroom. The constraint of bodies in spaces allocated for learning and contemplation harkens back to a monastic existence when minds focused on learning rather than the physical conditions experienced (Ivinson, 2012). In general, within formal education settings, as learners "mature", "stillness" is inscribed on the body. In prekindergarten classes, young children have chairs and tables to sit at, but there are also other locations in a class designated as a learning space where they can move, sit on the floor, and relax on rugs, pillows, or beanbag chairs. This is contrasted to "standard" university spaces allocated to teaching and learning where chairs and tables are fixed and immutable and one's body is constrained by the arrangement.

In our study of preservice pre-K and primary teachers in Sweden, most students did not associate learning science with a location in a formal educational setting (i.e., school, classroom) (Danielsson et al., 2015). Some preservice teachers connected spacetime in nature to authentic science learning. Yet a different spacetime, that is, the classroom and secondary school, produced material-discursive practices such that according to students were not engaged with science learning.

4.2.5 "Material Moments": Matter

> Knowledge making is not a mediated activity, despite the common refrain to the contrary. Knowing is a direct material engagement, a practicing of intra-acting with the world as part of the world in its dynamic material configuring, its on going articulation. The entangled practices of knowing and being are material practices. The world is not merely an idea that exists in the human mind. (Barad, 2007, p. 379)

In the following we highlight where matter influences students' science learning:

> In lower secondary school, science immediately became more boring. In biology class, we would just sit indoors and watch the **stuffed birds** and listen to **recorded bird calls** instead of going out to look and listen. Often the teacher just stood at the **blackboard** and wrote, and we would copy what he wrote. [...] In upper secondary school, it became even harder and even more boring. Then we were also just sitting still. We never got to be outside and look at things, instead the teacher followed the **text book** to the letter, because it was what was going to be on the test, instead of teaching us what we ought to know for the test by being out to observe and discover for ourselves.

Barad suggests that humans are part of the matter and the knowing; thus the knowledge this student produces through the engagement of listening to birdcalls in a classroom as opposed to going outside to hear the birds produced different material-discursive practices. While there is an entanglement between the nonhuman and human, the outcomes are very different.

"The teacher followed the **text book** to the letter." The student's statement is not surprising. Other research has shown how textbooks can drive teachers' curriculum choices. What is the inference of this entanglement of textbook with teacher's practice?

4.2.6 Spacetimemattering

> space and time (like matter) are phenomenal, that is, they are intra-actively produced in the making of phenomena; neither space nor time exits as determinate givens outside of the phenomena. As a result of the iterative practices that constitute phenomena, the 'past' and the 'the future' are iteratively reconfigured and enfolded through one another: phenomena cannot be located in space and time; rather, phenomena are material entanglements that 'extend' across different spaces and times. Neither the past nor the future is ever closed. (Barad, 2007, p. 383)

> A performative understanding of scientific practices, for example, takes account of the fact that knowing does not come from standing at a distance and representing but rather from a *direct material engagement with the world (emphasis in the original)*. (Barad, 2007, p. 49)

As researchers we are entangled with the data and the analysis; our return to this student's essay using a Baradian perspective rather than our previous place-based theoretical framework has produced different results. The entanglement of *spacetimemattering* produced a student's recollection of science as boring. While the pedagogical practices she recalls – a teacher "who just stood" at a blackboard writing notes, which she and other students dutifully copied – are (unfortunately) typical in school science classrooms, what strikes us as more problematic for her was the discipline, biology, and the birdcalls. One infers from her statement some regret they were not "being out to observe" nature for themselves while they were learning about Swedish fauna.

4.3 Conclusion

> Diffraction is not about any difference but about which differences matter. (Barad, 2007, p. 378).

> Gender is constituted through class and community and other structural relations of power. Gender, class and community are enfolded into, and produced through, one another. (Barad, 2007, p. 243).

Material feminism brings matter back into the discussion, analysis, and theorizing about critiques of science (Hekman, 2010). The challenge for feminist critiques that were built on reality being socially constructed through language and discourse was that matter was irrelevant and had no role until it was brought forward through language. After philosophy of science, analytic philosophy, and postmodernism, Hekman (2010) proposes that material feminism as the "fourth settlement" is the most critical and comprehensive as it addresses "epistemological, ontological, political, scientific and technical issues simultaneously" (p. 67). In Baradian theory, agential realism deals with these issues by stating that knowledge production is local, "objectivity is literally embodied" (Hekman, 2010, p. 73). Within agential realism, production is material/cultural with boundaries being temporary, subject to diffractive analysis. Also, agential realism notes that "constructed knowledge has real, material consequences" (p. 73) and includes an articulation of the ethics used to produce that knowledge.

Through these key ideas, Barad (2007) moves to an "ontoepistemological framework" (p. 44) which "shifts the focus from the nature of representations (scientific and other) to the nature of discursive practices" (p. 45) that has resulted in the "integration of a feminist philosophy of science with a feminist ontology" (Rouse, 2008, p. 145). We have used the student's recollection of learning science in school to engage in a diffractive examination of spacetimemattering. The question is then: are there differences here?

Feminist critiques have documented the masculine (and heterenormative) image of science – its practices and culture (Harding, 1986). When teachers and students engage in the teaching and learning of science, the gendered context is masculine. As we examine the preservice teacher's recollection about her science class, we ascribe characteristics to her, that is, her body is gendered female, and she is an undergraduate in a teacher education program studying to teach primary school. When asked to share a science recollection, she clearly articulates a preference for how she could/should be engaged with "science-in-the-making" through experiencing bird calls in nature rather than through recorded sounds.

In the retelling of her science experiences, the preservice teacher's experience illustrates the teacher's power and agency and the cultural norms that influenced his teaching. He "just stood **at the blackboard** and wrote"; this entanglement of the teacher with the blackboard and chalk produces a set of material-discursive practices that promotes a performance from the students, not to engage with scientific practices such as observation data collection or argumentation but that of "busy" work, taking notes. These intra-active practices also reinforce teacher's agency in writing on the board and the expectation that the students would copy the notes. The arrangement of the room and the matter within it and the curriculum focused on material that students could learn in another physical space generated an exclusion that for this student was a difference that mattered.

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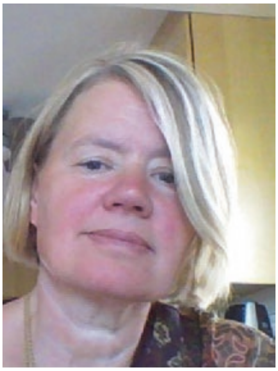

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Chapter 5
The Ethical and Sociopolitical Potential of New Materialisms for Science Education

Shakhnoza Kayumova and Jesse Bazzul

S. K. Jesse, we have had this conversation with you many times over the past year. What is really *new* about *new materialism*? Rick Dolphijn and Iris Van der Tuin (2013), in their recent book titled *New Materialism: Interviews and Cartographies*, argue that Rosi Braidotti and Manuel DeLanda first used the phrase during the 1990s. And you have been somewhat uneasy with the signifier *new*. I agree with your apprehension of the word *new* as it might signify meanings of *recent* and/or *novel* however, questions of ontology is decades, if not centuries, old. For instance, in the beginning of 1980s, examining materiality outside of anthropocentric hegemony was evident in feminist scholarship (e.g., Haraway (1979), "The Biological Enterprise: Sex, Mind, and Profit from Human Engineering to Sociobiology"), in philosophy (e.g., Deleuze and Guittari (1987) "Thousand Plateaus"), and in sociology of sciences (Callon and Latour (1981) "Actor Network Theory"). Moreover, an inquiry into a role for ontology in human knowledge production is certainly centuries old. Indegenious peoples, women of color, many non-dominant groups have always emphasized the importance of ontology. However, with the beginning of the twentieth century and emergence of Marxist ideas of social determinism, materiality gained a social signification – as a structural and dominant factor shaping the social, cultural, political, and economic systems. Manuel Delanda (2012) argues that "Marx's theory of value was indeed anthropocentric: only human labor was a source of value, not steam engines, coal, industrial organization, et cetera... we need to move beyond that and re-conceptualize industrial production" (p. 41). The *new*

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materialist inquiry moves away from deterministic, and/or universalistic notions of entities, and instead matter is theorized as active, complex, and emerging. In my understanding, the *new* is not used in relation to another a priori; it is not a signifier, but an already there qualifier (Dolphijn & Van der Tuin, 2013). As Rosi Braidotti (2012) describes, "neo-materialism" emerges as a method, a conceptual frame and a political stand, which refuses the linguistic paradigm, stressing instead the concrete yet complex materiality of bodies immersed in social relations of power" (p. 21). For me, personally, as someone engaged in science education, someone for who *matter matters* not only on the grounds of a theory, but also as a possibility for future theorizations, new materialism provides a lens to look through episto-ontological emergence (Barad, 2003). It allows me to see *what* (in terms of ontology) and *how* (through which forces) and in what ways matter (s) are contributing to current conditions of schooling, science education, justice, and social justice.

JB: I like how you've introduced new materialisms in way that historicizes and positions it in comparison to other theoretical perspectives. It is helpful to see new materialisms (NM) as a confluence of theoretical traditions, philosophies, and disciplines, all of which are open to contestation and debate. I would just add, in addition to social theory, the influence of the sciences such as systems biology and theoretical physics. The sciences greatly influenced the philosophies of Barad, Bergson, Braidotti, Haraway, Spinoza, and Deleuze and Guattari. The critical, creative ontological approaches of NM can guide practices in science and technology precisely because their scope is the material world. That is, NM attempt to critically and ethically restore what Jane Bennett (2009) refers to as "thing-power," the awesome potential of the material world independent of human subjectivity. However, I would like to outline a couple of criticisms as we get started. First, NM must recognize that large numbers of Indigenous peoples, activists, socialists, feminists, scientists, artists, workers, farmers, people of faith, and the oppressed in general have long understood the intimate relations and connectivity between life and the materiality of the world. Some approaches to NM seem to ignore this fact. Secondly, the political commitments of NM sometimes seem too obscure, or anti-collective. We need creative, critical ontologies that promote a strong sense of justice, collective action, and different political arrangements. In this metalogue, I will try to make the case that NM open up new ways of ethical being through response (ability) and collectivity. One slight modification I'd like to make to Roth and Tobin's (2004) approach to metalogue is to pose more questions for the reader, as metalogue can make the reader feel excluded. Some questions I think are important to consider generally are: How do you see NM and critical ontologies? Where could they be useful for research and classroom practice? How does a focus on ontology open new possibilities for critical, social justice work in science education? My hope is that this metalogue will address these questions.

SK: Jesse, thank you for proposing this format. Yes, as you mentioned, the intimate relationship and connection with living and nonliving entities in the world have long been understood as important by indigenous people, feminists, farmers, and many minoritized groups. They argue that epistomology, ontology, and axiology are interconnected and cannot be independent of each other. And I agree with you that *ontology* took a backseat with a historical, sociocultural, and political rupture that has started with the Age of Reason. Further, I do not view new materialisms as anti-collective. To me, using Barad's (2007) words, "[it] is not about Othering or separating, but on the contrary about making connections and commitments…[it is] about taking account of the entangled materializations of which we are part, including new configurations, new subjectivities, new possibilities"(p. 392).

JB: This is why I used the word "seem." Recently, I showed some of our new materialist work to a critical science education colleague, and she asked me why we were not talking explicitly about patriarchy, colonialism, racial justice, capitalism, etc. (Jean Aguilar Valdez, Personal Communication, Sept 2, 2015). Of course new materialists have addressed these things and often nurture the fundamental relationship between philosophy, science, and politics. Barad's (2007) philosophy gives a very special place to queering, becoming, and responsibility. Our work with Deleuze and Guattari's assemblages, which also greatly relied on Manuel DeLanda's work (2002, 2006), helped us work toward a sociopolitical ontological perspective for science education (Bazzul & Kayumova, 2015). In this chapter, I'd also like to explore the ethical imperatives implicit in Barad's (2012) notions of intra-action and queer becomings as part of the ethics of the *world-as-assemblages*, where being ethical ceases to be conceived in singular antropentric ends – in themselves (Bennett, 2009). I'd also like to employ Hardt and Negri's (2000, 2009) notions of *multitude* and the *common(s)* as helpful concepts for building creative, enabling, justice-oriented critical ontological frameworks.

SK: Excellent question and thank you for sharing this with me, Jesse. I see the value of Hardt and Negri's (2000, 2009) perspective on multitier and common(s); again thank you for provoking me to think through these ideas in relation to ethics and the *political*. Although, I do not want to sound like a defender or a proponent of new materialisms, I would also like to mention some ethico-political possibilities within this perspective that draw me to it in the first place. There might be different reasons why we are drawn to certain theories: (1) one simple reason can be that some of us are subjectified to a theoretical discourse that is available to us. At some point we are also products of our own respective academic assemblages – institutions, groups, human and non-human bodies – we have been influenced by the ideas, physical and affective entities, and practices, our academic mentors and academic circles we belong to; (2) another reason could be that a certain theoretical position spoke to us more than others. To me a theory as Deleuze says is a tool (see Deleuze and Guattari, 1987). We need lots of different theories in our toolbox to understand issues in our society, education system, teaching, and learning. Theories might be also conceived as situated in larger social, political, and cultural contexts. Depending on the purpose of the inquiry, whether it is to explain, understand, interpret, examine, critique, or deconstruct, all theories at some point can be considered *political*. Politics is everywhere, even more so in places where there is no such claim. Recently, the journal *Women: Cultural Review* published a special issue entitled *Feminist Matters: The Politics of New Materialism.*

In the preface of this special issue, Hinton and van Der Tuin (2014) reframe the question from where is the politics to the question of what forms of "political agency we evidence in new materialisms, and to ask to what do these political formulations respond" (p. 1). Hinton and Iris argue that this "no longer translates into the co-constitutive yet binary interplay of power (normative ideology), on the one hand, and resistance, on the other" (p. 2). It also makes me think that some of these tools, knowledge systems, and perspective have produced some of these *injustices* in the first place. To understand and examine contemporary forms and manifestations of patriarchy, colonialism, racial justice, and capitalism, in Grosz' words, we need "other ways of knowing, other ontologies and epistemologies that enable the subject's relation to the world, to space and to time, to be conceptualized in different terms" (Grosz, 2005, p. 173).

JB: Yes, you remind me of how Deleuze insisted that theories have to function! I think searching for 'the politics', could also mean asking the question, "where are the political possibilities?". Foucault (2003) claimed that politics did not inform his analyses, but felt the more pertinent question was to ask what politics had to say about an analysis or theory. I can see this relationship of politics to theory being especially valued by the historian, and also the scientist. I would ask the reader to keep the question of politics open. Barad's notion of "intra-action" opens possibilities for ethical and political action.

Barad (2007) maintains that it is a misrepresentation to see individual entities as having discreet predetermined properties that interact, rather entities are mutually constituted, and emerge in their intra-action. Entities reside *within* phenomena and are determined by/within a series of relations. Phenomena can be seen as entanglements where entities emerge in what we might call *assemblages*. Even if one takes a "softer" view of intra-actions, rather profound implications emerge. If individual things, people, places, etc. emerge through intra-action, then the entanglement of relations and forces, e.g., electrical, genetic, ideological, become vitally important to understand, map, interrogate, and influence. Difference, becoming, queering, become operative, every-day movements in understanding of phenomena. Viewing reality as relational assemblies of entities, and not a series of fixed forms, provides a radical way to view identities and responsibility. According to Barad, if entities arise within phenomena, there is no predetermined "right way" to act or be – ethics becomes a means by which we allow other entities to respond through a series of relations. This includes providing "others" the ability to respond a particular range and number of options, as well as the constraining of options. And since matterings, including human beings, are relational in space and time, our sense of responsibility is not just "our own" – we are accountable to the past and future and to "groupings" that *are not of our choosing*. Ethics here involves a mode of being that is *always already* relational to phenomena that exceeds consciousness yet, when realized, requires us to act.

SK: Yes, I like how you explain it that "if entities arise within phenomena, there is no pre-determined 'right way' to act or be—ethics becomes a means by which we allow other entities to respond through a series of relations. This includes providing 'others' the ability to respond, a particular range and number of options". Also, I am glad that you mentioned Foucault. I know we have had this conversation about Foucault and materiality. I would say to some degree Foucault was engaged with assemblies of different discursive forces and their effects on the body (although he might not have used the word assembly or assemblage). Foucault says that "People know what they do; frequently they know why they do what they do; but what they don't know is what what they do does." This quote reminds me what Barad (2012) describes as ethics that, "ethics is not simply about responsible actions in relation to human experiences of the world… [it] is about accounting for our part of entangled webs we weave" (p. 384). I also understand ethics beyond individual human beings, ethics as connection, ethics as collective, ethics as assemblage. From an ontological perspective, ethics is already prevalent in the life of which we all are part. Hence, when I think of ethics, it is not about correct responses to a "radically exteriorized other, but about responsibility and accountability for the lively relationalities of becoming, of which we are a part" (Barad, 2007, p. 393). According to this conceptualization of ethics, it is being responsible to oneself and to others with the ability to listen and with a commitment to be responsive. Barad argues that this responsibility and accountability is "not only for what we know, how we know, and what we do but, in part, for what exists" (p. 243). My understanding is that ontology, epistemology, and ethics make up already their parts of our onto-epistemological entangled life.

JB: Right, ethics emerges as *already integral* to phenomena. For me there is still the (political) problematic of ethical differentiation: what should be spoken, done, by whom and why. This problem also exists in a Deleuzian, rhizomatic ethics of becoming that must contend with the possibility of becoming terrible! Your last Barad quote stresses a responsibility for "what exists." This is because every possibility for action is constituted relationally. For example, resource development emerges through intra-actions between "sociocultural" and "natural" entities such as geologic formations, hydrocarbons, indigenous peoples, forests, corporations, discourses of government and environmental science, commodities, hope, and despair. The phenomenon casts a temporary arrangement of agencies, entities, and relationships. Though few of us drill for oil ourselves, we are an intricate part of this phenomenon when we use petroleum products in daily life, and consequently responsible for the "*onto-eco-ethico* state of affairs," ethical action emerges relationally through a sense of care, justice, and responsibility for what exists, offering a different horizon for ethics in science education. Although intra-actions do not cover all the ways to think ontologically about the relations between entities, they do demonstrate that ethics is always an emergent field of practice. What should also not be overlooked is the political problem of a 'public'; do rivers, plants, and micro-organisms warrant being part of democratic spaces (see Bazzul, 2015)? NM provide me with a method(ology) for disrupting the hierarchies that keep these entities excluded, exposing the emergent nature of what a "public" is.

SK: In my opinion one of the reasons there seems to be some sort of confusion around the new materialist conceptions of *matter* is that matter is continuously understood as a "thing." When I say a "thing," I refer to a traditional conception of inert, passive, controllable, and so on (see Jane Bennet (2009) for understanding of a "thing" as a vibrant matter and for notions of "thing power"). Barad's (2003) work and concept of intra-action help me to recognize that in the new materialist framework, "matter does not refer to a fixed substance; rather, matter is substance in its intra-active becoming – not a thing, but a doing, a congealing of agency" (p. 822). Understanding of agency in new materialism is starkly different than humanist notions of ability to act, "agency is not held, it is not a property of persons or things; rather, agency is an enactment, a matter of possibilities for reconfiguring entanglements" (Barad, 2012, p. 54). Engaging with ideas in the new materialism allows us to examine power imbalances as a part of material entanglements, and agency is in the intra-active enactment of both humans and nonhumans (Barad, 2012). Therefore, Barad suggests conceiving of agency, as "possibilities and accountability entailed… [in] articulations and exclusions that are marked by [different] practices" by taking into consideration of the particularities, singularities, and very power imbalances at play in contributing to multiplicities in mattering (p. 54). As you mentioned earlier, science education is a complex multiplicity, and some of the ideas in new materialism equally remind me Hardt and Negri's (2000) reading of Deleuze and Guittari's work about social singularities and that "every singularity is a social becoming… resistance and the collaboration with others, after all, is always a transformative experience" (p. 112). However, celebrating difference and singularity for the sake of difference stripes away the agency of what Hardt and Negri (2000) call *the common* and Bruno Latour refers as *collective*. My understanding of the common (the collective) is similar to Barad's notions of intra-active entanglement of humans and nonhumans. Cognizant that sociopolitical is not about pulling everyone to the center toward the same direction but instead allowing for different lines of flight to take their place and see the enabling power of that difference, multiplicity, and/or singularity – allowing for conditions in which margins are afforded to become new centers.

JB: You are getting at a very important point regarding NM. It demonstrates that agency is multimodal. Assemblies of horizontally situated entities, that encounter each other, emerging through dependent relations. This can be seen in the continual, and literal, breakdown of the unified humanist subject through biotechnologies, increased social connectivity, and also our current era of postmodern capitalism (Braidotti, 2013; Haraway, 1991) Hardt and Negri's (2000, 2009) concept of the *common(s)* and *multitude* can provide materialisms with an answer to the question of political efficacy. I am also excited to see we are merging Hardt and Negri with Barad, my theoretical interests with yours, which is a benefit of these metalogues. When Hardt and Negri warn against celebrating difference for difference sake, they are also saying that difference deserves proper recognition, as it is exactly what allows the common(s) to emerge, keep solidarity in a multitude of struggles, and push against those forces that would seek to harness and exploit the common (and according to Barad (2007), there are ethics involved in determining which differences matter more than others). While I agree that the production of common is coextensive with, and produced by, a multitude of (intra-acting) singularities, not every intra-action is one that produces the common, and not every *line of flight* maintains and creates the political grounds for producing the common(s). Furthermore, some common(s) are corrupt. We are coming back to Spinoza here, because the kind of "becoming" through and intra-actions that we are trying to cultivate embodies a kind of *immanence*, a characteristic of what Hardt and Negri call *altermodernity*. I think it would be helpful to sketch out the idea of a *sociopolitical assemblage*. Shak, you have been perhaps the only supporter of my use of drawings to illustrate concepts, encouraging me despite their childish appearance. I'd like to include some of these drawings from our paper on social ontologies here. Let's begin with your point about taking lines of flight toward new centers. Ontologically, we could say it may look something like Fig. 5.1, where new ways of being escape ordering and controlling structures. A line of flight could be engaging indigenous knowledge in science classes; helping it become a new "center".

An assemblage is a heterogenous arrangement of constituent material components, bodies, trees, insects, forces, affects, and discursive/coding components such as languages and DNA. They exist along a continuum of how coded and "bound up" or how reterritorializating/deterritorializing they are. If an assemblage is reterritorializing, it (re)captures and (re)appropriates new thoughts, practices, or behaviors,

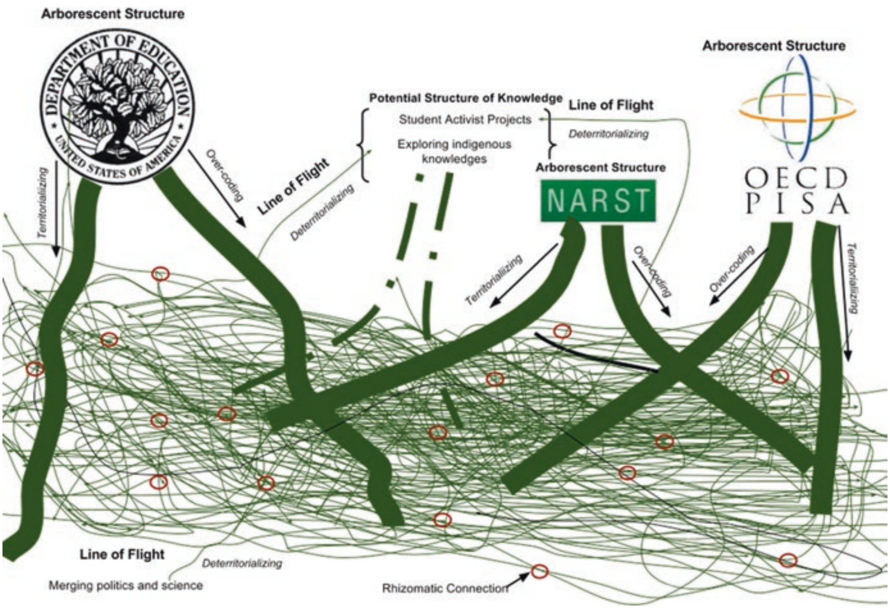

Fig. 5.1 Example of a line of flight and the creation of a new "center" in science education. (Source: Bazzul & Kayumova, 2015)

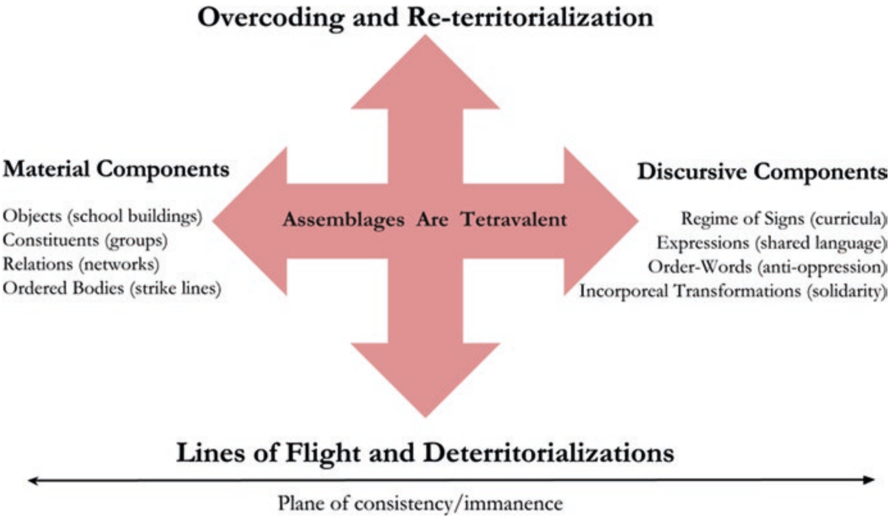

Fig. 5.2 Assemblages as material and discursive components

pulling them back toward a more rigid system. If an assemblage is deterritorializing, it allows for entities or components of the assemblage to escape or combine with outside entities/components, or forces, in ways that are different and unintended and/or to escape the material or discursive confines of the assemblage. Assemblages, along the lines described by Deleuze and Guattari (1987), can be seen as tetravalent, meaning they have four poles or dimensions that define their overall character, which are their material components, their discursive components, their propensity to capture and control (how overcoded by discourses and reterritorializing they are), and their ability to allow lines of flight or new configurations (how deterritorializing they are). I have tried to depict these four elements in Fig. 5.2. We can employ the concept of assemblages to describe particular arrangements of being in both actual (what is) and virtual terms (what could be). The practical synthesis of both discursive/linguistic and material components, along with their virtual character, is what makes the concept of assemblages powerful in sociopolitical terms. The pedagogical and research potential of assemblages is both in their actuality, for example, describing the intra-play of classrooms as complex assemblages, and virtuality, describing the kinds of educational arrangements that are sociopolitically just and/or desirable.

Perhaps you could elaborate more on what attentive engagement with the ontological provides educational research and practice? (Reader, my suggestion for you would be to literally sketch your own understanding of what (you think) we mean).

SK: Yes, my understanding is that new materialisms relocates the notion of agency from sole humans to complex assemblages of both human and nonhuman agents. In my understanding, this fundamentally challenges the very condition of knowledge and how we seek/produce knowledge. As Fox and Alldred (2015) argue, new materialisms have implications not only on "micropolitics of the research process," on the ethico-political grounds, but also the ontological perspective poses challenges on social, cultural, and educational inquiry and practice. Our paper on social ontologies (Bazzul & Kayumova, 2015) and sketches of *sociopolitical assemblage* in the context of science education provides an example of such an inquiry, which, in my view, decenters humans and their actions as the sole authors of agency. It takes into equal consideration the conditions of possibility, mechanisms at play, and the grounds on which humans and nonhumans coalesce and hold together. It seems to me that's where the theory opens itself up for a sociopolitical engagement. To me it is liberating – not to undermine the human action but to take into account the *assemblage of relations* on which the actions and capacities are made possible. And by no means I am suggesting that it is the sole condition that makes *sociopolitical engagement* possible; claiming so would mean to go back to old structure/agent dualisms. Instead I am suggesting that to be able to understand power, it is also important to understand matter and meaning making and what kinds of actions, capacities, and power relations are made possible in their mutual intra-activity. To examine how multiplicities of relations are built? And how things come and hold together in education. This is how assemblage theory and Deleuze and Guittari's work (1987) are important for me because they provide me with a language and units of analysis for mapping out *territorializations*, *deterritorializations*, *lines of flight*, and their social implications within the educational systems. For instance, I think about social justice work, student activist groups, power structures. How do they come together? What holds them together? On which grounds are people and things put in the same space? What are the conditions of possibility for socially just science education? What does it include? What does it exclude? And how do assemblages get made?

JB: Ok, so two challenges for new materialisms are to: (i) determine how to integrate useful insights from feminist, humanist, poststructuralist, Marxist, and scientific traditions and (ii) demonstrate how creative ontologies, and the breakdown of anthropocentric dualisms, will lead to better understandings of the material world, ethics, politics, and a world in common. So, it's a challenge of both practice and theory. Your question of what holds assemblages together, what is excluded and included, is important, and this may be where science educators need to better understand the mechanics of agential cuts (Kate Scantlebury, Personal Communication, December 19, 2015). Starting with the premise that education is an extremely complex, integrated series of phenomena (Davis & Sumara, 2005), assemblages are highly contextualized. Their use value resides largely in what they enable us to do. Diagrammatics are one way to outline (and interrogate) assemblages of educational politics, classroom dynamics, community activism, etc. Diagrams are co-extensive with fields of discursive and non-discursive entities (and is itself neither); if nothing emerges from the diagram, it has failed its purpose (Deleuze, 1988; Deleuze & Bacon, 2003)! Returning to Fig. 5.1, though not intended to represent an assemblage, we can see that it relays some material and discursive power relations in science education and can provoke debate about structure and agency. The National Association for Research in Science Teaching (NARST) is an arborescent structure/assemblage; it *overcodes* science education discursively (limits through code/discourse); it *reterritorializes* or reincorporates entities, people, capital, ideas, and structural relationships that would initially seem outside its boundaries to strengthen its dominance and rigid identity. However, *lines of flight* are inevitable. Knowledges from Indigenous cultures escape interests that align science only to modern western traditions; these discourses are ecologically entangled with rivers, land, insects, and communities – establishing new arrangements within school systems and research communities. What I am trying to say is that both the ethos and topology of the assemblage are emergent, and its success is context-dependent and enabling-dependent. Many things hold assemblages together, from the affective to the geologic. These forces, links, connections, and codings can be reterritorializing or deterritorializing, highly or slightly overcode(ing), *rhizomatic*, or *arborescent*. I've adapted a parametritized representation of how assemblages might be bound-up or free-flowing using an (old school) analog volume dial (Fig. 5.3). Figure 5.3 shows us that regardless of what comprises the relations in assemblages, these relations can be characterized, in this case how much these relations are restricted or free (will have to talk more about this).

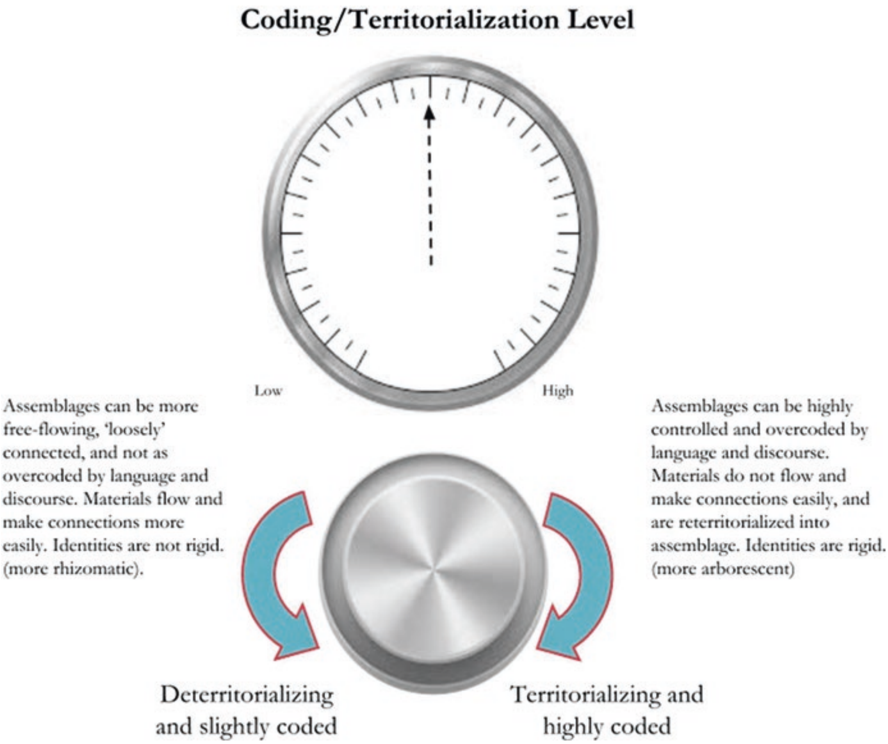

Fig. 5.3 Representation of more rhizomatic and arborescent assemblages

SK: Jesse, the diagram is a good illustration of how assemblages can be both *territorialized* and *deterritorialized*. For instance, schooling and the institution of education can be an example of territorialized, highly controlled arborescent structure. Formal science education is also a part of this arborescent structure and is expected to adhere to foundational knowledge systems and practices of schooling. As the diagram shows, it is not only that the language and discourse of foundational knowledge is overcoded, but also materials do not flow and connections are not made easily, and identities of the subject are presumed to be very rigid too. What holds the arborescence together is foundational and dominant power structure. So even when new methods and methodologies of science teaching and learning are discussed, adopted, and implemented to make science education more inclusive of diverse ways of doing science, the increase in quantity does not qualify the change in nature of "dominant" science. Working with ontological perspective and Deleuze and Guittari's notion of deterritorialization allows us to rethink the very "nature" of multiplicity and diversity. According to Deleuze and Guittari's ontology, multiplicities can only be rhizomatic; they have connections, dimensions, intensities, and productive differences, and they are in constant mode of becoming. I think classroom cultures are in a way, rhizomatic entities, and that's where we can observe the complexity of education. Children's identity work is also a part of complex multiplicity; it is in a continuous process of being and becoming (Kayumova et al., 2015). Therefore, even when there are a perfect set of standards, methods, methodologies, tools, and practices of science, it is almost impossible to manufacture a universal classroom culture. Why? Because each classroom has different people, different identities, different entities, and when these differences intra-act with one each other, it becomes very difficult to control the emergences. Although it is obvious what formal education and all reforms are after, to find an input-output model, no education system has been successful so far. There are always resistances, becomings, new commons, and lines of flight that constantly emerge at the margins. And these lines of flight have a potential to move margins into new centers, just like in a rhizome.

JB: Right, historically formal schooling has always had strong elements of arborescence, and there are always resistances – and so education represents a dynamic field of resistance and interplay of multiplicity. This raises the stakes for science education, making it so much more than an input-output, but a complex endeavor that recognizes the performativity of a nature. One that, as Barad (2007) puts it, "takes account of the fact that knowing does not come from standing at a distance and representing, but rather from a direct material engagement with the world" (p.49). You and I have been grappling with virtual ontological problems, one of which is, how do we go cast education as, in Karen Barad's terms, an ontological-epistemological-ethico-political field. Reader, like us you've probably been grappling with how to operationalize all of these concepts and ideas. Stay with us for Part II! Certainly classrooms are rhizomatic, and it is helpful to see them this way, as spaces that preserve and produce the commons through the interactions of multiplicities (Bazzul and Tolbert, 2017). For me, the dualism of Deleuze and Guattari's (1987) notions of rhizomatic and arborescence is problematic in positive ways. Arborescence, for example, is a part of existence much the same way as the rhizome, although rhizomes and multiplicities are more productive for the survival of life under late capitalism. The *arbor* (tree) *was* a becoming. It produces becomings through its intra-action (or interaction). At one point a few hundred million years ago, the genus *Gingko* was a rhizome. I think we are still "playing out" this interweaving of forces in human social life – between constitutive forces (becomings and new material arrangements) and controlling forces (e.g., the institution of private property and racialization). The power of assemblages is that it does not take for granted that a particular assembly of forces and entities will be enabling or that a line of flight, with its dimensions of multiplicity, will itself set the stage for further becomings. We can therefore also ask ethical questions of assemblages, such as: is the current assemblage in which I find myself doing harm! I have tried to contextualize new ontologies, ethics, assemblages, rhizomes in relation to education, but we need to go further, invite others, draw, dialogue, change, allow others to change, create a rhizome!

Our metalogue has opened up a conversation around the possibilities of new materialisms in relation to ethics, politics, and new ontologies. We have also outlined some criticisms, such as whether new materialists are new, and have the potential to enable political actions. Where I think we should go from here is headlong into the diagrammatic, which is both theoretical and practical (perhaps we are not ready to write a curriculum of becoming). We will bring in some new voices. But where shall we begin? My feeling is that diagramming can be a way for practitioners to give the necessary contextual elements to new ontologies and assemblages, forces, structures, bodies, and abiota, in their actuality and virtuality (see, e.g., De Freitas & Sinclair, 2012; De Freitas & Palmer, 2015). Reader, maybe the best advice we can give is to grab a crayon and draw/diagram a rhizomatic representation of what you read – one that is neither completely discursive or ontological nor actual and virtual.

SK: Excellent way of concluding Jesse. And thank you for pointing out De Freitas and Palmer's work (2015) as a good example of how new materialist inquiry could be used to see how children, materials such as cups and crayons, everyday science activities, and child plays are all a part of learning assemblages. De Freitas and Palmer conceptualize learning assemblages as "provisional configurations of things, teachers, children, learning theories, curriculum values, power/knowledge relations, architectural and spatial arrangements, forces of desire …[and] there configurations are not always possible to foresee, but emerge and become productive in complex ways" (2015, p. 2). And your invitation for picking up crayons and diagramming speaks to the similar productive intra-action with a theory, untangling assemblages of reader/author relations, undoing thinking/typing/retyping to theorizing/mattering with crayons, and further the engagement with the material and the material-discursive practices that emerge. This invitation also reminds me of concluding words from Freitas and Palmer, which I am reappropriating here to this context: how might theorizing and working with theories change if we draw/diagram concepts as agentive and generative of new ideas? I think there is no conclusion to this conversation, but an open invitation to continue it.

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Part II
Curriculum Matters

Chapter 6
Positing *An*(Other) Ontology: Towards Different Practices of Ethical Accountability Within Multicultural Science Education

Marc Higgins

> Science and justice, matter and meaning are not separate elements that intersect now and again. They are inextricably fused together, and no event, no matter how energetic, can tear them asunder. (Barad, 2010, p. 242)

Within science education, one location in which it is productive to heed Karen Barad's call to remember the entanglement of matter and meaning (i.e. what matters) is that of the multicultural science education debate. At the epicentre of this debate are questions of "what counts" as science and, in turn, course content within school-based science curriculum. Largely at stake is the inclusion or exclusion of traditional ecological knowledge (TEK) and Indigenous ways of living with nature (IWLN) alongside Western modern science (WMS), as well as the norms through which they are included, excluded, and juxtaposed. Between science educators who champion the inclusion of TEK and IWLN as equally valid[1] ways of knowing nature (i.e. cross-culturalists; e.g. (Snively & Corsiglia, 2001; Stanley & Brickhouse, 2001)) and those who do not consider these place-based ways of knowing nature as *equally valid* to the "universal" standard of WMS (i.e. universalists; e.g. (Cobern & Loving, 2001; Siegel, 2001)), the debate continues to be both unresolved and unresolvable. This debate often presents science educators with diverse and difficult queries regarding what it means to respect students and the diverse ways of knowing nature that they bring with them.[2] Additionally, complications arise when knowing

[1] Here *equally valid* does not signify that TEK and IWLN achieve equivalence or sameness with WMS but rather that they offer something that is of similar importance (e.g. the former presents frames for ethical and sustainable practices of living with nature, while the latter offers quantifiability, reproducibility, and predictability through laboratory-based experimentation; see Aikenhead & Michell, 2011; Aikenhead & Ogawa, 2007).

[2] Note that TEK and IWLN are but some of the diverse ways of knowing nature that students bring into a science education classroom.

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nature and respecting cultural diversity are framed as competing, conflicting, and mutually exclusive goals. This mutual exclusion is frequently the case as Bruno Latour (2004) explains: “the notions of nature and [cultural] politics had been developed over centuries in such a way as to make any juxtaposition, any synthesis, any combination of the two terms *impossible*” (p. 3, emphasis in original). Accordingly, how might Barad’s (2010) statement that “matter and meaning are not separate elements that intersect now and again” (p. 242) assist us in responding to the ongoing and ever-present conflicting and potentially incommensurable demands between epistemological validity and ethical responsiveness in science education? To what extent can science (i.e. knowing nature) and justice (i.e. respecting diverse cultural knowledges) co-exist within the science education classroom in relation to these competing perspectives?

To engage with this question, I turn to the multiple attempts to resolve the debate by working towards producing modest intermediary positions that attempt to develop and enhance potential points of agreement between positions (e.g. Alsop & Fawcett, 2010; Cobern & Loving, 2008; van Eijck & Roth, 2007). An example of such a point of agreement is the rejection of scientism, indoctrination, or imposition in science education. In the last few years, attempts to labour from shared assumptions towards intermediary positions have included (a) positing an ethics of incommensurability or co-existence (e.g. El-Hani & de Ferreira Bandera, 2008; El-Hani & Mortimer, 2007; van Eijck & Roth, 2007), (b) considering diverse and competing scientific knowledges as (re)contextualized processes rather than inert knowledges (van Eijck & Roth, 2007), and (c) pedagogically enacting an ethics framed by the vulnerability of *not* knowing (Alsop & Fawcett, 2010). However, as William Cobern and Cathleen Loving (2008) posit, most proposed and partial responses to the multicultural science education debate largely centre upon questions of epistemology. To explore how scientific knowledges might have “characteristics of verisimilitude, vis-à-vis the real world” (p. 440), Cobern and Loving (2008) suggest that the “real world” too must be seriously considered in the equation. Thus, instead, or in addition to strictly epistemological undertakings, Cobern and Loving (2008) propose that this debate be addressed through a (re)consideration of how the subject of scientific knowledge aligns with its object or how epistemology (i.e. Culture, knowing) aligns with ontology (i.e. Nature, being). While the alignment is but one type of relational configuration between matter and meaning, one which is revealed as potentially problematic later within the chapter, this insight provides a productive point of departure from which to consider the relation between epistemology and ontology in the context of the multicultural science education debate.

Within this chapter, I endeavour to simultaneously use and trouble Cobern and Loving’s (2008) call to consider the ontological situatedness of scientific knowledge that constitutes science education curricula. Inflecting this call with Barad’s (2010) understanding that science and justice are “inextricably fused,” I ask the question: *What types of ethical practices emerge within the context of multicultural science education when we account for, and are responsive to, ontology and its relation to epistemology?* To explore this question, I turn to the work of Karen Barad (2007) who reminds us that “how *reality* is understood matters” (p. 205, emphasis in original). This chapter is divided into three interconnected tasks. First, I begin by exploring the ways in which Barad's (2000) quantum physics-philosophy opens a space of accountability for and to ontological situatedness, enactment, and production within science education (see also Barad, 2007, 2010; Kirby, 2011). Second, I revisit the multicultural science education debate to ask ontological questions of the ways in which TEK and IWLN are situated therein, attending particularly to norms through which they are included/excluded. Lastly, I explore possible possibilities for a science education that is ethically shaped by ontological plurality and open to the ways in which matter has always mattered for Indigenous peoples.

6.1 Part 1: From Ontological Alignment to Positing *an* Ontology Within Multicultural Science Education

> How *reality* is understood matters. There are risks entailed in putting forward an ontology: making metaphysical assumptions explicit exposes the exclusions on which any given conception of reality is based. But the political potential of deconstructive analysis lies not in simply recognizing the inevitability of exclusions but in insisting on accountability for the particular exclusions that are enacted and in taking the responsibility to perpetually contest and rework the boundaries. (Barad, 2007, p. 205, emphasis in original)

When ontology is brought into the frame of science education, Cobern and Loving (2008) highlight that "we face a metaphysical choice" (Cobern & Loving, 2008, p. 441). This choice of how reality is understood and enacted is situated within the realm of metaphysics as it asks us to consider the relationship between epistemology (i.e. Culture) and ontology (i.e. Nature). Within science and science education, this relationship between epistemology and ontology has primarily been understood through competing claims of weak and strong forms of relativism and realism. In other words, science and science education scholars have critically and metaphysically questioned the extent to which epistemology aligns with ontology.

Within the context of science, Latour (1993) argues, most scientists reject absolute relativism because it requires the bracketing out of Nature. Similarly, scientists often also reject absolute realism because it wholly brackets out Culture. Thus, more frequently, scientists adopt a weak relativism or realism. What is contested between the two approaches, weak relativism or weak realism, is the question of whether knowledge about nature can be explained primarily but not exclusively through natural factors (i.e. weak realism) or through cultural factors (i.e. weak relativism). Within science education, similar discussions of realism and relativism take place and are often included in curricula through exploration of the nature of science (NOS). In short, NOS addresses how the culture of science epistemologically understands the nature of Nature, or ontology (e.g. Holbrook & Rannikmae, 2007; Plakitski, 2010; Rudolph, 2000).

However, "as soon as Nature comes into play without being attached to a culture, a third model is always secretly used" (Latour, 1993, p. 104). Latour (1993) refers to this as "particular universalism": a framework in which Nature is stable and outside of Culture and diverse cultural positionings mediate access to knowledge about Nature. The caveat, and means by which WMS maintains primacy, is that "one society - and it is always the Western one - defines the general framework of Nature with respect to which the others are situated" (Latour, 1993, p. 105). In other words, it is established as epistemic privilege.

Furthermore, for reasons that include but go beyond the troubling of this epistemic privilege, many critical science scholars (Barad, 2007; Kirby, 2011; Latour, 1993) have begun to examine and cast doubt upon the framework(s) through which questions of relativism and realism come to be argued. Under critical examination is the oft taken-for-granted assumption that is relied upon by many realist and relativist frameworks: Nature being a stable backdrop against which Culture gets to play out.

Within what is being referred to as the ontological turn, Barad (2007) draws from Niels Bohr's philosophy-physics to posit that ontology is not something that exists a priori. This is to say that scientific phenomena under observation do not pre-exist their observation but, rather, they are enacted with and through observation. Matter comes to matter in both senses of the word: it is at once important and worthy of consideration, as well as something that comes into being rather than remaining inert, static, and unagentic (Barad, 2000, 2007, 2010; Kirby, 2011). While the realm of matter and materiality (i.e. Nature) has always been the primary focus and domain of science education, a (re)consideration of how matter comes to materialize has important consequences for science education in terms of epistemology, ontology, and ethics. Of particular importance, and thus the focus of this chapter, is the problem and possibility that ontology is not, and has never been, a singular affair (Barad, 2007). Rather, it is always already plural and becoming differential through the working and reworking of metaphysical cuts (e.g. the norms of bodily production – subjects and objects).

To situate science and science education ontologically requires one to posit *an* ontology, as opposed to simply situating within "ontology" (read: singular). *An* ontology is an ever-partial (i.e. having exclusions) but never relativistic accounting for an always shifting Nature. Barad (2007) reminds us that part of the positing of *an* ontology goes beyond naming *which* ontology is at work: the "accountability for the particular exclusions that are enacted" through our metaphysical choices includes "taking the responsibility to perpetually contest and rework the boundaries" (Barad, 2007, p. 205).

Thus, returning to the metaphysical choice that Cobern and Loving (2008) present, one that asks which scientific epistemology best aligns and correlates with "ontology" (read: singular), it is fair to state that no choice is offered at all. Without considering *which* ontology or the ways that epistemology can be in relation with/in *an* ontology other than through alignment, they put forth, "there is simply no other rational way to account for human ability to increase instrumental epistemological power other than that knowledge has the characteristics of verisimilitude, vis-à-vis the real world." (p. 440). Here, the "rational way" that Cobern and Loving's

(2008) "common sense" metaphysical choice suggests is, again, WMS.[3] Rather than present a modest intermediary position, I suggest that Cobern and Loving (2008) simply displace the terms of the debate by (re)presenting them anew, albeit elsewhere (see van Eijck & Roth, 2007).

6.2 Part 2: Why Positing *an* Ontology Matters in Multicultural Science Education

The positing of *an* ontology and striving towards accountability for how we frame and enact ontology are of importance for scholars working within the context of multicultural science education. To take up the call to posit *an* ontology would necessarily require moving from questions of epistemology to questions of epistemology *and* ontology or even onto-epistemology (i.e. the co-constitutive entanglement of knowing and being; see Barad, 2007, 2010)[4] to ask the question of how epistemology and ontology relate to one another.

While there have been invitations to position diverse ways of knowing nature ontologically, this is often done in the way that Cobern and Loving (2008) implicitly suggest: alignment with the ontology of WMS. Presupposing alignment (re)produces a potentially problematic configuration because in the process it explicitly enunciates and upholds the often implicit message that ways of knowing nature other than WMS are lesser. These messages are reinforced not only through continuing to centre the ontology of WMS but also through failing to acknowledge that such ontology is but one possible ontological possibility amongst many. Take, for

[3] Cobern and Loving (2008) state, "epistemological realism is literally the common ground—the common sense—we all share" (p. 443). However, even if it is common, Cobern and Loving (2008) neglect to discuss *how* it came to be (made) common, as well as what this "common sense" produces. Without these pieces, the superpositional relation between *having* common sense and *being had* by common sense becomes blurred. It becomes something that we possess in common that also possesses us (see Apffel-Marglin, 2011).

[4] Barad (2010) draws from quantum physics and the concepts of entanglement and superposition to explore and understand how epistemology and ontology might come to co-constitute one another:

> *Quantum entanglements* are generalised quantum superpositions, more than one, no more than one, impossible to count. They are far more ghostly than the colloquial sense of 'entanglement' suggests. *Quantum entanglements* are not the intertwining of two (or more) states/entities/events, but a calling into question of the very nature of two-ness, and ultimately of one-ness as well. Duality, unity, multiplicity, being are undone. 'Between' will never be the same. One is too few, two is too many. No wonder quantum entanglements defy common-sense notions of communication 'between' entities 'separated' by arbitrarily large spaces and times. Quantum entanglements require/inspire a new sense of a-count-ability, a new arithmetic, a new calculus of response-ability. (p. 251)

Accordingly, onto-epistemology can neither be adequately referred to as both ontology *and* epistemology nor the two as one or a monistic whole but rather a state of superposition.

example, Harvey Siegel's (1997) positioning of diverse ways of knowing nature other than those of WMS:

> Science education must … treat members of minority, dominated cultures with respect. And it must treat the scientific ideas of these cultures with respect. But so treating these cultures and their scientific beliefs and ideas does not require those ideas be treated as correct or *as* correct as the scientific ideas of the dominant, hegemonic culture. (p. 101, emphasis in original)

Such often unacknowledged and taken-for-granted ontological positioning and posturing continues to have adverse effects on if, and how, TEK and IWLN are included within multicultural science education (see Aikenhead & Michell, 2011; Sammel, 2009). In short, when TEK and IWLN are articulated within and/or in relation to WMS's ontology, they are not only fragmented but also produced as lesser.

The ontology through which WMS comes to be, Cartesianism, is the classical Western ontological process through which meaning and matter are individuated through separation from that which co-constitutes them (e.g. Nature/Culture, mind/body dualisms). Such individualism, which Barad (2007) refers to as the "metaphysics of individualism," can be characterized by the enactment of separate, separable, and pre-existing objects and subjects which causally interact within segmented linear time and rectilinear space. The challenge posed to science education is one of discerning how and when such ways of knowing in being (re)produce forms of hegemony (e.g. scientism). For example, TEK and IWLN, due to their relational entanglements of matter and meaning, are ruptured and reduced through such a configuration framed by ontological alignment with Cartesianism. While many science educators have argued that TEK and IWLN stand up to the terms of WMS (e.g. validity, reliability, empirical observation), they never stand up as well as WMS on WMS' terms (Aikenhead & Michell, 2011; Cajete, 1994, 2000). Furthermore, such a deficit-based framing (i.e. how it fails to fit WMS's epistemological and ontological enactments) obscures the importance of distinctions, as well as rich contributions that TEK and IWLN have to offer.

TEK and IWLN's alignment with Cartesianism will always result in theories that are viewed as not "*as* correct as the scientific ideas of the dominant, hegemonic culture" (Siegel, 1997, p. 101, emphasis in original). They fail to cleanly fit the separate and mutually exclusive ontological and epistemological categories established by WMS because TEK and IWLN do not make such clean and clear cuts between epistemology and ontology and their constitutive domains. This is not to state that it is inherently wrong in an absolute sense to centre Cartesianism[5] and that there are no moments in which it is an appropriate ontology to posit (e.g. when

[5] It is important to note however that Cartesianism and Eurocentrism, "the idea that the people, places, and events of Western European cultures are superior and a standard against which other cultures should be judged" (Lewis and Aikenhead, 2001, p. 53), co-constitute one another. As such, particular attention needs to be paid to how these produce science education and educator, as well what such a science curriculum and pedagogy might come to produce (see Higgins, 2014).

considering WMS[6]). However, to posit *an* ontology is to be held accountable to the patterns of difference, the lines of inclusion/exclusion that are produced through the "metaphysical choices" that we make. Thus, to put forth *an* ontology invites a differential consideration and an ongoing accounting for and ethical accountability to the ontological norms through which TEK and IWLN have been included or excluded from science education. To posit *an* ontology also invites a curricular investigation of how diverse knowledges are ontologically situated and produced, without needing to resort to relativism (see McKinley, 2007).

6.3 Part 3: Positing *an*(Other-Than-Cartesian) Ontology: Towards Ontological Pluralism in Multicultural Science Education

> One does not make the subject matter relevant by starting with an unchanged traditional curriculum and coating scientific facts with "relevant examples" to make them go down easier. *In teaching for agential literacy, science is understood (not "in context") but in complex intra-action with other practices*. (Barad, 2000, p. 238, emphasis in original)

To posit *an* ontology within science education is to recognize that diverse ways of knowing nature are not simply different ways of reaching the same ontological goal within the oft taken-for-granted or unacknowledged ontology of Cartesianism. Teaching a culturally pluralistic science classroom must go beyond the "candy coating" of this standard ontological account with culturally relevant examples. Rather, as Barad (2000) invites us to consider, if we are to teach in a way that encourages students to understand ways of knowing nature as the enacted entanglement of epistemology and ontology, what she refers to as *agential literacy,*[7] then we must come to understand them as complex and co-constituted practices. In part, this entails pedagogical exploration of diverse ways of knowing alongside the ways of being that co-constitute them (e.g. Barad, 2000).

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[6] Part of the reason for this, if we take Barad's (2007) notion of *onto-epistemology* seriously, is that the epistemology and ontology of Western modern science are always already simultaneously enacted. Furthermore, it has been argued that the two were also historically codeveloped (see Apffel-Marglin, 2011; Latour, 1993).

[7] Elsewhere (Higgins, 2016), I differentiate between Barad's (2000) notion of agential literacy and scientific literacy:

> Agential literacy goes beyond scientific literacy's accounting for the diverse natural and cultural agents that constitute experimental phenomena studied and produced within the context of science education. First, it considers the ways in which agents are always already natural-cultural. Secondly, it accounts for the ways in which these agents not only constitute but are also constituted by phenomena. Third, agential literacy ethically re(con)figures accountability as a process of not only accounting for, but also being accountable to these agents and their intra-action in the world's ongoing becoming (pp. 190–191).

Furthermore, I provide therein a school-based example of what it might mean to enact science education through a cross-cultural conception of *agential literacy*.

To posit *an* ontology is significant within multicultural science education because it can be said that, using the language of the ontological turn, matter has *always* mattered to Indigenous peoples in the ways in which they come to know nature (i.e. TEK and IWLN). In other words, Indigenous peoples have never fully enacted the Nature/Culture binary (i.e. the mutually exclusive bracketing of nature and culture) that is commonly accepted as a defining characteristic of Western modernity, its ontology of Cartesianism, and WMS (see Bang & Marin, 2015; Cajete, 1994, 1999, 2000; Peat, 2002). For example, Cajete (2000) highlights the ways in which animal-human relationships conventionally map onto Nature/Culture breaks down within Indigenous ways of knowing in being:

> Most Native languages do not have a specific word for 'animals.' Rather, when animals are referred to they are called by their specific names. That fact that there are no specific generic words for animals underlines the extent to which animals were considered to interpenetrate with human life (p. 152).

Beings that are often considered within the realm of Nature (e.g. animals, plants, mountains) have always been agents within the realm of Culture (see Apffel-Marglin, 2011; Bang & Marin, 2015; Barnhardt & Kawagely, 2005; Cajete, 1994, 2000). Thus, to posit *an* ontology rather than presenting ontology as singular, universal, and presupposed invites a differential consideration of and an ongoing accounting for, and ethical accountability to, the ontological norms through which TEK and IWLN have been included or excluded from science education.

For example, Indigenous science educator Gregory Cajete (1994, 1999, 2000) proposes that we consider ways of knowing in being – that is, the co-substantiation of epistemology and ontology – as ecologies of relationships. These ecologies of relationships that are enacted with/in these ways of knowing in being are often referred to as both external and internal to a human(ist) subject (which is conventionally considered the sole agent within Culture) while noting that some of the relations external to the subject do not require a subject at all (e.g. other-than-human agency). Externally, we often speak of relationships with other humans, relationships with other-than-human bodies (e.g. plants, rivers, mountains), as well as relationships with more-than-human bodies (i.e. spiritual beings) (see also Apffel-Marglin, 2011; Bang & Marin, 2015). Internally, the relationships between the heart, mind, body, and spirit are often called upon. Furthermore, the boundary between exteriority and interiority is one that is porous, and it is this porosity that allows us to be with/in relation. This ontological porosity (i.e. how matter and materiality are never fully discrete quanta) extends to space and time to make being in the world a question of process, flux, and holistically being *of* the world (see also Barnhardt & Kawagely, 2005).

To consider ontological plurality is not a renewed commitment to relativism: there are meaningful "points of resonance" (Peat, 2002) between WMS, TEK, and IWLN. In their analysis of such convergence, Ray Barnhardt and Kawagely (2005) note, "there is a growing appreciation of the complementarity that exists between what were previously considered two disparate and irreconcilable systems of thought" (p. 12). This is a sentiment which physicist Peat (2002) also shares:

> It is at this point that a tantalizing paradox presents itself. On one hand it seems that the very activity and busy-ness of our analytic, linear Western minds would obstruct us from entering into Indigenous coming-to-knowing, yet, on the other, scientists who have been struggling at the cutting edges of their fields have come up with concepts that resonate with those of Indigenous science. (p. 6)

Despite these points of resonance between ways of knowing in being, this is not to suggest that there is *an* external reality that we can differentially access through diverse cultural frames (see Latour, 1993). Again, plurality needs not be thought and enacted as relativism (see McKinley, 2007). Rather than relativism, to account for and to be accountable to ontological situatedness (i.e. the co-constitutive relation between *an* epistemology and *an* ontology) might be a way of enacting what Barad (2007) asks of a re(con)figured objectivity – an accounting of and for the diverse network of agents, forces, and flows which locally and globally come to produce the scientific phenomena that we seek to explore within science education (see also Barad, 2000, 2010).

It is nonetheless important to note that science education will be at its most fruitful when it works to engage with spaces of difference between diverse ways of knowing nature to work against the ever-present risk of conflating diverse systems into sameness.[8] This includes, but should not be limited to, the ways in which ontological sameness produces dialectic negation discussed herein. Accounting for and being accountable to difference is not only ethically significant; the distinctions within this plurality can help (re)shape rich and robust knowledge traditions, as well as foster the possibility of intercultural hybrids that bring with them the best of both worlds (e.g. Barnhardt & Kawagely, 2005; Cajete, 1999; Higgins, 2011, 2014, 2016).

6.4 Conclusion: Positing *an* Ontology as an Ethical Call

> Responsibility is not an obligation that the subject chooses but rather an incarnate relation that precedes the intentionality of consciousness. Responsibility is not a calculation to be performed. It is a relation always already integral to the world's ongoing intra-active becoming and not-becoming. It is an iterative (re)opening up to, an enabling of responsiveness. Not through the realization of some existing possibility, but through the iterative reworking of im/possibility, an ongoing rupturing, a cross-cutting of topological reconfiguring of the space of response-ability. (Barad, 2010, p. 265)

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[8] For example, Cajete (1994) invites us to consider the similarities *and* differences between IWLN and quantum physics:

Scientists study the tracks of subatomic particles that exist only a millionth of a second. They find the human observer influences the energy relationships and even the nature of existence of these subatomic particles. Humans do participate with everything else even at this level of natural reality. Indigenous people understood this relationship of human activity as concentric rings that extend into the spirit realm. (Cajete, 1994, p. 55)

Within the context of multicultural science education, the relationship between science (i.e. knowing nature) and justice (i.e. respecting diverse cultural knowledges) often continues to be dichotomized within multicultural science education. This make it such that the debate between the predominant universalist and cross-culturalist positions rarely produces productive intermediary positions from which to take up both of these competing claims in the ways in which they are articulated. While there is a responsibility to be accountable to both, "the space of response-ability" is foreclosed without being able to account for and be accountable to the "incarnate relation that precedes the intentionality of consciousness" (Barad, 2010, p. 265) that many science educators inherit: Cartesianism and the Nature/Culture cut that it enacts (see Higgins, 2017). Given that the Nature/Culture binary makes science and cultural politics incommensurable, responsibility and response-ability require "an iterative (re)opening up to, an enabling of responsiveness" towards other-than-Cartesian possibilities. Thankfully, as Latour (1993) reminds, the Nature/Culture binary is never fully achieved or achievable. *We Have Never Been Modern*, as the eponymous title of Latour's (1993) book proclaims; there is always already the possibility for knowing in being otherwise.

Towards this end within this chapter, I use and trouble Cobern and Loving's (2008) suggestion that the primary and almost exclusive focus on epistemologies within the multicultural science debate has detracted from considerations of how epistemology aligns with ontology. As is demonstrated herein, Cobern and Loving use this (re)signified natural-cultural interplay to make a stronger case for universalism (i.e. "Epistemic Realism Really is Common Sense" [p. 425]). However, I have argued earlier the possibility for something else to emerge from this insight by differentially engaging with it, particularly if we also take seriously the notion that ontology is not a singular affair. Such differential arrangement can support us to recognize that plurality can be achieved not by refuting Cobern and Loving's claim but rather by (re)situating it within *a* context: *an* epistemology of epistemic realism (i.e. the epistemology of WMS) really does align best with *an* ontology of Cartesianism (i.e. the ontology of WMS). To recognize that Cartesianism is but *an* ontology creates space in which WMS achieves "distinction not privilege" (Cobern & Loving, 2008, p. 444), not requiring universalists' claims of onto-epistemic alignment to be refuted.

Notably, this potential for science without scientism requires science educators' response-ability towards positing *an* ontology, accounting for, as well as being accountable towards how it is produced and what it produces. Given science education's norms and history of inclusion/exclusion around traditional ecological knowledges and Indigenous ways of living with nature, positing *an* ontology invites a (re) consideration of science education's complimentary and supplementary spaces of knowing nature. Specifically, this calls for a renewed engagement with TEK and IWLN. As they have their own distinct onto-epistemological alignments or entanglements, positing *an* ontology calls for an ethical response-ability to account for the relational ontologies which come to constitute them rather than requiring them to align with Cartesianism. To engage in such ontological pluralism need not rely on ontological or epistemological relativism as there continue to be meaningful patterns of differentiation and similarity that can be productively engaged with (see McKinley, 2007).

I conclude with further questions about the space of ethical response-ability offered by positing *an* ontology: if how we think (e.g. Nature/Culture binary) is the very thing preventing forward momentum within the multicultural science education debate, how do we think about how we think without using the very thing with which we think (when the thing with which you think is part of the problem; see Higgins, 2014, 2018)? How might science educators move towards ethical response-ability when responsibility is not something that we simply *have* that pre-exists our engagements but rather is also something by which *we are had*, that is produced in its complex flow through and by us? How can we be accountable to how we are always already (re)produced by science education as educators? Similarly, how can we foster response-ability to what we produce within the ever-changing field of possible possibilities for science education (as part of the world's ongoing becoming)? Lastly, what types of theory-practices might facilitate the im/possible but necessary accounting for what our onto-epistemological enactments produce within science education? Response-ability, as Barad (2010) reminds, is not achieved "through the realization of some existing possibility, but through the iterative reworking of im/possibility" (p. 265). While there is no singular solution to such questions, positing *an* ontology paves pathways to engage with the im/possibility of being wholly accountable and ethically responsive. To reiterate, situating science education ontologically by putting forth *an* ontology is not about who is right or who is wrong, nor is it about a renewed commitment to relativism. Rather, it is about coming to recognize a plurality of possibilities, and in turn, it means being accountable to how scientific knowledge is produced and producible and what it produces in turn within and beyond the science education classroom. Because "how reality is understood matters" (Barad, 2007, p. 205), the (re)working of lines of inclusion/exclusion that such understandings and enactments produce is always already becoming something else, and this (re)working towards positing *an* ontology is an ethical call which we must all heed, albeit differently.

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Chapter 7
Intra-actions that Matter: Building for Practice in a Liberal Arts Science Course

Catherine Milne

My previous exploration of material culture, outlined in Chap. 2, really activated my thinking about how I might apply my interest in instruments as material culture into a course of study that had the goal of reengaging undergraduate learners with science. In this chapter, I make a case for using phenomenology and feminist theory to build a curriculum that seeks to value the learning of the students in the course and describe the phenomena I produced in the process.

7.1 Relevance for Science Education

I have long been a proponent for a role for history in the teaching and learning of science (see Milne, 2011) because current approaches to the teaching and learning of science often present science to learners as finished or completed so that students learn their role is to learn the science concepts that constitute the basis of finished science. Rarely are students afforded opportunities to experience some of the thinking that helped humans grapple with the challenges associated with trying to understand why objects and living things behave the way they do, that is, science in the making rather than "finished science and the 'the answers'" (Bruner, 1992, p. 7; Rheinberger, 1995). In science education, often concepts are afforded more ontological power and are considered more real than the lifeworld experiences of the learner. The power of concepts is reinforced when experiences, such as those involving laboratory activities, are designed to confirm conceptual understandings or scientific facts. For example, students are sometimes given the task in chemistry (you might ask why but that is another question) of "finding" the boiling point of water

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with the expectation that they will obtain a value of 100 °C. If they do not obtain such a value, they are often tasked with the responsibility of explaining why they were not able to do so. The implication of this task is that the student is responsible for not obtaining the "correct" value, and if they did not, they have done something wrong. However, history shows us that such a "fact" is context dependent, and such a value is more of a cultural artifact than the "truth" (see Chang, 2004). But, when students are criticized by the teacher for generating an outcome from their lived experiences at odds with the teacher's expectations of what is the "correct" answer, students' perceptions that science is not for them can be reinforced. Of course, this example also got me thinking about the instrument, the thermometer, which is a key actor, in the construction of the practice of the measuring of temperature with respect to the boiling point of water. As I noted in my earlier chapter, in these types of lessons, instruments are taken for granted and assumed to have no role or agency in the construction of the phenomenon that the student is expected to record, and their role in the process of constructing the phenomenon, such as the boiling point of water, is ignored.

These reflections on the role of instruments and the power of concepts really initiated my search for alternative perspectives that would help me to develop a course in which students might see a place for themselves in a science context. My search led me to explore a number of philosophical and research perspectives used by scholars that have grappled with the following elements: the materiality of the classroom (Roehl, 2012), phenomenology in science education (Østergaard, Dahlin, & Hugo, 2008), and phenomenology of technology with the development of instruments as epistemology engines (Ihde, 2012).

In their development of a phenomenologically based physics curriculum, Edvin Østergaard et al. (2008) note the importance of German science educator Martin Wagenschein (2008) who wrote extensively about the importance of experience and observing for learning in science. In his paper, *Save the Phenomena*, Wagenschein argues:

> I have nothing against nurturing abstract intelligence, but I am against isolating it. I do not speak for a flight into the phenomena, but I do say that they should have priority. I am advocating for something, namely for experience, such as I have described here, being fundamental and remaining so. Of course quiet observation, reflection and dialogue take time. It is a remarkable thing that one often looks in vain for such learning in schools. (pp. 5–6)

Wagenschein goes on to argue that when an explanatory framework involves the evocation of something that cannot be observed directly, then it becomes even more important to give priority to observing without instruments. His examples also highlight the close relationship between observing and questions although that is not the focus of the argument he is making on saving the phenomenon. Unfortunately, students' classroom experiences of science often present science as theoretical, abstract, and disconnected from their lives (see Beach, 1999). As I noted previously, a focus on the learning of concepts results in students being presented with science as finished, the implication being that the role of a student is to learn the facts and concepts of known science rather than experiencing science and making sense of those experiences from a cultural science perspective. Østergaard, Dahlin, and Hugo proposed a phenomenological approach to science learning that was appealing to me as I explored developing a curriculum for a liberal arts natural science course for undergraduate students. One of the attractions of phenomenology for me was its emphasis on the role of sensing and feeling, what Østergaard, Dahlin, and Hugo describe as the "precognitive phase." They say:

> Phenomenology agrees that knowledge is constructed by the learning subject and its holistic perspective acknowledges the need to consider learning processes in cultural contexts. However, phenomenology tries to balance the predominance of abstract conceptual explanations by connecting abstract knowledge to being and acting in the world as the basis for genuine understanding. (2008, p. 98)

For me, this perspective provided a path between the everyday experiences that could be accessible to all students and the culture of science and provided a pathway for thinking about building a course that had the goal of starting where students feel comfortable before introducing how science wants us to see the world. Influenced by the work of philosopher, Edmund Husserl, phenomenology helps us to appreciate how the "subjectivity of the researcher participates in the construction of scientific knowledge" (Østergaard et al., 2008, p. 124). In other words, the doing of science is key for the knowing of science. Of course, Husserl went further arguing that natural science sometimes forgets how scientific knowledge is related to everyday experience.

For bridging the gap between everyday experience and scientific concepts, Østergaard, Dahlin, and Hugo recommend the following:

1. Develop a rich picture of observational phenomena because the perceptual lifeworld should be given priority over abstract scientific models since it is our experience that provides a context for giving a purpose to science. Dahlin, Østergaard, and Hugo (2009) call this the "ontological reversal."
2. Choose some of students' everyday concepts from rich phenomenological descriptions to move to scientific concepts. Recognize that action is primary to cognition, so that curriculum will take students from acting in the world to a cognitive understanding of the world. Dahlin et al. (2009) call this the "epistemological reversal" that has an appreciation for the primacy of attentive practice. Of course, such a valuing also requires giving attention to the aesthetic dimensions of phenomena such as the sensual, feeling, and imaginative aspects because these aspects reinforce greater engagement with experience. Thus there is value in exploring objects and experiences and trusting our observations of the natural world rather than relying on a Wikipedia search.
3. Introduce scientific concepts/models that are often experienced as abstractions of phenomena as a continuation rather than a contradiction of everyday experiences. Dahlin et al. (2009) call this the "pedagogical reversal" in which competencies are cultivated instead of beginning with imparting ready-made conceptual knowledge. At the same time, we can use introduced concepts to support students to deepen their understanding of and appreciation for phenomena.

For me the benefit of this approach was threefold. It provided a pathway for the development of science concepts while also supporting students to develop a richer understanding of and appreciation for phenomena; however phenomena are defined. It supported the systems-based way concepts are connected in science. And it offered the possibility of students seeing themselves as powerful with respect to their understanding of their experiences with their lifeworld instead of seeing themselves as reproducers of conceptual and given knowledge. Importantly, phenomenology reminded me that the curriculum I wanted to develop needed to support students to realize that observations, even scientific ones, are contingent, and that our observations come from us mattering in the world. Phenomenology, as presented by Dahlin et al. (2009), offered me a way of thinking about building curriculum by focusing on everyday experiences, which could provide a pathway to environmental issues that ultimately were to be the focus of the course. I was already in the thrall of the idea of "evocative objects" having read Susannah Mandel's (2007) chapter on apples in Sherry Turkle's book, *Evocative Objects: Things We Think With*. What I appreciated about Mandel's chapter is that she did not try to tell the reader what to think. Rather, she involved the reader in her experience with apples and engaged us in what Turkle described as "the object as a companion in life experience" (p. 5). Consistent with one of the other themes important to this course, Turkle notes, "Material culture carries emotion and ideas of startling intensity. Yet only recently have objects begun to receive the attention they deserve" (2007, p. 6). Turkle's reflection on the lack of attention and love objects are given with respect to their role in knowledge building, really resonated with my thinking, especially my sense that in the building of a curriculum, which had as its goal supporting learners to see a role for science in their lives, I needed to incorporate the notion of evocative objects.

At the same time, I began to read Don Ihde, postphenomenologist and philosopher of technology, and Karen Barad, feminist theorist and physicist. Ihde, in his work on the role of technology in knowledge production, especially his commentary on the camera obscura (Ihde, 2000), noted how tools and technologies, like the camera obscura, transform the experienced world, so it becomes very different from "an eyeball world" emphasizing the "role of embodiment in relations to technology uses" (Ihde, 2015, p xii). He proposed the idea of "epistemology engines," technology that is used to "model the process of knowledge production" (Ihde, 2006, p. 79). This started me thinking of how I could use the making and use of camera obscuras and then prisms and spectroscopes to support students to recognize these technologies as both epistemology and ontology engines (see also Milne, 2015). In other words, technologies, or instruments as I was thinking of them, were not just tools students use so that their differing observations involving light can be applied to understand the nature of light but also technologies that change their perceptions of what is real while continuing to provide a context in which practices, such as observing, questioning, claiming, and measuring, are valued. This perspective provided the justification I needed to emphasize the building and use of instruments in the course in a way that both problematized students' experiences and observations of the world and helped them to develop conceptual understandings.

Karen Barad helped me to think of these technologies or instruments as apparatus where interactions between human and apparatus limit and/or define and change the phenomenon that is constructed through our observations. Historically, with the emergence of experimental philosophy, the words and notions of instrument and apparatus were used interchangeably (Wilson, 1996). Barad argued that the relevancy and context approaches to developing science curriculum were all wrong because relevancy is undertheorized, and often context is constructed in a way that instantiates bias and promotes powerful ideologies about how certain groups respond to science (see Barad, 2000). She argued further there is potential for context-based approaches to reify a nature/culture dualism that seeks simplistic cause and effect relationships between science and culture. She was also critical of courses for students in which entertainment becomes a substitute for learning. Her position is that for the benefit of all science learners, science educators have a responsibility for teaching "science in a way that promotes an understanding of the nature of scientific practices" (Barad, 2000, p. 223). She asks:

> If science students do not learn that doing responsible science entails thinking about the connection of scientific practices to other social practices, then what is the justification for our current confidence as a society in the ability of scientists to make socially responsible decisions? (p. 223)

Of course, in this note Barad goes further presenting an ethical challenge of making socially responsible decisions, and she provided me with further justification for a focus on human impact, what it means to be socially and ethically responsible, and what each of us can do. This meant that the course would not only explore issues of human impact but also, in terms of energy consumption and carbon emissions, what each of us can do to reduce our impact on the planet. Barad (2000) also challenges us to think about developing curriculum that takes "account of discursive and material constraints on knowledge productions" (p. 223) and inspires a love of science based on recognition of its strengths and limitations. She argues for science literacy as agential literacy. Barad argues further that there is no inherent cut between objects and agencies of observation, and phenomena are constructed through the cuts we make during the experimentation and the measurement process. For her, practices exist as the "agential intra-action of material-discursive apparatuses" (p. 234), and these apparatuses are not merely simple instruments. Indeed, Barad captures the dynamic and agential nature of instruments when she describes apparatuses as "material reconfigurings of the world that do not merely emerge in time but iteratively reconfigure spacetimematter as part of the ongoing dynamism of becoming" (Barad, 2007, p. 142). I do think of instruments as an example of the apparatuses identified by Barad that offer the possibility of affording scientific literacy which in Barad's words is about "learning how to intra-act responsibly within the world" (2000, p. 237).

Barad also provides two other principles for the development of the curriculum: diffraction and ethics. In her articulation of diffraction, Barad acknowledges her debt to Donna Haraway when she writes, "as Haraway suggests, diffraction can serve as a useful counterpoint to reflection: both are optical phenomena, but whereas reflection is about mirroring and sameness, diffraction attends to patterns of difference" (Barad, 2007, p. 29). Both Haraway (1992) and Barad (2007) are critical of the use of reflection as the trope or metaphor for knowing and self-accounting, which is how it is typically used in educational contexts. Alternatively, diffraction allows us to be comfortable with the "differences our knowledge-making practices make and the effects they have on the world" (p. 72). The metaphor of diffraction helps me to be comfortable with the differences that emerge from the relational nature of knowledge building rather than seek to constrain these differences through detailed instructions for what students should write about when I invite them to write about their learning. These writings also become consequential for lessons moving forward in the course. In my experience, such an approach is atypical in science education where emphasis is often on ensuring that all students in a class are doing exactly the same things and writing about the same things. Observing a science classroom, you would be most likely to see this in "lab" where all students are required to follow the same laboratory procedure and in the extensive use of rubrics or scoring guides for assessment. Thus, diffraction is more than a metaphor. It is a structural component of the course design and scheduling. Since diffraction maps the effects of difference and does not constitute a reflection of difference, it provided me with a rationale for inviting/requiring students every week to write about their responses to their experiences in the course, make connections to their everyday experiences, and write about any questions that emerged. Thus, students writing a response would be a required element of the course and indicative of their entanglement with their experiences in the course. As Barad notes, "a diffractive methodology is a critical practice for making a difference in the world. It is a commitment to understanding that differences matter, how they matter, and for whom. It is a critical practice of engagement, not a distance learning practice of reflecting from afar" (p. 90).

My goal was that a focus on diffraction and knowledge-making practices would help students to understand their role in the "world's differential becoming" (Barad, 2007, p. 91), with the potential for helping them to understand that the decisions we make about enacting practices are also ethical because they have consequences for us and the material world.

Reading and thinking about Barad supported my revising of the curriculum elements proposed by Østergaard et al. (2008) to the following:

1. Begin with practice to produce phenomena. This element provides the justification for starting the course with observing in a variety of forms. Encouraging students to note the agency of context and how our different ways of interacting with context produce different phenomena. Begin to explore how science engenders purposeful observation and what that might look like.
2. Explore how constructed apparatus engage humans in intra-actions that forge new realities and ways of knowing. For example, students will build their own acid-base indicator using red cabbage or some other plant, and they will also build a camera obscura and spectroscope using found objects and explore the world in concert with the apparatus they construct.

3. Phenomena and concepts will be experienced as a continuum as the constructed phenomena provide a context for concepts. For example, red cabbage indicator/human intra-action provides the context for understanding acidity and basicity and pH and camera obscura, and prism and spectroscope intra-act with students to create phenomena that provide a context for deciding on the nature of light and other forms of radiation.
4. A diffractive methodology makes a difference and provides insight into the effects of practices on the world. In the course, I interpret a diffractive methodology in terms of using self-assessment as the method for evaluating learning in the course (see Milne, 2014a, 2014b). As an educator, I have a responsibility to support students to begin to develop some ability to evaluate their learning. One benefit of such a strategy is that it allows for greater degrees of freedom in how students evaluate their learning from the course. It allows them to focus on the aspects of the course that have meaning for them and from which they have intra-acted with apparatus to become entangled in a learning reality. One apparatus that is key for this methodology is the use of response cards on which every week students write a commentary in which they may make connections to other experiences they have had, describe their learning, and/or ask questions. Sadly, students' experiences with self-assessment and self-evaluation tend to have been extremely limited before they become members of this course. So building a learning and assessment environment, where students are ethical with respect to their learning and trust that I am ethical in my claims about self-assessment, requires a range of experiences within the course.

These principles informed my development of the curriculum (see Table 7.1).

7.2 Interpreting Barad in Developing a Curriculum

While principles from Barad (2000, 2007) galvanized my thinking about the kind of pedagogy that had the potential to support students to learn about practicing responsible science, I was developing a curriculum for the general studies or liberal arts component for undergraduate education rather than for committed science majors, and this context further influenced my thinking about the curriculum. At my institution, all undergraduate students are required to complete two full courses in the natural sciences as part of their liberal arts core requirement. The students registering for this course have, in general, little to no interest in science as a career, and often their previous experiences in science at high school have been negative. As one student noted in her views about science when she began the course, "Science… Yuck!" At the same time, many of them have educational experiences where conceptual understandings are privileged, and I recognized that for some students, perhaps for many, their expectation coming in to the course would be that the course content would focus on conceptual understandings associated with climate change, so they might be hoping to cruise through the course with the minimum of effort.

Table 7.1 Outline of course plan

Experiential areas	Instruments/material	Practices	Concepts
Light	Evocative objects, e.g., apples	Observing/claiming/ questioning/testing	What is the nature of visible light? How do humans make observations?
	pH paper		Acidity/basicity/pH
	Red cabbage indicator		
Camera obscura development and use	Camera obscura – pinhole/screen	Observing in the service of science	Reflection/refraction
		Capturing light	History of citizen science (Miller-Rushing et al., 2012)
	Prism – prism/screen	Generating spectra	Natural white light is not unitary
		Measuring – nanometers	
Spectroscope development	Spectroscope – diffraction grating/ screen	Using observations to develop explanations	Different light sources produce different spectra
			Visible radiation and the identification of IR (William Herschel, 1800) and UV (Johan Ritter)
How infrared (IR) and ultraviolet (UV) radiation were discovered	Thermometer	Questioning – are different colors also different with respect to heat?	Energy transfer
	Prism	Measuring	Energy conservation Thermal equilibrium
Ozone layer/global warming	Energy footprint	Building molecules	Energy use and energy accounting (Squarzoni, 2014)
	Thermometer	Question – where does carbon dioxide go?	Global energy transfer
		Calculating energy use	Ozone hole – stratospheric ozone
			Greenhouse gases
The ocean	Bromothymol blue indicator	Modeling	Ocean acidification
	Vinegar		pH
			Chemical reaction
			Buffering
			Equilibrium
Air quality	Schoenbein paper (developed by Christian Schoenbein to test for ozone)	Exploring local environment	Tropospheric ozone
	Testing kit for particulates	Modeling	Chemical reactions
		Testing for ozone and particles	

However, I felt it was important for them to observe their world and to value those observations and to begin to ask questions about how the tools they intra-act (for Barad [2007] human and apparatus collude in the construction of phenomena through their intra-action) with, in practices like observing, transform the phenomenon they register as experience. As Edmund Husserl (1970) notes, mathematical formulas are sometimes seen as more real than our concrete lived experiences in which they are grounded, and I had a sense that some students, especially those for whom school science had actually "worked," may have that perspective. My observations of chemistry classrooms in action and my conversations with chemistry teachers reinforced the privilege assigned to conceptual understanding and the lack of attention given to the chemistry of the experienced world of the students. Often students are expected to explain the everyday but are isolated from the everyday. As much as possible, I wanted the course to ground students in their experiences so that we could use these experiences to build understanding.

7.3 Begin with Practice to Produce Phenomena

I decided that the course called *Science in our Lives: Environmental Studies* would have a citizen science focus that would begin with students observing the world in which they lived in ways that provided access to experiences that served to foster a need to know science. The United Nations Environment Programme describes citizen scientists as "people who are not professional scientists take part in one or more aspects of science – systematic collection and analysis of data, development of technology, testing of natural phenomena and dissemination of the results of activities." (Park, 2014, p. 37). Students also read the paper, *The history of public participation in ecological research*, by Abraham Miller-Rushing, Richard Primack, and Rick Bonney (2012) and worked in small groups to develop a timeline for citizen science based on that reading. This activity helped them to see that science began with citizen scientists, so being a citizen scientist was a possibility for them. For this element of the course, students were also required either individually or in pairs or small teams to work on a citizen science project and to complete an ethnography of the project. They could either volunteer for a project through zooniverse (n.d.) or scistarter (2016) or another project that was interesting to them. This meant that projects could range from a project called "Celebrate Urban Birds" (Cornell Lab of Ornithology), which required students to go out and observe birds in their urban neighborhood (the university is located in a densely urban environment), to "Old Weather" (zooniverse) which involved students reading Captains' logs from the nineteenth century looking for references to weather conditions.

As Barad noted (1998, 2007), humans are entangled with apparatus, and it is through this entanglement or intra-action, and the cuts made to limit what counts, that phenomena are constructed. So, I wanted students in the course to understand how, through our intra-actions with instruments, new phenomena emerged engendering new questions and reality (see Table 7.1 for part of the syllabus), and I wanted them, as much as it was possible, to build instruments or apparatus from everyday materials. Barad (2007) argued that understanding does not come from being at a distance and representing something but from "direct material engagement in the world" (p. 49). She argued further that representation, that is, the ability to present representations, the ability to convert experience into mental objects, is often expected and accepted as key evidence of student learning. But representing also makes the human active and material objects passive, thereby separating the human and the material from each other. According to Barad, it is through practices that both the human and the material actively participate in the becoming of the world, and it is through this participation, which she calls "intra-action" between organisms and apparatus, that phenomena are produced. Rather than humans, like you and me, observing phenomena that exist separate of ourselves, the material world and us work through practice to construct the reality of phenomena. A practice like observing brings together living and nonliving to produce the world we experience. Also, it is through these practices and associated intra-actions that the boundaries of each phenomenon we report are created. As I noted in my earlier chapter, in science and in everyday life, we are entangled with instruments as apparatuses, and through this entanglement, we create phenomenon.

Barad (2007) explored intra-action and entanglement through the study of optics, and I saw connections in her text to the liberal arts course I was planning to develop that began with the question of how we can support students to be more like citizen scientists. This question was complemented by further questions, such as what skills do they need to be able to think about adopting such a role and why is it important in the twenty-first century. In developing the course, I began with a focus on observing and thinking about the role objects play in the observations we make. Also, as schools focus more and more on literacy and conceptual approaches, there seems to be a decline in opportunities for students to learn to make observations and for their observations to be the valued as providing them with insight into how the world works, even before they begin to make measurements or engage in any other scientific practices that conceptually are valued more. So first, participants need to engage in observing and valuing their observations and the context in which those observations are made. Maurice Merleau-Ponty claimed that:

> The whole universe of science is built upon the world as directly experienced, and if we want to subject science itself to rigorous scrutiny and arrive at a precise assessment of its meaning and scope, we must begin by reawakening the basic experience of the world of which science is a second-order expression. (1962, p. viii)

For me, Merleau-Ponty's quote suggests that we need to provide students with opportunities to experience the world through practices and make observations of the world they are experiencing before seeking to explain those observations. For example, as a way of having students think about the importance of light to humans and the world with which they are intra-acting, I began by also asking students what they needed so that they would be able to observe their world. Encouraging students at the beginning to make observations, without making any judgments about those observations, is the first step toward having students value the observations they make. From my perspective, such an approach is even more important for challenging learner perceptions that the virtual world, which for them holds the answers to questions they ask, is more "real" than the actual world that they move through every day.

7.4 Explore How Constructed Apparatus Engage Students in Intra-actions

In the course I developed, part of this introduction to observing also required students to read *Apples*, by Susannah Mandel (2007), in which she describes how she finds apples to be evocative objects. Building from the reading, students are engaged in making observations about specific apples. The phenomenon of observed apples is engendered by the practice of observing and the intra-action between students and specific apples in the practice of observing. The apples, including all the types of apples that are available at that time of the year, provide the basis for connecting observing with text. Observing apples is the first step to encouraging students to use and value their ability to intra-act with the world through observing, a world they experience everyday but tend to take for granted. I detect resonances with both Merleau-Ponty and Mandel in Barad when she describes the evocative experiences associated with being a participant in scientific practice rather than an observer, "holding the instruments of science in one's own hands, … placing the instruments at one's lips to draw in the rich a penetrating aromas of scientific practice" (Barad, 2007, p. 247).

Of course, Merleau-Ponty makes us appreciate that in the process of observing, it is the world acting on our eyes that causes us to see it which is how we become conscious of our thinking about the world. In other words, the world has agency just as we do. And we are of the world. Barad (2007) helps me to see that the process is intra-active and the practice of observing is iterative and mutually constitutive, because we are entangled in the world and the world is entangled in us. Such observing with apples also initiates the first claims students make because their observing is also entangled with their previous experiences with apples. For example, a student claim that lemon juice is the only material that stops a cut apple going brown becomes a question of whether or not lemon juice is the only substance that prevents browning, which is open to investigation and measurement allowing students to explore the relationship between claims/questions and evidence. Once students are comfortable making observations, they can then explore the question of how instruments can influence the observations we can make by working in pairs to build a camera obscura. Consistent with a desire to optimize the agency of both student and materials, no instructions are provided, but students are encouraged to search for a procedure for making one that is appealing to them resulting in a variety of designs (see Fig. 7.1).

Fig. 7.1 Variation in camera obscura design

I decided to start with camera obscuras because I saw connections with Ihde's (2012) exploration of camera obscura as an epistemology engine, but Barad's work also led me to appreciate the camera obscura as an ontology engine, that is, instruments that support us to think of the world in ways we did not imagine before we had access to new technologies. The notion of ontology engine also supports us to imagine the potential of other instruments/apparatuses to be ontology engines (see also Milne, 2015). I also think it is important for students to know that such instruments have a history and have been constructed and described through the centuries, but they can still be used today to construct phenomena. Known since antiquity, camera obscuras were first described in China and used extensively by Arabic scholars like Al Hazen (see Crombie, 1990). In *Problems*, for which Aristotle is thought to be the author although there is some debate about that, he wrote:

> Why is it that during eclipses of the sun, if one views them through a sieve or a leaf for example, that of a plane-tree or any other broad-leaved tree or through the two hands with the fingers interlaced, the rays are crescent-shaped in the direction of the earth? Is it because, just as, when the light shines through an aperture with regular angles, the result is a round figure, namely a cone 2 (the reason being that two cones are formed, one between the sun and the aperture and the other between the aperture and the ground, and their apices meet), so, when under these conditions part is cut off from the orb in the sky, there will be a crescent on the other side of the aperture from the illuminant, that is, in the direction of the earth. (Foster, 1927, book xv)

In this snippet of text, we can imagine Aristotle and his students explaining how the images are formed when light passes through something in nature that acts as a camera obscura. However, Aristotle did not describe how it might be possible to make a camera obscura. Making a camera obscura and intra-acting with them to construct phenomena became part of sixteenth- and seventeenth-century experimental science. The interesting issue about camera obscuras is that they need three elements, a light source, an aperture, and a screen (Ihde, 2012), and changing one of

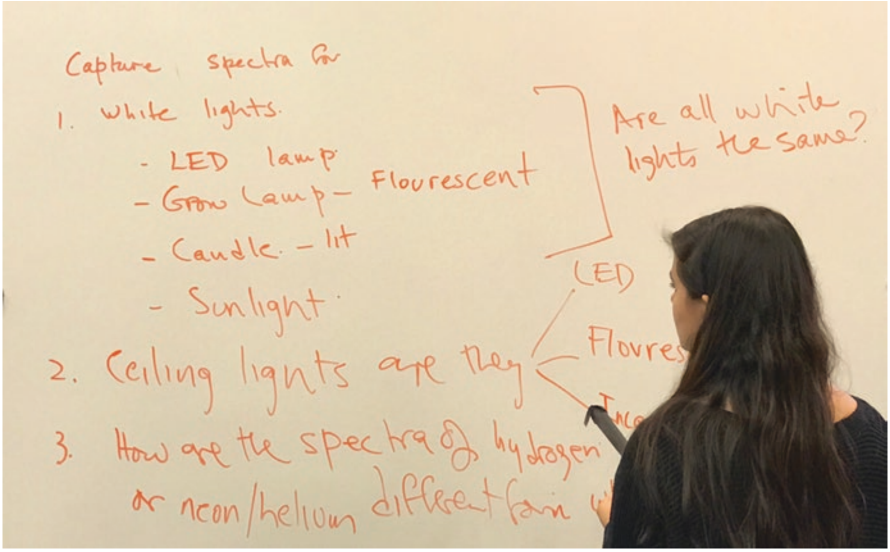

Fig. 7.2 Entangled with spectroscopes

these elements with a prism or a diffraction grating instead of the pin hole alters the phenomenon that can be observed as we intra-act with different instruments. The observations students make with a camera obscura also provided a context for asking questions about how these observations can provide insights into the nature of light, which is also something that science cares about. Noting the loss of clarity, reversed and inverted images allow students to make claims about light and its interaction with the camera obscura that can be tested further. Also, other instruments such as prisms and spectroscopes allow students to create new realities as they explore entanglements with these instruments and the questions that are generated as a result (see Fig. 7.2).

7.5 Phenomena and Concepts Will Be Experienced as a Continuum

Once students had explored the nature of light relevant to an ongoing exploration of the environment through emergent realities of white light, visible spectra, and a variety of spectra depending on the light source, they had a context to appreciate the discovery of radiation either side of the visible spectrum, infrared and ultraviolet radiation. In their observations with light, some students had already noted the relationship between light and warmth which was also noted by William Herschel in his report on radiation which he called “calorific rays” and which we now call infrared radiation (Herschel, 1800). At the same time, students were asked to explore the nature of the measurement units typically used to indicate the size of wavelengths

Fig. 7.3 Using a tool (apparatus) Schoenbein paper to detect tropospheric ozone

of light, called nanometers, by building models of the size of the wavelengths of various colors of light and explaining their models to the rest of the class. Recognizing that ultraviolet rays were shorter and more energetic than infrared rays provided a context for discussions of the identification of three different types of ultraviolet radiation based on wavelength. Exploring infrared radiation also provided a context for investigating concepts such as thermal equilibrium and energy transfer in the forms of conduction, convection, and radiation.

Experiences with thermal equilibrium and energy transfer provide a context for exploring the role of ozone in the atmosphere and ozone depletion, greenhouse gases, and global warming. At the same time, students were introduced to chemical reactions such as combustion and respiration which contribute to the release of greenhouse gases. Recognizing carbon dioxide as a long-lived greenhouse gas then raises a question of where does the carbon dioxide go, which provides a context for exploring ocean acidification. Building on the ocean acidification study students' conduct, initiates the question of whether greenhouse gases, like carbon dioxide, are the only pollutants about which we should care. This question provides a context for testing for tropospheric ozone and particulates in the air which are at the level humans breathe in air (see Fig. 7.3 for some student results) and for understanding the chemical reactions that we use to build the apparatus we need to explore each of these contaminants.

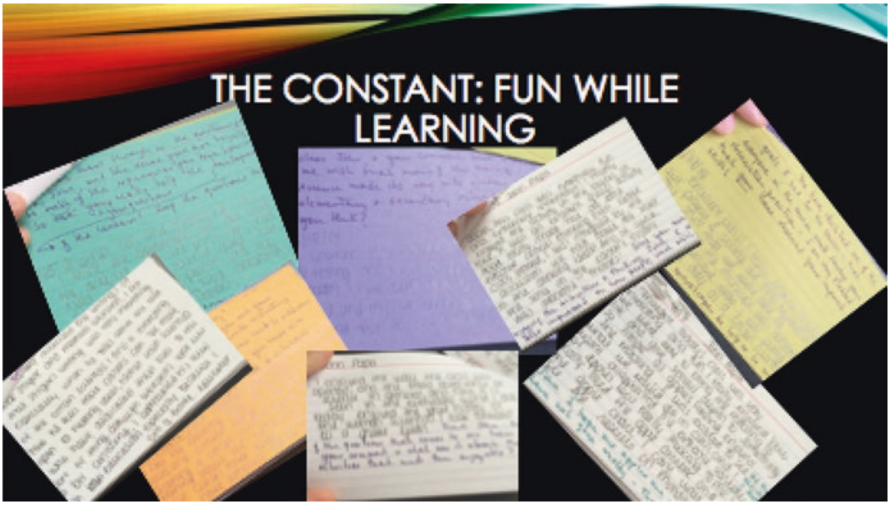

Fig. 7.4 Response cards. Diffraction in action

7.6 A Diffractive Methodology for Making a Difference

As a metaphor and as methodology, diffraction requires students to be comfortable and adept at evaluating their learning. Many students in the course are first year students, so their previous educational experiences were of high schools in which final examinations or external assessments played key roles in convincing the tertiary institution to admit them as undergraduate students. Although many of the students may not see science in their academic plans, in general, they have been highly successful at school and come with certain expectations about how learning is evaluated. The response cards they were asked to complete once a week provided an apparatus in which students intra-acted in an ongoing way, so that the phenomena of learning could change over time (see Fig. 7.4 for an example from one student). Also students were required to develop a 10-slide PechaKucha, a fast-paced timed presentation in which each slide is shown for 20 seconds, at the end of the course as a public presentation of their learning over the course. In these PechaKuchas some of the philosophies that informed the development of the course came to the fore in students' presentations (see Fig. 7.5).

Also, students sometimes diffracted on how what they were doing in the course was liberating while also acknowledging the possibility that experiences in the course could be interpreted differently by other observers (see Fig. 7.6).

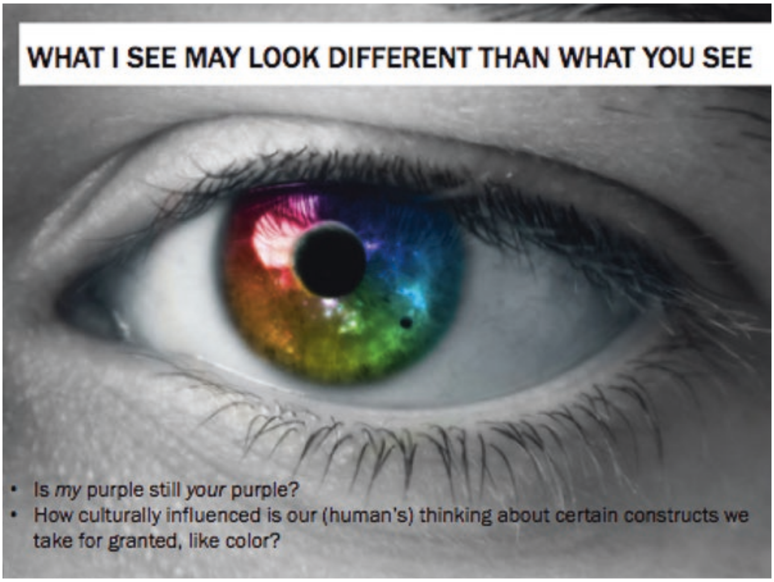

Fig. 7.5 Understanding and constructing phenomena

Sunlight in our community

Unlike other classes, we were allowed to go out and explore our surroundings.

We learned much about the impact sun has on our daily lives.

We learned about sunlight and our eyes, how our eyes are just reflectors of an image.

This was done through our spectroscope assignment.

We also learned about sunlight in regards to our Schoenbein papers.

Everyone thought we were hoodlums posting on buildings, but it was science.

And finally, we used sunlight to go next to all the smart and well dressed Stern boys on their way to class.. Thanks sun!

Fig. 7.6 My reality may not be yours!

7.7 Final Thoughts

I sat down to develop a course that would support students to develop some level of scientific literacy, seeing science as part of their everyday lives. So I looked for a philosophy that would help me to think about how I might do just that. Initially, phenomenology provided me with apparatuses to begin to develop some structures for beginning with practices that were familiar to everybody. I started with observing because that seemed to be a practice that is part of the human condition, so everyone can do it, but phenomenology also helped me to understand how we could make context part of the conversation as the curriculum could also help students to appreciate how context dependent observing is. Of course, this is not typically how observing is presented in school science classrooms. When observing is used, it is often presented as a practice or skill that students need to have, but they are often expected to know implicitly how to observe the way science expects observing to be performed. I wanted students to be comfortable observing, to challenge what it means to observe and begin to understand how science values purposeful observing. In the course, that meant we had to also explore through the course practices, such as idealization (attributed to Galileo), measurement, making a claim, developing questions, identifying variables, developing procedures, and communicating evidence, all practices that are valued by science.

However, it was Karen Barad's feminist theory that really galvanized my thinking and planning because it also provided a way to think about a course structure that provided me with strategies for integrating ethics and assessment. As I began teaching this course, it felt wonderful to see students engaged in practices, but I also felt a little saddened because their conversations about science highlighted how negative had been many of their previous science experiences. However, even more important from my perspective was how their previous science experiences had not provided them with a narrative or system that they could use to tell others about their learning and experiences in science. Of course, the structure that I developed for this course did not appeal to everyone. On their evaluations a student commented, "We spent too much time making observations of nature," and another, "We would have been better off studying the conceptual understandings associated with climate change." These two comments indicate that, for a course that was not part of their passion or the reason they were at university, some students would have liked more structure or a perhaps different course structure. But for the majority of students, the focus on observing was valued with a student saying, "I really enjoyed being asked to use our observations as a source of information on how something works." Indeed, most students voiced their appreciation for their experience in the course as one student commented: *I just wanted to take a moment to thank you for an amazing class and semester together. You're* (sic) *class really reinvigorated my interest in the science, especially since after high school, I thought I was done with the subject.* Another: *I'm really glad I took this class. Not only was it a way to have fun while learning, it also improved my communication skills. I enjoyed working with classmates and having open discussions … I am now a more aware citizen, I*

Fig. 7.7 "Science and me, before and after"

hope the lessons I have learned about being eco-friendly by recycling and observing will make the world a better place. This was the first science course in my life I actually enjoyed coming to!

Oh, and that student who said "Science…. Yuck!" at the start of the course? (see Fig. 7.7) had a more positive view by the end!

These images communicated a thoughtful recognition by this student of her identity with respect to science. Obviously she is not going to go off and change her major to science, but her imagery does communicate a fragile connection to science that was absent before the start of the course. The issue for her is that this is a single one-semester course, and whether that tenuous connection persists to any degree is an open question. My experience with this course emphasized for me the importance of building into curriculum an appreciation for how apparatuses (instruments) and humans (students) co-construct phenomena through practices such as observing, measuring, and claiming. Remembering always that all instruments are constructed, and they often need to be of a certain quality before they can intra-act with humans to form phenomenon. For example, in his manuscript, Herschel (1800) describes how the thermometers, which he used to show that different colors of light also radiated different levels of heat, needed to be of a certain quality to allow him to be confident of the phenomena that were produced. Apparatuses, as instruments and other forms of material culture, intra-act with humans and through differential entanglement produce the phenomena that are valued. Perhaps a greater focus on the intra-action between human and matter would help us to develop more nuanced learning experiences for children and youth.

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Chapter 8
How Does Matter Matter in Preschool Science?

Sofie Areljung

8.1 Introduction

At the time of writing, it seems that "new materialism" has a stronger hold in research in early childhood education (involving children up to the age of 8 years) than in other grades. In this chapter, the term "new materialism" refers to contemporary work that rejects anthropocentrism and rethinks the role of matter in meaning-making processes. Such work has contributed important insights into how matter, and not only humans, produces possibilities and limitations in children's lives and in early childhood education practices. There are currently very few examples of new materialism work that specifically target *science education* in early childhood education. In an attempt to reduce that research gap, this chapter explores how matter matters in science education in Swedish preschools (for children aged 1–5 years).

8.2 New Materialism and Research in the Field of Early Childhood

Today, Western early childhood education (ECE) pedagogies and research are commonly shaped by ideals of putting the individual child in the centre of attention (Taylor, Pacini-Ketchabaw, & Blaise, 2012). Yet, a growing number of scholars challenge the idea of foregrounding individual children, by instead considering children as intertwined with the material parts of the world. One example is Karin Hultman (2011), who emphasises that children's relations with material things are

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very important parts of their lives, since material things offer opportunities for enjoyment as well as demanding attention. In 2012, the academic journal *Contemporary Issues in Early Childhood* had a special issue on "Children's Relations with the More-than-Human World". The articles therein revolve around how matter impacts on children's possibilities of acting and making meaning. The issue includes examples of how the materialities of the dressing up corner and the sandpit (Duhn, 2012) and the clock (Pacini-Ketchabaw, 2012) produce rules and boundaries that determine what children can do and wish to do. In other words, matter, and not only humans, actively dictates what happens in ECE practices. The editors, Affrica Taylor, Veronica Pacini-Ketchabaw and Mindy Blaise, proposed that this special issue "was the first of its kind in early childhood" (2012, p. 84). Three years later, Jayne Osgood and Miriam Giugni/Red Ruby Scarlet (2015) went so far as to suggest that there is a "material turn", a paradigm shift, taking place in early childhood education research.

Doubtlessly, the field of ECE research is a vibrant arena for rethinking the role of matter in educational settings. As Hillevi Lenz Taguchi (2011) points out, the agency of matter can be more demanding to children than any verbal instruction from teachers. For example, Lenz Taguchi writes about how the "agentic force" between a pile of buttons and a child's hand could bring about touching, picking and sorting buttons, no matter what the teacher's instruction might be. Similarly, Pauliina Rautio (2013) talks of how stones can call on us to pick up, organise and carry them. Rautio proposes this as an example of how children can engage with material things in repeated actions, so-called autotelic practices, without any apparent external reward. Further Hultman (2011) claims that in their investigative practices, children pose hypotheses *with* matter and not *about* matter, since "things whisper, answer, demand and offer" (p. 77, my translation). From my perspective, Hultman's statement strongly signals "science education", since it involves investigations and posing hypotheses concerning the physical world. Yet this is not Hultman's focus. In fact, it is rare that any of the ECE studies employing new materialism perspectives talk explicitly of science education. Still many of them target children's learning with the physical world, which in my view coincides with children's learning about science. One exception is the work of de Freitas and Palmer (2016), who rethink pedagogy around conceptual change and particularly scientific concepts. Drawing on a case of children building towers of plastic beakers, de Freitas and Palmer suggest that force and gravity emerge *within* the building activities, thus within the beakers-and-children relations, rather than force and gravity being static concepts that transcend the material world.

Apart from de Freitas and Palmer's (2016) work, why has there been so little explicit focus on science education in the research literature that employs new materialist perspectives on early childhood education? Possibly because, in many countries, science education has historically not been articulated or prioritised as part of the ECE curriculum. Nevertheless, science learning goals are increasingly evident in many ECE curricula around the world, and the related research field is expanding. I propose that there is much to gain from building on the body of new materialism and ECE research, if one uses an explicit focus on how science learning emerges in matter-child relations. Preschool is an interesting arena for exploring how matter matters to science education in general, since it is an educational setting for children as young as 1 year old, where practice cannot rely on children's verbal communication. Since adults are often so distracted by verbal language that children's relations with the material world go unnoticed (Lenz Taguchi, 2012), it is likely that in preschool, verbal language is not as much "in the way" for a researcher's attention to matter-child relations, as in educational settings for older students.

8.3 Agential Realism: Agentic Matter, Intelligible-Making and Intra-actions

In seeking to understand how matter matters in preschool science education, I find Barad's (2003) theory of *agential realism* potentially rewarding. Barad aims to bring matter back into a discussion that she perceives has been too dominated by human-centring and language. *Agential realism* suggests a radical new way of understanding how things come to be (Højgaard, Juelskjær, & Søndergaard, 2012, p. 67), which is closely tied to Barad's view of matter. While in most theoretical stances, matter is seen as passive, one key feature of *agential realism* is that everything, not only human matter, is agentic (Barad, 2007). Barad (2003) claims that everything always engages something else and that objects do not exist on their own but emerge in mutual processes that she calls intra-actions. Intra-actions are contrasted with interactions, where the prefix "intra" signifies what happens *within* relations, while the prefix "inter" signifies relations *between* objects. Thinking with *agential realism*, the perceived borders of an object, for example, my own bodily borders to the rest of the world, "become" as a result of relations with other matter, such as, the floor, the air and the light.

The idea of objects emerging in intra-actions connects to Barad's (2007) view of knowing, which is described as a part of the world making itself *intelligible* to another part. I will use "floating" to illustrate how I understand this idea. In the intra-action of floating, I see that the water and the floater become intelligible to each other as properties and phenomena emerge such as temperature, buoyancy, weight, wave patterns and sound. Without the mutual relation of the water and floater, the properties of the water would not emerge, not its coldness, buoyancy or viscosity nor the wave patterns. Neither would the weight, the floating/sinking ability, and the movements of the floater emerge without intra-actions. To think about knowing as parts of the world making themselves intelligible to each other means that science learning is something that emerges in mutual relations. For example, learning about several scientific concepts could emerge within the relations of the water and the floater (be it an item or a living being). Further this view of knowing implies that we cannot know from a distance, instead knowing and being are mutually implicated, and we are part of the material world that we continually endeavour to understand. As Barad (2003) puts it: "We do not obtain knowledge by standing outside the world; we know because 'we' are *of* the world" (p. 829).

Floating is a particularly interesting example since the themes of "water" and "floating and sinking" are popular parts of science activities in ECE settings in many parts of the world. Not surprisingly, water and buoyancy occur as central themes in several research examples from early years' science. One example is the work of Christina Siry and Charles Max (2013), showing a series of situations where children had access to a big water tank and different items. Initially, the children's investigations centred on how different items float and sink, but as the children noticed that crayons dissolved in water, the focus shifted to systematically investigating that phenomenon. Siry and Max portray the dissolving crayons as a critical event in this series of ECE activities. In their interpretation, in terms of steering the investigation, the agency is allocated to children and teachers. A more matter-oriented perspective would suggest that the material is a critical actor here, seeing that the intra-action of water and crayons is what directs the children's attention to further investigate the phenomena of dissolving.

In all, there are movements in the research field of early years' science education towards acknowledging children's engagement with material as an important part of practice. However, to date the field has not embraced the idea of matter as an agentic part of preschool science activities. In an attempt to potentially change how we understand and organise science education in ECE (preschool), I will use two key ideas in the *agential realism* framework, namely, "agentic matter" and "intra-action", to investigate: *How does matter matter to science learning possibilities in preschool pedagogy?* In addition, I seek to outline: *What are the implications for science teaching in preschool, from acknowledging matter as agentic and science learning as emerging in intra-actions?* My starting point is that power is crucial in science education in ECE, regarding power as regulations of what are possible, desirable and meaningful ways of acting in the ECE settings. Regulations of science learning are produced by the matter, children and teachers reciprocally. As this chapter explores implications for science teaching, I am particularly interested in the boundary-making practices of teachers restricting children's intra-actions with different parts of the material world.

8.4 Reconsidering Empirical Data with Agentic Matter and Intelligible-Making in Mind

In this study, I revisit data from two of my previous research projects that concern science in preschool (Areljung, 2016; Sundberg et al., 2015). The data set produces different facets of preschool practice, since it consists of field notes, photos and audio and video recordings from practice, as well as recorded group discussions with teachers. In previous analyses of this data, we have studied conditions for science education, in ways that rendered matter inferior to humans and human dialogue. In one study, the material things were considered as tools used by humans

(Sundberg et al., 2015), and in the other study, the material things appeared as props in accounts from preschool practice (Areljung, 2016). This chapter is an attempt to flip that view and instead acknowledge matter as agentic and science learning as emerging in intra-actions. In seeking to uncover how matter matters to science learning in the particular sequences, I have been helped by asking: What if the particular matter or the particular intra-action had not been there? Specific examples of such questions in relation to the above-mentioned example of water and floater could be: What if there had not been water in that tank? What if there had been no floating? These questions help to cast light on the science learning that was possible thanks to the matter and the intra-actions that *were* in the sequences. In order to target the implications for science education, the analysis of possible science learning in the various situations has been accompanied by questions of power: What types of intra-actions are desirable, meaningful and accessible in preschool practice?

Despite my field notes being written before I had developed an interest in how matter matters to science education, some notes contained multiple references to material things. They were generated from situations involving 1–2-year-old children and were strikingly different from my field notes involving older children. The latter were dominated by my attempts to record spoken dialogue. In situations involving the older children, I can recall that I was not often looking at what was going on. Rather I was primarily looking down on my notepad, trying to capture as much of what the children and teachers were saying as possible. I was the typical adult that Lenz Taguchi (2012) describes, an adult too distracted by verbal language to notice matter-and-child intra-actions.

The empirical data presented in this chapter was selected because I judge that they are likely to resonate with the reader, as they represent situations common to early childhood education, and because they propose questions that inform science teaching. Recognising agentic matter as a prerequisite for intra-action, I start with a section where that idea is foregrounded, while the following examples delve into different aspects of science learning in intra-action.

8.5 Agentic Matter Dictating What Science Learning Is Possible in Preschool: The Ground Example

As mentioned above, one key aspect of *agential realism* is that matter is agentic, rather than passively waiting for humans to use it (Barad, 2003). Still we seldom recognise the agencies of material things, since we perceive their "work" as everyday normality (Taylor, 2013). Hultman (2011) argues that the pedagogical practice in preschool is built out of a myriad of non-human matter that dictates children's scope of action. Hultman also states, as mentioned earlier, that material things can "whisper, answer, demand and offer" (p. 77) and that children pose hypotheses *with* matter rather than *about* the matter. To think of matter making or giving suggestions may not be foreign for a scientist. When it comes to the scientific practices of posing hypotheses and searching for patterns, presumably many would agree that matter determines what is possible to ask and see. However, Barad (2007) posits that the intentionality, for example, of the asking and seeing, is not an exclusively human affair, but that matter is also an agentic factor.

To illustrate the importance of acknowledging matter as an agentic factor in preschool science, I have chosen a field note that concerns the ground:

> 25 November 2013, The Pea Preschool. One of the teachers tells me that it is dreary to be outdoors during this time of year, when the ground is hard and before the snow has arrived.

The teacher's comment about November being a dreary time of the year is something that I recognise from other preschool teachers that I have met. This teacher indicates that the dreariness is related to the ground being hard and snow-free. Why is that? Is it because of how the ground invites and responds? Thinking about the ground, I realise that one could distinguish so many different seasons from it and that different grounds matter to the scope of possible science learning. The preschool year in the north of Sweden, starting in August after the summer vacation, still has sun-heated ground with some plant growth. In September the ground is covered with leaves which could be moved around, for example, by raking leaves, putting them in piles and throwing them up in the air to rain down over you. October grounds are more damp, and in November and December, at least some days, the ground will be frozen and covered with a thin layer of snow crystals in the morning. In January and February, there is a layer of snow on the ground. This snow is sometimes relatively warm and possible to mould, sometimes it has a hard top layer, and sometimes it is light and feathery. When the snow melts in March and April, there is sometimes ice and sometimes "slush" on the ground. Then the ground gets wet again, with lots of water puddles and mud. In May plants spring from the ground, and in June it explodes in lush vegetation.

By discerning the state of the ground and the time of year, it becomes clear that the scope of possibilities for learning science varies in line with the changing matter. In sum, the ground is agentic on children's movements in different ways – encouraging and responding to the children's stepping, jumping, touching, pressing, rolling and sliding – at different times of the year. Hence it follows that over the year the ground provides children with possibilities to learn about different phenomena. For example, the sandpit is agentic, suggesting and determining what is possible to do (Duhn, 2012). Still, if we see a child playing in the sand, we usually do not see the sand as an actor. Hultman and Lenz Taguchi (2010) claim that our human-centred tradition leads our attention to the child's action and hinders us from seeing the role of the sand. These authors challenge the traditional way of seeing by proposing that the sand plays with the child as much as the child play with the sand.

In construction play, common to many ECE settings, building materials such as sand, mud and snow act differently on children depending on how cold and wet they are. In the northern part of the Northern Hemisphere, the August sand is warm and dry on the surface, and a few shovelfuls down it appears colder and wetter. The water holds the sand together, inviting children to build with it. In the "dreary" time of year that the Swedish preschool teacher referred to, the water has frozen which means the sand is solid and non-moveable and does not seem to engage children in long-lasting explorations.

How does the ground and time of year matter to children's potential learning about force and motion? For example, what type of ground makes sliding possible? Snow and ice, and perhaps mud and slippery wet leaves, yes, but a frozen and naked ground or ice covered with gravel has less potential or possibility for sliding. Here it is useful to consider Susanne Klaar's and Johan Öhman's (2012) account of how a child learns about friction by walking up and sliding down a hill, whose surface has patches of ice, grass and mud. The child adjusts her/his posture in relation to the surface by leaning forward when walking up a slippery hill, and when it is possible, she/he walks on the less slippery grass surfaces. When sliding down however, the child avoids the types of surfaces that she/he looked for when walking upwards. Further she/he seeks to gain speed by pushing her/his hands at an angle towards the ground. Reading this account from an agential realism perspective, I see that several important phenomena emerge in the ground-child relation: the incline and friction of the ground, the contact surface between the ground and child and the mass centre and posture of the child as well as the friction of their shoes and clothes. The ground thus contributes to producing children's embodied learning about forces and movement.

Acknowledging the ground as agentic means that the time of year becomes crucial to how one thinks of and organises science teaching. Certainly the scope of possible science learning differs between seasons of ice, snow, water puddles, lush vegetation, carpets of withered leaves and the "dreary" frozen November ground. The time of year pushes the science curriculum.

8.6 Learning Science as Matter and Children Make Themselves Intelligible to Each Other: The Bridge and Children Example

Another key aspect of *agential realism* is that all types of matter and living species always exist in relation to each other and that they come to be through mutual changes inside an intra-action (Barad, 2003). One example of such reciprocity is found in the above-mentioned example of a sandpit and a child, where Hultman and Lenz Taguchi (2010) argue that the sand and the child become together, since a change in one renders a change in the other. The following field note could also be read as "becoming together":

> 18 November 2013, The Magpie Preschool. I have accompanied two teachers and six 1–2-year-old children on their excursion to the forest. The forest area is rather open, and there is a layer of wet birch leaves on the ground. In the area, there is also a ditch with a wooden board placed across it, serving as a bridge. Some of the children tread carefully over the slippery bridge and after a while they jump on the bridge. The teacher asks: 'Can you feel it swinging?'. One of the children jumps again. The teacher says: 'Look, when the child behind you jumps, it swings'.

One important aspect of the matter in this example is its attraction to teachers and children. Though the ditch is long, their time is primarily spent near the wooden board (bridge). The board disrupts the place by being of another material than the rest of the forest ground and by being perpendicular to the ditch. It suggests being walked upon. When children carefully tread across the wooden board, they adjust their bodies by crouching down, with a lowered mass centre, and walking with small, slow steps. This is probably because the bridge is slippery and also because of its location a few decimetres above the ground. As the bridge and children become familiar with each other, the children's posture and steps become more confident. Thinking with *agential realism*, the bridge-child-child can be regarded as an intertwined system of bodies, where the bridge and the children make themselves intelligible to each other. Without the board, the children would not walk differently. The properties of their bodies emerge due to the height and slipperiness of the board. Without the children, the board would lie still and its property of slipperiness would not emerge. Another intra-action that can be discerned from my field notes is the bridge swinging and children jumping. Not all bridges would yield in this way, since this depends on the material and thickness of the board. Further the board would not yield without the children jumping. The children would not swing if the board was made from a less flexible material. And as the teacher highlights, the non-jumping child also swings when the yielding board and the other child's jumping render the whole system to swing. If a child was standing completely still (motionless) on the bridge, fewer aspects of the wooden board and the children would be made intelligible to each other. Much less would be learnt about the importance of surfaces, friction, bodies, mass centres and movements, if material and children did not intra-act through jumping and walking.

8.7 Matter and Matter Making Themselves Intelligible to Each Other: The Water, Colour and Paper Example

Another example from my research that can be read as science learning in intra-action comes with the following field note:

> 25 January 2013, The Snow Preschool. Five children aged 1-4 years and one of the teachers are involved in painting with water colour. There is a crumpled piece of paper in a bowl of water on the table. The teacher lifts the piece of paper out of the bowl and says that this is how paper gets when it is wet. Several of the children want to touch it. One child says that they should try what happens when there is water colour in the water, which they try, sensing the water-paper mix with their hands. The teacher takes out a dry and blank piece of paper and holds it next to a wet one, asking the children to look and listen while she shakes the papers. Afterwards a child crumples the dry, blank piece of paper and pushes it into the water.

This example accentuates that intra-action does not necessarily involve human bodies. In this case, the water, the paper and the water colour are made intelligible to each other through the intra-action of absorption and dissolution. These phenomena change the paper, the water and the stain, and through them their properties emerge. Still, seeing that the children dip their hands in the bowl of water, the children seem to want to be part of this paper-water-stain system. The teacher holds a wet, crumpled paper next to a dry paper, and the blankness, flatness and squareness of the latter paper could be understood as inviting change. Hence when the child crumples the paper and dips it into water immediately after the teacher-initiated sound comparison, this could be read as the child responding to the agency of the material.

8.8 Changing, Doing Again and Messy Material: The Water Hose Example

One key issue in the water-paper-stain-child example above is *change*, which seems to be an important part of children's relations with the material world. A couple of years ago, I collaborated with five teachers in a project aiming at developing a pedagogical model for science in preschool. During one of our project meetings, the teachers expressed that, in their experience, children – especially the youngest children – enjoy it when they can do things over and over again and when their actions have some notable impact on the material world. The teachers shared examples like turning the lights on or off or causing a sound by knocking on the table. Then the teachers and I discussed how these urges could be met in the preschool environment:

Teacher A: I am thinking about an activity wall for the youngest children, where they can push a button, or move something. These things that the youngest children can't help but get involved with. To cause a change in the shape of a sound or…

Teacher B: Turning something on and off, opening and closing a shutter…

During this discussion, I mentioned noticing that my 2-year-old nephew seemed very engaged when throwing stones into the sea and reeling in the water hose. One of the teachers responded:

Teacher A: That kind of thing, to reel out and in, is spot-on. Because then children are able to do it themselves, no one else has to restore it to the starting point, but the child can reel out and reel in, which are two different explorations somehow.

At that point in time, I had only scratched the surface of new materialism approaches to understanding science education. In retrospect, I can see that the teachers' comments about how young children appreciate change and repetition connect to Rautio's (2013) work on autotelic practices and the inherent reward for children from their repeated actions with material things. Further it resonates with Hultman's (2011) plea for teaching to embrace the important relations between children and matter in matter-child relations. As indicated in the excerpt, the teachers and I were engaged in finding materials that impact on children and that could be impacted on by children. What we were looking for were reversible intra-actions, which could be repeated over and over again, without causing harm to the child or to the physical surroundings, such as opening and closing a shutter. On the other hand, tearing all the leaves off a tree branch, or breaking the branches, would not be reversible since the leaves or branches could not be put back on the tree again, and further it could cause harm to the tree.

In the quoted dialogue, one of the teachers promoted the type of events that do not require an adult to "restore it to the starting point", which indicates that matter-and-child intra-actions should not necessitate constant intervention from adults. What does that idea imply in preschool settings? In the previous examples, matter such as sand, snow, mud, a slippery bridge and a water-stain-and-paper mix are intra-acting with children. Many of these experiences can be said to be "messy", a concept used by Elisabeth Nordin-Hultman (2004) to address the preschool materials that are wet, sticky, dirty, loud or easily spread. In her study of Swedish preschool settings, Nordin-Hultman notes that "messy" materials are often placed where they are inaccessible to children, for example, on high shelves. Her finding highlights that learning with matter is partly a question of access, as adults make children avoid some material things because of the risk of destroying the things and hurting themselves or of making a mess.

8.9 Painting the Sensation of Your Best Roll

One group of teachers that I have worked with framed science activities around the physics verb "rolling". This identification included activities such as rolling up and down and sidewards in a green field, rolling each other and teachers, recording the sound of rolling, painting with rolling items and photographing things that roll and do not roll (see Areljung 2016). On one occasion the children were encouraged to practise their best rolling in a room equipped with a sofa, a mattress and a carpet on the floor. One child prepared his rolling very thoroughly, moving slowly and straight over the mattress. Another child said she was performing a "jump-roll", and afterwards her hair stood out from her head due to static electricity. When the children were satisfied with their rolling, they showed it to the teacher, who took photographs and asked the children how their rolling felt. Next they were instructed to paint the sensation of their best rolling. One child said that he had painted his roll "in different colours next to each other" and that he wanted his roll "to be straight" (Fig. 8.1). The other child explained that the blue balls in the picture were her hair when she was rolling and the yellow part in the middle of the picture was "a little discomfort in the tummy" (Fig. 8.2).

In these activities, the children expressed and explored their experiences of rolling through moving, talking and painting. This rich repertoire of modes of expressions made way for children to extend their science learning and made visible dimensions of rolling that would otherwise go unnoticed for the teacher or, in this case, the researcher. The first picture, painted by the child who had rolled with his body as straight as possible, made me think of the contact between the body and the surface in each frozen moment of rolling. In one moment the mattress is in contact

Fig. 8.1 A roll that is straight and "next to each other"

Fig. 8.2 A roll including "a little discomfort in the tummy"

with one side of the body, from the head to feet, and in the next moment, this contact is between another part of the mattress and another head-to-feet part of the body. In that sense the mattress and child can be said to roll *together*, since the mattress pushes the child and the child pushes the mattress, which in a sense relates to Newton's law of force and counterforce and in another sense to Barad's idea of intra-action or Hultman's and Lenz Taguchi's (2010) sand playing with the child and child playing with the sand.

When it comes to the second painting, my interpretation is that the red square in the picture was the surface on which the child was rolling. The picture made me think about how the mattress, through the rolling, changes the child. It changes the sensation inside her body, "causing a little discomfort in the tummy", as she puts it. The rolling also makes her hair static, by electrical charges moving from her to the mattress. The children's paintings draw attention to rolling as a close relationship between matter and bodies. Seeing this from an *agential realist* view, the mattress is not a passive object, rather it becomes together with the child, and they change each other in the process of rolling. Further the child and the mattress are not viewed as separate entities but as bodies becoming in the rolling, in the contact with each other. The mattress and the child make themselves intelligible to each other in the rolling, and there emerges learning about rolling and the items that roll.

8.10 Implications for Science Education in Preschool

It has been strikingly rewarding to revisit my empirical data from preschool practice and think about them with *agential realism*, as it has foregrounded ways of learning science that I had not noticed in my previous work with the same data. I realise that one crucial argument for thinking of science education in terms of agentic matter and intra-action is that it supports activities that are important to children (Hultman, 2011; Rautio, 2013). Another argument, which I hope is conveyed through the above examples, is that thinking of science learning as intra-action helps to cast light on learning possibilities that would otherwise go unnoticed (for adults). In all, I contend that this chapter contributes important insights to science education in ECE, which I attempt to summarise below.

First, the above examples suggest that a teacher can think about a particular educational setting in terms of the science learning that is suggested by the matter in that setting. The example with the dreary, frozen November ground shows how the agentic matter impacts on the child's possibilities to act and make meaning of the world. Further it highlights the importance of time, as the ground drives the science curriculum, making different learning possible at different times of the year. The case with the swinging wooden bridge draws attention to how matter draws attention to itself, as the bridge was the place in the forest area where teachers and children spent most of their time. Further it illustrates how learning emerges in intra-actions, as the bridge and the children make themselves intelligible to each other, with their properties emerging through the walking and jumping. Without the bridge-children intra-action, the slipperiness and yielding of the bridge would not emerge, nor would the balance and mass centre of the children. The water-paper-colour example illustrates how different materials make themselves intelligible to each other. When there are several materials, more properties could emerge, compared to if there was only paper, or only water or only water colour. Altogether these examples imply the need to, as Lenz Taguchi (2011) argues, consider what kind of intra-actions might be possible in a certain time, space, room and structure of things.

Secondly, if we acknowledge that engaging bodily with matter is a central part of science learning, it becomes imperative that children have real access to engage with the material world with their bodies. The type of intra-actions that can be repeated over and over again (see Rautio, 2013) seem to be engaging especially for the youngest children; thus the provision of these experiences are crucial for teachers who want to support the youngest children's learning in science. Another crucial question is the children's access to modes of expression for extending their science learning. In the example with the paintings of "the best roll", the teacher addresses the bodily sensation of the mattress-child intra-action, and children tell how rolling changes their hair and how they feel in their tummy. In this case, verbal language is not privileged but combined with modes of expression such as body movement and painting.

Ultimately, if we agree that science learning emerges in intra-actions, we need to draw attention to, and disrupt, power relations that prevent children from learning in active engagements with the material world: Who may learn about forces and motion by actually engaging in the possibly messy intra-action of rolling down a hill?

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Part III
Classroom Matters

Chapter 9
New Materialisms and Science Classrooms: Diagramming Ontologies and Critical Assemblies

Jesse Bazzul, Sara Tolbert, and Shakhnoza Kayumova

Jesse We've come together to consider the potential of new materialisms (NM) for science teaching and learning to promote a more socially and ecologically just world. As we know, integrating feminisms, critical theory, and science and technology studies (STS) with science education practices is a transgressive act in a number of ways. Or, to put it another way, maybe we haven't really done our job as critical scholars unless we've transgressed the disciplinary boundaries of science education. In an earlier piece, Shakhnoza and I developed a theoretical stance on NMs and creative ontologies, as well as their importance for a sociopolitically engaged science education (Kayumova & Bazzul, 2018). A theoretical tool we felt was helpful was Deleuze and Guattari's (1987) *assemblage*—a heterogeneous "gathering" of material and discursive, living and nonliving entities and forces. The power of assemblages is how they describe the co-being of entities for the purposes of ethical *becoming*—becoming ethical, politically active, free, different, etc. (Bazzul & Kayumova, 2015).

This metalogue will attempt to contribute to a praxis for NM *orientations*. As Sara Ahmed (2010) points out, although materialities orient us toward modes of life, activities, and particular modes of being, orientations also affect what material

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entities matter or what constitutes a significant object, entity or force for educational communities. Part of the way we've agreed to lay out a praxis for NM is through diagramming. Through diagrams, which are simultaneously both discursive and non-discursive, we can consider the multiple ways students and teachers are already, and will be, oriented to the world. With them we can ask the following: What orientations matter? How do these orientations bring forth a multiplicity of ontological realities (virtual or actual)? How do educational communities find and (re)make particular entities significant? In thinking of educational communities (classrooms, neighborhoods, cultural centers) as assemblies of discursive and nondiscursive entities, maybe it's beneficial to begin with what it means to have/bring/develop/assign/require *orientations*. As we consider various bodies oriented in educational spaces, we come to see that some bodies matter more than others. My hope is that in diagramming from a NM perspective, we come to trouble the "givenness" of orientations.

I've begun a diagram (Fig. 9.1), which is an assemblage of entities meant to provoke a discussion about how students and teachers are always already oriented to matter/entities. Again, these orientations, and the reciprocal (re)production of orientations by material entities, are important to understand before/as we work toward different material arrangements for a more ethical and just world. I've included the following discursive and material elements: T-shirt corporate logo, iPhone, community, building/school, oceans/plants, syringe, principal's door, desks, and chairs. I have two questions for both of you going forward. In this beginning assemblage (Fig. 9.1), what forces, material entities, human/nonhuman bodies/subjects, and affects would you add to get at student/teacher orientations? And more generally, how would you approach the application of NM for science teaching and learning that promotes ethical ways of being that strive for ecological and social justice?

Sara This last question is an important one, Jesse, and it's one I've been grappling with (maybe a bit perplexed by) for a while, which is why I'm really looking forward to exploring with you and Shakhnoza the possibilities afforded through taking a diffractive approach, through the lens of NMs, on science teaching and learning. I spend a lot of time in science classrooms, which requires me to prioritize issues of

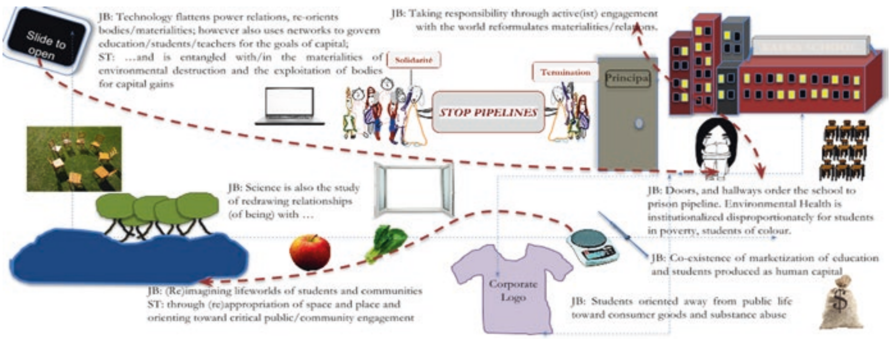


Fig. 9.1 How are students and teachers always already oriented by material entities?

practice, justice, and ethical engagement as they play out within a highly localized classroom/school context. And I find science classroom spaces simultaneously incredibly dynamic yet also highly constrained. The constraints, however, are often more obvious than the possibilities. So how can NMs help us better conceptualize the possibilities (or "lines of flight") afforded within these spaces (assemblages) (see Bazzul & Kayumova, 2015)? We understand schools and science classrooms as microcosms of/embedded within larger societal structures, as necessarily constituted within larger interconnected assemblages, on the one hand, but yet at the same time offer their own unique possibilities—lines of flight—given their particular microecologies, "hidden spaces," and dynamisms.

Jesse turned our attention to orientations (Ahmed, 2010)—and how *our orientations also affect what material entities matter*. I am intrigued by this idea for what it may have to offer in understanding/(re)conceptualizing "problems of practice" and ethical engagement in science education. How can NMs help us more clearly conceptualize the role of both material-discursive intra-actions *and orientations to matter* in seeing/engendering (*or not*) lines of flight? In an effort to more carefully explore this question, I've added elements to the assemblage that I'm going to refer back to throughout the metalogue as I draw from the stories of youth and their teachers at a local high school focused on civic activism through sustainability science, youth empowerment, and art as voice. I worked together with the science teacher, her students, two other university partners (a graduate and undergraduate student), and the school leadership team for 3 years on a collaborative research project we call Community Engagement and Youth Leadership Through Science Education (CEYLSE). Using this assemblage (CEYLSE) as a context for exploration, I want to better understand if/how NMs can illuminate the orientations to matter and lines of flight that are emerging from/co-constituted within this particular assemblage and contrast those with the orientations and lines of flight that the youth, their teacher, and other CEYLSE participants share about their prior school/science experiences. So I have added several images to the assemblage, including fresh produce, a girl experiencing depression/anxiety, and chairs in a circle outside. These are only some of the entities embedded within the assemblage, but they are ones that come up in the stories of CEYLSE participants that I will draw from in this chapter.

I think part of what we are doing in this chapter is cautiously exploring the potentially tangible and practical applications for science teaching and learning that emerge, for us and our readers, via a diffractive analysis of examples from our research and teaching. We might also conceptualize these applications as "critical-liberatory" lines of flight within science education research and practice. I also hope our discussion can help scholars/practitioners (re)orient to a "science education" that more explicitly attends to how contexts of oppression and marginalization can be transformed through a focus on justice, ethical engagement, and civic activism in science education.

Shakhnoza Dear Sara and Jesse, I am excited about our metalogue, partly because it gets to the question of "so what about new materialism(s)?" It opens up a space for an important discussion about "what is science education?" How do we define "science education for social justice?" And how do perspectives in new materialism(s) help us to understand and even possibly redefine what we mean by justice-oriented science teaching and learning? For instance, in my own research, I have used new materialism(s) to examine the role of physical entities and classroom materialities as forces actively working in the constitution of emergent bilingual Latin@ as learners and performers of science (Kayumova, Zhang, & Scantlebury, 2018). Perspectives and assumptions in new materialism(s) have helped me to attend to the physical entities in the learning of science and ask the question of how "very materiality plays an active role in the workings of power" (Barad, 2003, p. 809). In a way, I consider new materialism(s) as what Sara Ahmed (2010) calls "orientations" in my research, toward bodily and material issues of justice in science education. The very material entities (be it a paper, pencil, flask, beaker, funnel, Petri dish, or a meter stick) and material assemblies constituted in teaching and learning of science have a capacity to orient a researcher, students, and science teachers toward particular modes of practice and being (ontologically), and each of us reads these orientations differently based on each of our subjectivities (epistemologically).

Jesse Let's spend some time developing relations between orientation and materiality, that is, the multiple ways entities are oriented toward each other physically, biologically, affectively, discursively, and institutionally, in terms of representations. How do teachers and students play with current material assemblies and their always already constituted orientations toward new forms of being in the world? Let's try and go deeper into our orientations with the hope of drawing together some of these materialities. I have added what I would call overcoding, territorializing (controlling) lines in Fig. 9.1 (in blue) as well as lines of possibility, or lines of flight, away from these controlling lines (in red). Teachers already are engaged in some of these possibilities. Pedagogically speaking then, I wonder if this kind of diagramming can act as a beginning point for teachers and students to assemble their materialities, tease out orientations, and continually redraw what orients them and how they desire to be oriented in the world. I want to begin moving from some broad orientations to specific science teaching and learning contexts as we move through the rest of the chapter. One thing I hope will emerge is that as new relationships with materialities form, the very nature of the entities in a relationship (intra-acting) will change. I think "Draw! Create a rhizome!" as Deleuze and Guattari (1987) put it.

Sara I agree, Jesse, that it seems fitting to turn toward more specific relations/intra-actions between orientations and materiality in the contexts of science teaching and learning. I've been thinking of Melanie[1], a CEYLSE youth participant who has struggled with severe anxiety, a lot of it coming from the fact that she dealt with really tough life situations at a young age: "When I was little I got made fun of a lot and no girls would ever play with me because I was obviously gay when I was younger before I knew I was. I guess everybody else knew I was." She hated school, explaining that she "had issues with kids and teachers" and struggled with "a lot of

[1] Pseudonyms

home life issues. I already had anxiety from the beginning and a messed up vision of the world and what I thought it was. It made it hard for me to interact with people…I've had teachers tell me I was stupid and I sucked and all this stuff. Then I was getting bullied really badly…. My lockers were getting graffitied and I was getting shoved into lockers and girls trying to fight me all the time, and guys tried to fight me too" (Melanie, Spring 2015). But as a 16-year-old freshman who dropped out of school for a year before attending the Leadership and Empowerment for Youth (LEY)[2] high school, she has developed a new orientation toward school *and science* that has emerged for her as *a line of flight* from a new assemblage, one which her current school/teachers and school science experiences have afforded her and her prior school (assemblage) could/did not: "I always hated school but this year I love school…I'm a lot more motivated now than I've ever been. It's just fun going to school now" (Melanie, Spring 2015). Prior to enrolling in LEY, her orientation to school was to disassociate, given that school was a territorializing/controlling entity that produced immense physical and psychological harm. Her line of flight was dropping out of school—emerging from her *orientation to school as a toxic, harmful place*—which was constituted by various material-discursive entities, such as physical/verbal abuse, being bullied in unsupervised spaces (e.g., the hallways, lockers), her sexual orientation, etc.

Yet, I'm sure the three of them are (sadly) all too familiar with the question: "But what does this have to do with science teaching and learning?" We must understand science teaching and learning as a part of a larger assemblage of materialities and discourses. Melanie's reorientation to science was constituted within and through the material-discursive entities of her new school, such as the small school environment [fewer "hidden" spaces for bullying], the art space, the caring school community, and the expansive approach to science teaching and learning in her classroom ["I find 'people science' more interesting than I do other types of science like molecules and all that stuff" (Melanie, Spring 2015)]. In science class, the students and teachers explored questions of gender identity and read about baby X (Gould, 1972). They analyzed the colonizing and racializing discourses of how the Ebola virus outbreak in West Africa was positioned in the media (see Schindel Dimick & Tolbert, 2016). They studied environmental justice issues and their disproportionate effects on minoritized communities. These material-discursive entities afforded new intra-actions and orientations toward school and science. She came to see science as a way to (re)author herself as "smart" and "aware" and school as a place to engage her public voice through art (see Fig. 9.2). In our drawing, I've represented her (re)orientations with several figures, including a girl who is visibly upset and a window. The window represents the new physical school space, which was intentionally designed with attention to issues of spatial justice but is also a discursive representation of Melanie's emerging outward (versus inward) orientation toward "school" and the "world."

Shakhnoza Great questions Jesse and excellent examples Sara. Melanie's story and her artwork compared to the drawings we have had in this chapter so far also demonstrate the differences not only in our own situated experiences with/toward

[2] Pseudonyms

the material world in terms of our social, cultural, ethnic, classic, sexual, and even linguistic location but also signify certain privileges and constraints each of our location provides. Once again, Melanie's art reminded me of my own constraints as a researcher and how limited I am in my own thinking and understanding of vast experiences and knowledge that students practice day to day. I am fascinated that the intra-action of bodies, images, words, and physical entities constituted in the orientations of Melanie's art material/assemblages. It seems to me that the intra-actions of words, bodies, and physical entities in those images are forming their own symbolic and cultural orientation in the world. When I look deeper into those material/assemblages, I notice how gender and sexuality are important parts of these intra-actions. I am also reminded of Melanie's words: "My lockers were getting graffitied and I was getting shoved into lockers and *girls trying to fight me all the time*, and *guys tried to fight me too*" (Melanie, Spring 2015). How are all of these related to science? As you said earlier Sara, Melanie's "new orientation toward school *and science* emerged…from her *orientation to school as a toxic, harmful place*, which was constituted by various material-discursive entities, such as physical/verbal abuse, being bullied in unsupervised spaces (e.g., the hallways, lockers), her sexual orientation, etc." Going deeper into her image exemplified very similar phenomenon. Melanie did intra-act with science not only through cultural tools but also through material tools, her body being one of them, and she (re)authored not

Fig. 9.2 Melanie's artwork on display at the LEY school exhibition/family night, December 2014. Text reads, clockwise from left corner, SWEETHEARTS AGAINST SOCIETY; SEX IS NOT VULGAR – SLUT-SHAMING IS; R.I.P. BEAUTY STANDARD; FIGHT LIKE A GIRL [art not shown reads: SPACE BABES – OUT OF THIS WORLD AND OUT OF YOUR LEAGUE; PRINCESSES AGAINST PATRIARCHY; NOT YOUR BABE; I DO IT FOR ME]

only herself but her body and other materialities including her voice (Kayumova, Karsli, Allexsaht-Snider, & Buxton, 2015).

Jesse It seems this metalogue is taking a productive turn toward sex/gender and sexuality. Sara has shown us that science education can both reorient and disorient students. In Ahmed's (2006) book *Queer phenomenology*, she argues that space needs to be made for disorientations, which can happen through critical classroom praxis. A disorienting, queering practice in science education can address the sometimes ignored materiality of queering and queerness. To put it in Barad's (2007) terms, in the space of intra-actions, materialities (including humans) *do* become queer or radically different. Science education is a relevant space to make sense of queerness on both a material and discursive level. At stake, at both a scientific and sociopolitical level, is the nature of identity. And because the universe intra-acts, we would be wise to know about its queer becomings, from slime molds to drag queens. More good news for students, all materiality is sociohistorically, culturally, and politically constructed (we knew it!)—but so too are social, historical, political, and cultural realities physically and biologically constructed (we knew this too!). The implication for students is the material world and the sociopolitical are entangled, such that individuals do not preexist their formation in material-discursive intra-actions. What it means for a body to be sexed/gendered and sexualized is always in a state of becoming with surrounding entities. What students and teachers can look for is how identities are constituted intra-actively, as well as how differences and exclusions are constituted simultaneously (and why these matter). If "homosexuality" occurs in hundreds of species, if intra-actions queer how we come to understand phenomena (Barad, 2007), if the quantum queers the very notion of beginnings (Barad, 2010), and if amoebas queer the boundaries between group and individual, how can we pretend that sexuality and sex/gender are static constructions (except through a radically blind nature/culture divide)? As Barad notes, nondominant sexualities have long been called "crimes against nature" in juridical battles against sexual becoming; however, it seems the opposite is true. As Barad states, "What if the very ground, the 'foundation' for judging right from wrong, is a laming queen, a faggot, a lesbo, a tranny, or gender-queer" (Barad & Kleinman, 2012, p. 80)? Have a look at Fig. 9.3. Sexuality is a phenomenon, both cultural and material, understood by humans through grids of intelligibility and material organization according to Foucault (1977). How could students virtually (re)construct their material world to show its/their "queerness"?

Sara So in this chapter, we are exploring science teaching and learning through the lens of feminist new materialisms with the goal of helping ourselves and others in science education (teachers, students, researchers, scholars, administrators, etc.) and rethink (or better understand) how school science constitutes phenomena (bodies, intra-actions, topics of study, "possibilities," and "limitations," e.g., as lines of flight or territorializing entities, etc.), as well as how the phenomenon/phenomena of "school science" are constituted within larger material and discursive entities. Jesse has pointed out that "What students and teachers can look for is how identities

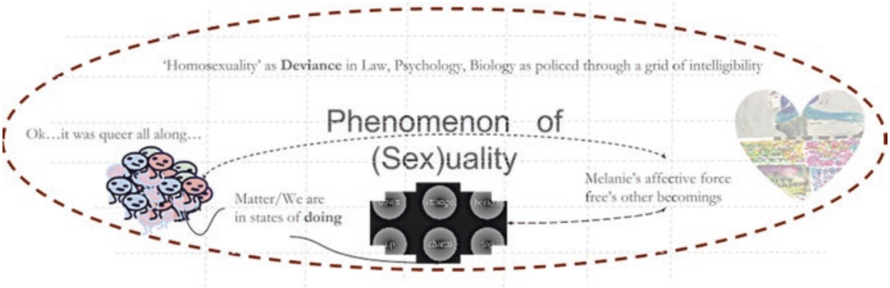


Fig. 9.3 The phenomena of sexuality

are constituted intra-actively, as well as how differences and exclusions are constituted simultaneously (and why these matter)." And, this is important work—we can see how intra-actions constituted Melanie's physical, emotional, and discursive orientations toward *school* and *(school) science*.

I also want to circle back to another statement that Melanie made. Recall that she finds "people science" more interesting than "molecules and all that stuff." And, through a more localized community science approach to science instruction, she began to understand science as a way to become more informed and socially aware. Yet, the constitution of both "science" and "school science" as entirely distinct from content areas, such as the humanities, for example, has had the (historical and ongoing) effect of constituting science teachers as those who regulate and monitor disciplinary boundaries—to the extent that some of the most complex pressing interdisciplinary issues facing our world, such as climate change, environmental injustice, etc., linger in a sort of marginal space, rarely appearing in either school social studies or science curricula but rather more as elective studies, if at all. Barad (2000) reminds us that:

> Agential realism provides an understanding of the nature of scientific practices that recognizes that objectivity and agency are bound up with issues of responsibility and accountability. We are responsible in part for what exists not because it is an arbitrary construction of our own choosing, but because agential reality is sedimented out of particular practices that we have a role in shaping. (p. 235)

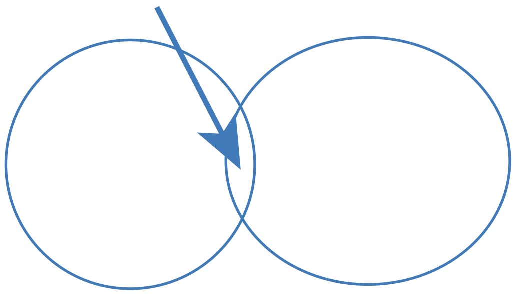
For me, this brings us back as well to Shakhnoza's argument about our roles as academics and what it means for us to intra-act responsibly within, as Shakhnoza states "a privileged position in terms of our time, resources, and structures/hierarchies we occupy." How do we understand our own material-discursive intra-actions within the world? (How) can agential realism help us (re)orient our intra-actions in more ethical and responsible ways? Jesse raises critical questions about revealing the queering material-discursive "mechanisms" of phenomena: "How could students virtually (re)construct their material world to show its/their 'queerness.' How does recognizing the queering power of phenomena transform our being in the world?" And I would ask these same questions of ourselves, of teachers, and of our communities. I think facilitating opportunities for students to "see" the queering power of phenomena, including the phenomenon of "school science" (e.g., as not *just about* "molecules and all that stuff"), is yet another intra-action that, in effect, constitutes new possibilities for science teaching and learning, along the lines we have been discussing. Barad (2001) also states that when we view ourselves as constituted within material-discursive practices, "realism is reformulated in terms of the goal of providing accurate descriptions of agential reality--that reality within which we intra-act and have our being--rather than some imagined and idealized human-independent reality" (p. 236).

Shakhnoza Sara and Jesse, you both raise important questions. I can speak to this from my own situated experiences as a teacher and as a student and also from the lenses through which I am reading these experiences. For instance, when I am listening to you speaking about queering, Jesse, I am thinking of it as a line of a flight. This also speaks to some of the interdisciplinary issues raised by Sara, such as climate change, environmental injustice, and why do they "linger in a sort of marginal space, rarely appearing in either school social studies or science curricula but rather more as elective studies?" Could it be because these interdisciplinary topics are also some sort of queering issues? Could it be that they are also lines of flight and affective domains, which have emerged at the margins of two intersecting circles with intra-active common grounds? I am also imagining that they are new centers of their own (Fig. 9.4).

Back to your point about humanities Sara, issues of identity, justice, and representation are central to humanities. Yet, humanities often privilege epistemologies over ontologies, and ontologies, physical entities, and different forms of bodies have always been central to sciences. I argue new materialisms are making that bridge between social and natural by emphasizing the intra-action of discursive with material, which is on its own some way of queering of the current forms of knowledge production (Barad, 2007).

Jesse We've certainly given readers much to think about: orientations, queering, and critical ontologies, the vulgar—yes, teachers can and should go there. Let's take some time to talk as K-12 educators. What kinds of things can we do? The erotic (yet nonsexual) tones of the last few posts remind me that affects, emotions, and sexualities are inseparable from immersion in phenomena or environments. To nurture a complex, multifaceted study of natural phenomena, we need to create spaces. Place-based science education, as phenomenological encounter based in the life-world of students (Bazzul, 2014), can help set the stage for seeing the world in material-discursive assemblage. Science educators (see Doug Karrow and Xavier Fazio's (2010) work as an example) are increasingly turning to these approaches to establish deep connections—connections that cannot be determined beforehand. I recently explored the artwork of Andy Goldsworthy with my environmental science teachers. In short, Goldsworthy's work captures the inexhaustibility natural environments that through time different forms, emotive and symbolic, emerge from what is otherwise seen as banal by humans alienated from nature (Matless & Revill, 1995). After a tough workshop, consisting of me trying to relate poetry to nature, the

Fig. 9.4 Interdisciplinarity



documentary *Rivers and Tides* (Riedelsheimer & Goldsworthy, 2006) sparked the interest of science teachers who haven't succeeded in finding opportunities for students to (re)engage phenomenon in the "natural" world. What sensibilities, configurations, selves, and forms can students materially create and why?

Sara I agree that "affects, emotions, and sexualities are inseparable from immersion in phenomena or environments," as you mention, Jesse. We are starting to see that trauma can be passed along intergenerationally through DNA (Yehuda et al., 2016) [though it is my understanding that this knowledge has been recognized among Native communities for much longer than it has among scientific communities (Amanda Holmes, personal communication, October 1, 2015)]. I wonder how this growing [scientific] recognition of the role of trauma and other affective dimensions of our lifeworlds informs what we conceive of as "science" and/or as relevant to science education. In working with youth through CEYLSE, the teacher and I planned a unit around trauma and other physiological-affective dimensions of being (e.g., addiction, anxiety, etc.) through the study of neuroscience. Our primary goal for this unit was to engage students in seeing the interconnectedness of classroom science with other palpable experiences that we felt were closer to the students' own but also to empower them with knowledge that our experiences are physiologically dynamic (e.g., the (re)creation of new neural pathways in recovering addicts). In other words, from our perspective, it was one way to engage students in seeing how/why science "matters." Students were also given opportunities to research some of these particular topics in more depth. One student chose to study schizophrenia, because of the way it had affected her personally. Inevitably, in studying these kinds of material-affective issues, the teacher was compelled to stop the class periodically and (carefully, lovingly) address the range of emotions that students experienced as a result of studying phenomena in which some of them were so intricately (and affectively) entangled. So then, learning to teach science also means recognizing the spectrum of reactions and sensitivities that these (embodied) "scientific" experiences produce in the classroom. So what I think I'm trying to say here, Jesse, is that I see the immense value in your work with the environmental science teachers in terms of cultivating a more embodied approach to environmental learning through art, poetry, and how it relates to cultivating an ethic of radical caring that is/must (now) be central to (science) learning—given the ways we all need to think about (re)orienting ourselves to each other, to the Earth, etc.

Shakhnoza Jesse and Sara, your examples remind me of a recent study I read by Walters et al. (2011) entitled *Bodies don't just tell stories, they tell histories: Embodiment of Historical Trauma among American Indians and Alaska Natives*. Situating their study in Native American communities, authors suggest "traumatic events targeting a community (e.g., forced relocation) …have [had] pernicious effects that persist across generations through a myriad of mechanisms from biological to behavioral" (p. 179). Walters et al. argue that there is a need for a theory that engages with historically traumatic events and which examines how traumas "become embodied and affect the magnitude and distribution of health inequities" (p. 179). This also goes back to what you are suggesting Jesse that in order to nurture a complex, multifaceted study of natural phenomena, we need to create spaces that allow us to do this work. In my own work with middle grade science teachers and students, I have also witnessed the importance of affective and bodily dimensions of teaching and learning (Kayumova & Tippins, 2016). However, it seems to me that in science education, majority of publication outlets are overly consumed with cognitive and traditional content-based aspects of teaching and learning that anything outside of these boundaries is often conceived as illegitimate and unintelligible. Metaphorically, I would say that we as knowledge producers (researchers and teachers) often run the risk of perpetuating, what Gayatri Spivak (1995) names as "epistemic violence," when we do not seek possibilities to speak about the limitations of dominant epistemological and ontological views of our field. I have been particularly excited to dialogue with you about new materialisms and discursive/material entanglements, because I conceive it as one of the ways in which we can question the limitations inherent in our own conceptions of teaching and learning.

Jesse Shakhnoza, you bring up a point I'd personally like to end on—which is the importance of engaging different ways of looking at materiality—precisely for the purposes of fighting back against epistemic violence, to use Spivak's term, and the freedom to think differently. Why else would we venture into creative, critical ontologies, materialisms, and critical scholarship? Our practical approach, I feel, is about radical inclusion, where affects, objects, and discourses emerge in relation—and to understand this is to engage in a new ethics of coexistence and co-creation. Metalogues like ours open a way for educators to merge and combine ideas for teaching and learning. In summary, I'd like to end by emphasizing two practical points about materiality, creative ontologies, and science teaching. Thinking about materiality and creative ontologies, especially as assemblage of the discursive/material, can potentially give "voice"/agency to marginalized excluded modes of being and identities, whether human/nonhuman or biotic/abiotic. There are no limits to the "boundaries" of science teaching and learning, just like there are no boundaries to the modes of life that can be imagined. We've raised questions about sex/gender and sexuality, cultural production, ecology, and art. Our task was to find a practical application for considerations of materiality and the inclusion of critical, creative ontologies to science teaching and learning. Our messy conversation is evidence of the kind of emergent ideas and considerations that can come from these critical perspectives.

Sara Through this metalogue, we explored how feminist new materialisms can help us engage with new possibilities for science teaching and learning. One question of particular interest for me is/was how FNMs can help us “see” (and how our intra-actions constitute) opportunities for critical-liberatory lines of flight within science education research and practice. In this regard, I feel that our discussion has opened up more questions than answers, but I see that as a new possibility as well. Haraway, drawing on bell hook’s (1990) notion of yearning, states that:

> Yearning in technoscience is for knowledge projects as freedom projects—in a polyglot, relentlessly troping, but practical and material way—coupled with a searing sense that all is not well with women, as well as billions of nonwomen, who remain incommensurable in the warped coordinate systems of the New World Order, Inc. (p. 269, Haraway, 1997)

I feel like this “messy conversation,” or “troping,” is in and of itself a yearning for new possibilities, possibilities that bring us closer to what Jesse calls a “radical inclusion” in/for science education and the world(s) which we are a part of and seek to understand.

Shakhnoza Ditto Sara! This also means that we may need to engage in “messy conversation” not only about our scholarship but also about politics and political nature of this work. As Eisenhart and Towne (2003) once said, “[t]he danger, if this does not occur, is that political forces will foreclose on a narrow definition of national education” (p. 32).

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Chapter 10
Agency, Materiality and Relations in Intra-action in a Kindergarten Science Investigation

Jana Maria Haus and Christina Siry

10.1 Introduction

In this chapter, we examine young children's science investigations to explore how the materials and intra-actions at hand mediate and diffract what occurs next in intra-action. By doing so, we consider what it means to "do science" in hopes of emerging with new perspectives on the ways in which science is done in an early childhood science class.

The construct of intra-action "recognizes that distinct agencies do not precede, but rather emerge through, their intra-action" (Barad, 2007, p. 33) and supports a focus on the ways in which this *"signifies the mutual constitution of entangled agencies"* (Barad, 2007, p. 33, *original emphasis*). Multi-theoretical, multi-methodological research approaches guide a multifaceted analysis of how the unfolding science investigations in a kindergarten classroom are structured and afforded by human and non-human agents. We draw on post-human theoretical perspectives and notions of materialism (Hultman & Lenz Taguchi, 2010) and agential realism (Barad, 2003) to examine agency in relations between human and non-human bodies. As we focus on generative relationships in science investigations, Karen Barad's methodological approach of diffraction provides a way "of attending to entanglements in reading important insights and approaches *through* one another" (2007, p. 30, *emphasis ours*). Entanglement as "the connections and responsibilities to one another" (Barad, 2007, p. xi) provides a lens in this chapter to consider intra-actions between one human and one non-human body within a kindergarten science

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activity to gain understandings of how they cause action and *become for one another*, as we draw implications for early childhood science practices.

10.2 Theoretical Underpinnings

Our research projects are grounded on theoretical perspectives that frame education and learning as cultural, social acts that emerge and evolve in interaction with others (Roth & Lee, 2007). As participants engage in learning situations, their possible actions are mediated by the structures at hand (Sewell, 1992), and thus much of our previous work has been guided by a focus on the dynamic and dialectical relationship between structures and participants' agency, their "socioculturally mediated capacity to act" (Ahearn, 2001, p. 112). In this manuscript, we build upon our previous work examining the fluid, ever-shifting relationships between structures and agency (e.g. Siry, Wilmes, & Haus, 2016) to now consider the agentic potential of non-human bodies in a science investigation. Above we introduced the notion that intra-action between non-human and human bodies constitutes the *becoming* of an activity. This is especially relevant for education research as "coming-to-knowing is inseparable from coming-to-being" (Higgins, 2016, p. 188). Further, the human body is "not fixed or finished…[and] not the only agent involved in the activity" (de Freitas & Sinclair, 2013, p. 457) as all participants and matter in a context *become* through intra-action.

10.2.1 Agency Through a Post-human/New Materialist Lens

Building on the above-mentioned focus to frame agency as a construct that is not solely "located only in the human individuals" (Rautio, 2013, p. 369), we note that possibilities for agency can happen in and through intra-action between non-human and human bodies. Post-human theoretical perspectives position agency as a construct that arises within "a human-nonhuman working group" (Bennett, 2010, p. xvii), and thus, each situation is constituted, and comes into being, from this interplay between human and non-humans and their surroundings.

Theories of new materialism (Barad, 2007; Lenz-Taguchi, 2011) and post-humanism (Hultman & Lenz Taguchi, 2010; Rautio, 2013) highlight how intra-action between participants, both human and non-human bodies, is critical for understanding teaching/learning. New materialist perspectives provide a lens on understanding the ways in which everybody, human and non-human, exists in relation to others, "relations in which we are (all) embedded and entangled" in (Taylor & Hughes, 2016, p. 13). Agency is produced, and producing, within the intra-action and relationship between the bodies (Barad, 2007), and each intra-action occurs within the entanglement of any being (human and non-human). "A lot happens to the concept of agency once nonhuman things are figured less as social constructions and more as actors, and once humans themselves are assessed not as autonoms but as vital materialities" (Bennett, 2010, p. 21). Agency is thus attributed to human and non-human bodies (Bennett 2010), and matter and material has "(intra)agency"

(Rautio, 2013, p. 404). Possibilities for taking agency exist *through* matter as connected throughout time and space (Jobér, forthcoming). Thus, herein we turn to see what happens once we adopt a distributed perspective on agency to consider human and non-human bodies in intra-action, first beginning with an elaboration of our use of diffraction and then turning to our data resources to illustrate what can be learned from applying a distributed perspective on agency guided by a diffractive reading of data from the kindergarten classroom.

10.2.2 Diffraction, Differentiation and Contradictions

Barad's understanding of diffraction (2007) is linked to Donna Haraway's (1992) use as a counter-notion to reflection. Haraway states that while both are optical phenomena, reflection mirrors without changes, whereas diffraction points out the "small but consequential differences" (Barad, p. 29). This understanding supports our use of different frameworks for making sense of social life. "[D]iffraction does not fix what is the object and what is the subject in advance, and so…diffraction involves reading insights through one another in ways that help illuminate differences as they emerge: how different differences get made, what gets excluded, and how those exclusions matter" (p. 30). Diffracting, or blending, of different elements that work together is at the focus of exploring intra-actions (Ringrose & Renold, 2016). One encounter, actor, object, subject, etc., *layers* over another, and each new layering/diffraction constitutes a new situation and constellation with meaning. In using diffraction, Barad draws the metaphor of throwing stones in water, as she writes that when a stone is thrown, water ripples can be overlapping, and in this overlapping something new can be formed. This notion can inform teaching and learning as we will address in the implication section later in this chapter. Before these overlapping layers become one again, for a moment, they are different and distinct. This newness emerging from an understanding of intra-action is particularly what we hope for, as we seek to generate new theoretical understandings and implications for working with young children in science. When we take the perspective that teacher's instructions, or children's ideas, for example, are utterances that layer over one another, students and teachers both become *with*, *through* and *for* one another, in turn shaping what happens in science instructions in school. This perspective can be applied to data in the entanglement and layering of material object and child, and we also take inspiration from it as a view on the use of varied frameworks; as in the constellation of each new perspective, there is new meaning that emerges.

Perspectives emerging from post-human theoretical frameworks mediate the standpoint that social encounters within a group shape what unfolds in a scientific investigation. Materialist theories decentre the human as being the sole cause for action and interaction. Children and materials each become with one another; they cause, change and intra-act (Barad, 2007) with each other, "working" reciprocally. As such, the materials come together as an assemblage that "possess agency: not in and of themselves, but in this agential assemblage they become another body or agent" (Youngblood Jackson & Mazzei, 2016, p. 106), which means that agency is not something that is inherent to only human but also to non-human participants. These participants become "what they are" as they "materialize through intra-action through time and space" (Pacini-Ketchabaw, 2012, p. 157). The assemblages becoming through the intra-actions afford and mediate the following and resulting intra-actions between the human and non-human bodies, as we show in the sections that follow.

10.3 Data Resources and Methods of Analysis

The data we examine was collected within a science education research project (Assessing science process skills in narratives [the ASPIN project], funded by the University of Luxembourg's internal research grant program, 2013–2016, co-PIs M. Brendel and C. Siry) focusing on children's narratives of their investigations. The school from which the data resources were generated is located in a midsized town in the European country of Luxembourg, and it serves pre-K and kindergarten classes. Kindergarten is mandatory in Luxembourg, and children attend in 2-year "cycles", with kindergarten classes being mixed-aged, usually with children ages 4, 5 and 6 years old. This study was conducted in one of these classes, which in the school year 2014/2015 had a total of 18 children and 1 teacher. The specific data examined in this article consists of a 2:14 min sequence of a small group interaction between six kindergarten children (aged 5–6 years) as they engage in an investigation closely linked to a previous science lesson.

Data resources were collected by Jana, the first author, in the form of video recordings of 18 science lessons during the 2-year study. In this paper, we zoom into one of these lessons and, in particular, a sequence from a small group science investigation, which started with children's questions about glass bottles they saw in a classroom cabinet. The teachers built upon children's questions regarding the bottles, and a class discussion ensued regarding the attributes of the bottles and whether or not sound could be produced. Teachers and children together planned to explore the phenomena of sound by blowing into or tapping onto bottles. Within this small group activity, a group of six children explored the glass bottles filled with varying amounts of water to investigate different aspects of sound. During the whole class lesson, Jana was a participant observer, while in the small group activity that followed, she facilitated the six children's exploration of sound with the bottles.

10.3.1 Emergent Research Focus

The focus on the intra-action between the human and non-human actors in this particular exploration of sound emerged from ongoing recursive, iterative analysis of the data resources. Jana participated in all the science lessons, and they were also recorded with two video cameras. After each lesson, the video recordings were viewed, first at normal speed and then at a slower pace to refine the focus of concern. Over time, the focus became more specific; first on the small group activity and then on what children were doing when they were free to explore the materials at hand (eight bottles on the table filled to various degrees with blue-tinted water). Emergent research approaches allow for adapting analysis according to what is learnt in process. Herein the focus on the role of the materials performed in the intra-action emerged and became central to the ongoing analysis that has come to shape this chapter, as we focus on how the bodies in this science investigation intra-act and in this intra-action *become together*. As such, we ask the question:

- How do human and non-human bodies intra-act to mediate science investigating in this kindergarten class?

This question necessitates considering both the intra-actions between the bodies as well as the ways the intra-actions mediated science investigations. Thus, this focus emerged through the analysis, as Jana began analysing with a humanist perspective (coming from a cultural-historical background) and then when the analysis moved to focus on the non-human bodies in order to gain a more complete understanding of the intra-actions around science. Thus, we consider the relations between the children and the materials in this lesson, as well as the scientific investigations produced from the intra-actions.

10.3.2 Recursive, Iterative Analysis

Several steps have been taken to guide the analysis. As introduced above, recursive, iterative video analysis served as the main point of analysis from which the initial focus emerged and from this, a focus on the 2:14 min sequence. This sequence was chosen because it concerned a time when children intra-acted without direct instruction and it ends when the bottles, that moved a lot on and off the table, were all standing still in the middle of the table, as Jana joined the group to guide the activity. Three analytic tools have been developed, one focusing on the human bodies (transcripts), one focusing on the non-human bodies (graphics), and a third focusing on both together (photo-offprints). The first and second tools separate the human and non-human bodies for analytical purposes, and thus for transcription purposes the humans were the first point of entry into the data resources, and for the graphic representations, the bottles were the first point of entry. Then photo-offprints from the video sequence served to continue the analysis by bringing the two together diffractively for further interpretation. The purposes and aims of a diffractive reading are elaborated in the sections to come, as Jana started reading the actions and intra-actions in the data diffractively through one another to arrive at a different vantage point for analysis.

10.3.2.1 First Analytic Tool: Transcribing and Documenting Human Actions

The first analytical tool is a transcript of the sequence as a whole. For this purpose, the videos were viewed repeatedly, and the 2:14 min sequence was transcribed for each of the six children individually. Through this viewing, the focus on materiality became a central lens to make sense of the participation of all actors in the science investigation. The children engaged with the bottles and with each other with many overlaps, and in each second of the encounter, there were often multiple actors (see Fig. 10.1 for a sample transcript excerpt). In sum, each of the children's verbal contributions was first transcribed for this initial analytic tool, and then a description of the gestures, gazes, body positions and motions of each child was layered onto the transcripts.

The spoken word (data resources in Luxembourgish and German) was transcribed and translated to English, and the non-spoken components were described for each of the six children. After this separating of the spoken and non-spoken participation of the children, these were brought together and merged into one document, including description of the gestures, body position and gaze, to examine how "the blending or diffracting of elements or agents working together" (Ringrose & Renold, 2016, p. 223) can be analysed and interpreted. An example of this is presented below to illustrate the multiple overlaps in speech as well as actions, in this case, in 12 s of an excerpt. Thus, the different modalities used by the participants were separated out for initial analysis and then were brought together diffractively. The sequence was looked at multiple times at various speeds, as well as muted to focus on movements of bottles and children, gestures, mimics and intra-action of both. A microanalysis allows for a broad and wide analysis in terms of the

00:00	Fynn: "Nooo, that is not right!" ((gets up from his chair and stands next to it))
00:02	Graham [((gets up from his chair, leans forward to the bottles and switches bottle A and B))]
	Kenny ["My shoes … (inaudible) … My shoe" ((is sitting sideways on his chair and has his right foot on the seat of the chair, looking at his shoe))]
	Evelyn ["SCHHHHHHH" ((passes by the table))]
	Mary [((swipes the tabletop with both hands))]
00:03	Kenny ((takes his shoe off the seat of the chair))
00:04	Graham "It goes down the stairs" ((lifts his right knee onto the seat of the chair))
00:05	Fynn "It goes dooooown the stairs!" ((kneels on the seat of his chair, stretches his right index finger in the air and makes a movement from bottom right upwards))
00:08	Graham ["Uuuuuup the stairs!" ((moves his right index finger along the bottles from bottom right to left and back))]
	Evan ["It goes uuuuup the stairs"]
00:11	Graham "That is… (inaudible)"
00:12	Fynn ["It goes up the stairs and it goes down the stairs" ((moves his right index finger along the bottles from right to left))]
	Evan ["De de de" ((moves his finger along the bottle in front of him))]
	Mary [((moves her right index finger along the back of her left hand))]
	Evan [((touches bottle A at the bottom and then moves his right index finger in a spiral movement, starting on the right of the bottle, upwards))]

Fig. 10.1 Transcription (including gaze, body position and gestures)

non-spoken component of conversations (Tobin, 2015) and, in particular when looking at the, often non-spoken, intra-actions between a human and a non-human body.

10.3.2.2 Second Analytical Tool: Documenting Non-human Movements

For the purpose of documenting and interpreting the movement of the non-human bodies (the bottles), a second analytical tool was developed. This map-like representation resembles dancing steps instructions to illustrate the movement of the bottles during the sequence. The graphic representation shows how each bottle was moved around the table, who moved or touched the bottles on and off the table and at what time during the sequence. To create this representation from the recursive video viewing, Jana began in the same manner as with the transcription, by identifying the movement of each bottle individually and then documenting its movement with arrows for the 2:14 period, as well as labelling which bottle/child intra-acted and at which point in time. This process was completed for each bottle, and through the creation of this tool, the focus on bottle E emerged, as it was noted that bottle E had the most encounters with the children during the sequence.

10.3.2.3 Third Analytical Took: Human and Non-humans Together

The third analytical tool is photo-offprints from the video recording illustrating the children and the bottles *together* intra-acting, also presented in detail below. These offprints were used to document, illustrate and focus on 1/10 of a second, allowing for micro-level consideration of the intra-actions between the human and non-human bodies (e.g. minimal shifts in body position and gaze, shifts in positioning of bottles, etc.). The offprints have been grouped together into sequences for analyses and served herein to illustrate both the analytic foci and the interpretations that emerged. These graphic representations of the movements support a focus on how materials involved in intra-action shaped the intra-action itself.

These three analytical approaches were applied to all actors in the sequence (bottles and children), and from this method, the focus on one child (Larissa) and one bottle (bottle E) emerged, as they are examples of the intra-actions happening among the human and non-human participants in the sequence under consideration.

10.4 Data Analysis and Discussion

Larissa and bottle E have been analysed with a specific focus on their way of intra-acting with the other bodies (human and non-human) within this intra-action. The way they each caused the other to act and *thus become* in this situation was investigated by considering how the bottles and children each became different through intra-action with each other (Pacini-Ketchabaw, 2012). The bottle and Larissa are examples that emerged through the analysis, thus diffractively challenging our way of understanding and analysing data. They each allow focusing in on the finer details of what can happen in intra-actions of human and non-human bodies. Larissa and bottle E were at a table with five other children. The rest of the children were having free playtime at the other side of the room, with the presence of Evelyn, their classroom teacher, while these six children were engaged in the sound explorations at the table.

10.4.1 Introducing Two Main Actors in the Intra-action

We divided the data sequence into four excerpts for analytic discussion and interpretation. The six children in the group sit at a table on which eight bottles are standing, holding varying amounts of water (see Fig. 10.2).

10.4.1.1 The Non-human Body: Bottle E

Bottle E is one of the eight bottles on the table in front of the children at the beginning of the science investigation. The bottles have been arranged by the teacher according to their amount of water, and bottle E is the 5th out of 8 bottles (see Fig. 10.2).

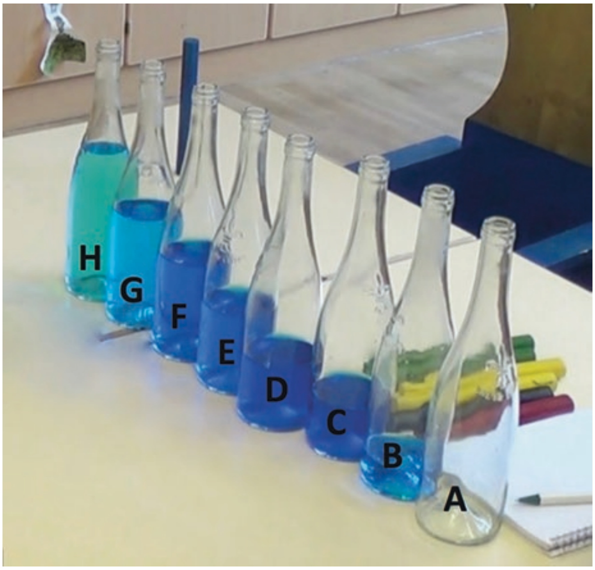

Fig. 10.2 Set-up of the bottles

10.4.1.2 The Human Body: Larissa

Larissa is a 5-year-old girl who has been in this kindergarten class for 1 ½ years. She is sitting with the five other children at the table with the bottles. Once all the children are seated, they begin to intra-act with some of the bottles. Larissa sits on her chair and watches the other children; until at 00:36 she reaches forward, takes a bottle off the table, raises it to her lips and starts blowing into it. It should be noted that the other children around the table began at 00:04 to touch bottles and at 00:27 to blow into some of the bottles.

10.5 Excerpts

We examine and diffractively analyse below four excerpts with different foci on Larissa and bottle E participating as active agents in the intra-actions.

10.5.1 Excerpt 1: Larissa's Eye Gazes

This first excerpt is from the initial 00:35 s of the investigation, during which time Larissa watches the actions of the human and non-human participants as they intra-act with each other, and the direction of her eye gaze provides indication of her focus in this intra-action, even though she is not engaging verbally or using her body in other ways. She sits quite still in her chair, and her posture remains consistent, with her hands folded on top of the table. Several offprints illustrate the shifts in her gaze, as she follows the actions of the other children and bottles (Fig. 10.3).

As the arrows above depict, Larissa watches the actions of the others and the movement of the bottles. As in the first two pictures above, she looks at the water levels in the bottles. In pictures 3–7, she follows the hand movements of the boys in front of her with her gaze. In picture 8 she looks down at her entwined fingers on the table, and in picture 9 she observes how the boy is holding the bottleneck. All this time her posture changes minimally. She tilts and moves her head slightly, but her arms and hands rest in the same position for most of the 35 s.

As the children move bottles around, they excitedly talk about the bottles (e.g. Fig. 10.1) and engage in collaborative meaning-making, discussing the appearance of the bottles and speculating about the sounds each will make, while Larissa appears to be waiting and watching. Her eyes follow the others' actions, as she observes their hands and what they are doing to, and with, the different bottles in front of her. She quietly engages in observing the actions of the group, as she tilts her head, smiles and moves her fingers while her hands are still held together. The gazing can be understood as an autotelic practice, because she appears to do this for the sake of doing it. It is an agentic action that does not seem linked to any external reward, rather, the gazing as the activity is the goal and reward in itself (Rautio,

Fig. 10.3 Larissa's eye gazes

2013). It can also be understood as an agentic practice, as agency is the *capacity* to act, and not necessarily a direct action and choosing to sit and watch can also be considered agentic. Further, she is in fact engaging with the bottles and with the group through her eye gazes. While there is no direct physical intra-action between her and the bottles yet, there is a co-existence of the actors and a space between her and the bottle that can also be understood as intra-action. Rather than hierarchies of being, the interest is on the co-existence of two kinds of material entities (Rautio, 2013). Simply because the bottle and the child are both actors in this setting, they constitute the intra-action and become *for* and *with* one another, even though there is no physical intra-action. But because the bottle is an agent, Larissa is able to gaze at it in intra-action with the other children, and because Larissa gazes at the bottles and the intra-action between the bottles and children, the bottle becomes an agent for Larissa to look at. The intra-actions, and the absence of physical intra-action, diffractively constitute and add to the becoming and being of the bodies (human and non-human) that form and constitute the activity around the children and the bottles. After the episode of observing, Larissa, quite suddenly, grabs bottle E (35 s), leading into excerpt 2.

10.5.2 Excerpt 2: Larissa and the Bottle Physically Intra-act

From 00:37 to 00:48 during the overall sequence, Larissa and the bottle produce sound. This is the first moment that the bottle physically intra-acts with Larissa, as it is taken and used by her to produce sound.

Fig. 10.4 Intra-actions between bottle E and Larissa – sound

In Fig. 10.4, each intra-action is represented by an offprint, numbered from 1 to 12. At 00:35 Larissa leans forward across the table, grabs the bottle and pulls it towards her. After, she leans back in her chair (frame 1), takes a breath and blows into the bottle (00:37, frames 2 and 3). The bottle is tilted but still partially on the table. She then (00:40) pulls the bottle closer to her body and off the tabletop (frame 4), takes a deeper breath and blows into the bottle again (frame 5). At 00:44, she takes another deep breath while looking at the ceiling (frames 6, 7 and 8) and then blows into the bottle again (frame 9). This time, she and the bottle produce a sound. She looks at the bottleneck (frame 10), wipes her mouth and chin (frame 11) with the back of her left hand (she holds the bottle in her right hand slightly above the tabletop) and then exclaims "Yessss! It worked for me!" (00:47). Simultaneously she throws her left arm in the air and holds the bottle in her right hand higher up (frame 12).

As Larissa blows into bottle E, they jointly produce a sound. Certain materials display attributes that invite intra-action with them (Änggård, 2016; Lenz-Taguchi, 2011). In this excerpt, we observed that the bottles' attributes offer certain possibilities to intra-act with them (e.g. the shape of the bottle with its long bottleneck invited Larissa to blow into it, the colour of the water animated her to take bottle E, etc.). It could even be questioned whether the materials demand the child to intra-act and thus shape what is happening in the activity. As we reflect on the effect the bottle has on Larissa and vice versa, Rautio (2013) inspires us to imagine how we would exist and what it would be like, if there were no bodies (human and non-human) to intra-act with: "we would miss out on a reference point and thus have one less viewpoint to ourselves, the kind of beings we are" (p. 404). When asking this "what if" question, the materials are a crucial part of the activity, as they are the tools needed for investigating the concepts of sound and thus for meaning-making. Pushing the new materialism notion even further, the bottles are as much actors in this intra-action as the children. Therefore, the "what if?" question could also be posed vice versa, asking what would have happened if there were no children to intra-act with the bottles. Looking at this intra-action diffractively, subject and object are not defined in advance, and bottles and children are both essential actors in this intra-action. Thus, the activity is clearly shaped and structured by their mutual presence and activity.

10.5.3 *Excerpt 3: Entanglement of the Bottle and Larissa Jointly Produces Condensation*

Right after exclaiming her joy of having produced a sound in excerpt 2, Larissa starts to probe the bottleneck from 00:48 until 00:55. As a result of the blowing into the bottle in excerpt 2, condensation accumulated in the bottleneck of bottle E, which Larissa observes. She puts her index finger in the bottleneck and twists it, and she repeats this action five times (see Fig. 10.5). Larissa does not speak about this, and in fact, she does not look to the other children or bottles. She focuses closely on the action of her finger and the intra-action with the bottle as the condensation is investigated. She then moves on to her next focus point. Here it is important to note that while Fig. 10.5 looks like a sequence in itself, each picture is the starting point of a smaller sequence where she probes the bottleneck (five times in total). This happens quickly and sequentially; it is a repeated action. She keeps investigating the phenomenon and probing the bottleneck, as if probing it once was not enough.

The condensation is a resulting phenomenon of the earlier intra-action between bottle and child. Larissa needed the bottle for the intra-action and the bottle needed Larissa for it. It was an active and repeated intra-acting of both agents, resulting in collaborative meaning-making. As materials can demand or ask to be intra-acted with (e.g. Lenz-Taguchi, 2011), the bottle appears to ask Larissa to continue her action and jointly investigate the condensation phenomena with it. Furthermore, it is an autotelic practice – it is rewarding for Larissa without any external reward –

Fig. 10.5 Intra-action between bottle E and Larissa – condensation

she does not talk about or share the discovery with the other participants, rather, she simply investigates the condensation through her intra-actions with the bottle in this excerpt. The structures of the investigation are open enough that she can engage in this autotelic practice with the bottle, agentially explore the condensation that has accumulated in the neck of the bottle and move on to the next component of her investigation.

10.5.4 Excerpt 4: Larissa and the Bottles – Distributing

In this excerpt (01:08–01:56), Larissa touches all bottles on the table as she begins to distribute them to the other children. She is almost ceremonial about the distribution; as she takes each bottle and hands it to a group member, she comments with a sentence, a motion, a nod or a whisper to the respective child. At 01:08 she hands bottle E to Fynn and says, "Now it is Fynn's turn", and then she reaches forward and pulls bottle H, which is simultaneously grabbed by Kenny, who pulls it towards him after exchanging looks with Larissa. She then takes bottle E, which was pushed back in the middle of the table by Fynn, and moves it in front of Evan (01:21). Simultaneously, she grabs bottle A with her free hand and places it in front of Kenny, who is blowing into bottle H. He pushes bottle H back in the middle of the table (01:24) and looks at Larissa, who smiles and nods at him. As if waiting for this sign as a cue, he takes bottle A and pulls it towards him (01:27). At 01:30, Larissa takes bottle E from in front of Evan, who has not touched it at all, and moves it in front of Mary, while whispering something inaudible to her. As she does this, both Graham and Evan reach forwards. Graham takes bottle H, while Evan grabs bottle B. Larissa then takes bottle G (01:35) and pushes it in front of Fynn. At 01:37 Evan ends his intra-action with bottle B and sits back on his chair. Larissa then takes bottle F and places it in front of Evan, who takes it with both hands (01:45). She then takes bottle B and moves it in front of Jana, who just arrived at the table. Once she is done with this task, she takes bottle C for herself (01:50), leans back in her chair and blows into it. Then, at 01:54 she leans across the table to reach for bottle A, stands up and quickly lifts it into the air and to her lips, before putting it down on the table again. She sits back in her seat and watches Graham intra-act with bottle A she just put back. Interesting to note is the way she folds her hands once she is done and leans back in her chair to resume the position of the observer as in the beginning of the sequence (excerpt 1 and Fig. 10.6).

This excerpt illustrates an entanglement of child, bottle and the other factors that constitute it as a situation. Because of the intra-action between bottle E and Larissa, the activity unfolded as it did. The bottles offered themselves to, and were distributed by, Larissa. This intra-action is understood as a diffraction; in that it causes Evan, Mary and Fynn to further intra-act with the respective bottle. Each actor (human and non-human) agentially participated in multiple ways; for example, Evan, who chose not to intra-act physically with bottle E, instead chose to intra-act

Fig. 10.6 Intra-action between Larissa and the bottles – distributing

with bottle B. This was facilitated by Larissa's engagement in collaborative meaning-making with the materials and her peers.

10.5.5 Excerpt 5: Bottle E

For illustrative purposes, we use the aforementioned graphic representation, resembling the form of dancing steps instruction (Fig. 10.7), which we describe interpretively next. At 00:35, Larissa takes bottle E and pulls it towards her. Immediately she blows into it and continuously does so with the apparent aim of producing a sound. At 00:47 Larissa exclaims that it has worked and holds E aloft in the air in a movement of triumph. At 00:48, Larissa pokes her left index finger into the bottleneck because condensation has occurred due to the blowing and tiny beads of water are visible. She probes the bottleneck, before blowing into it again (00:55). At 1:07 she places bottle E in the middle of the table again, where Fynn is touching it only 4 s later (1:11) and then pulls it towards him, while he sits back in his chair. Immediately, he blows into the bottle (at 01:17) and then places it back on the table. Larissa takes bottle E again (01:18) and moves it across the table in front of Evan, who does not touch it. After several seconds, Larissa grabs it again (01:28), hesitates briefly and then places it in front of Mary. Mary touches the bottleneck (01:33) and blows against it first, before tilting and blowing into it (01:42). After some time (01:50), she pushes it in the centre of the table again, where Kenny takes it shortly after (01:52). Mary's and Kenny's hold on the bottle overlaps for a split second. Kenny then pulls the bottle towards him (01:53) and lifts the top of the bottle to his lips (01:55), as if he was pretending to drink from it. He holds it with both hands, before pushing it back in the middle of the table (02:04) where it remains for the rest of the activity.

Summarizing, bottle E is moved frequently in 2 min. Four children actively intra-act with it (blowing, poking, tilting, lifting, pretending to drink from it), and another child had the chance to intra-act but chose not to, which is as much an agentic

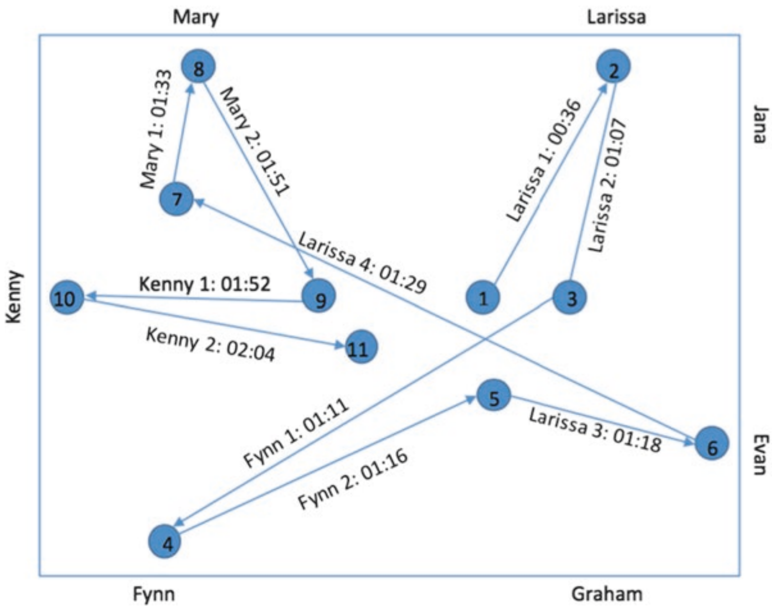

Fig. 10.7 The movement of bottle E (00:36–02:04)

practice as physically intra-acting with it. Each new intra-action is consistently linked to the conjoint actions of the bottle together with the child. This is illustrative of the different entanglements between child and bottle intra-acting at that moment in time, because all the actors in the entanglement afford the activity itself and thus shape it (the activity, the material and themselves as actors). Each child utilizes bottle E and is used jointly by bottle E to engage in collaborative meaning-making, be it the phenomenon of condensation, the concept of sound, experiencing the weight of it or examining the colour of the dyed water. Looking at this sequence diffractively, there are many small actions that happen which all have consequences and afford the next action (e.g. Ivinson & Renold, 2016, p. 171), much like the stone thrown into water causes ripples and waves that change the next, changing the one after that.

10.6 Connecting the Excerpts

In this section, we use the theoretical perspectives that guide this work to bring together the analysis and interpretations elaborated in the excerpts above, as we return to the question that guides this manuscript:

- How do human and non-human bodies intra-act to mediate science investigating in this kindergarten class?

We analysed these four excerpts diffractively to consider the entanglement of ideas, materials and actors (Barad, 2007) and gain new understandings of what emerged from the intra-actions in this investigation.

10.6.1 Science Investigations Mediated by Intra-actions

When we apply the introduced notions of materiality to analyse this science activity, we arrive at the stance that through the intra-actions of human and non-human bodies, something new was created. This newness is the collaborative meaning-making of science; i.e. producing condensation and different sounds by tapping and blowing, scientific practices and further investigations by children and bottles in their entanglement. It is a reciprocal act, because through and within the intra-action, the actors become and because of the becoming, they intra-act. The situation changes, and the agents in the intra-action change, as each constitutes the other in new ways. Because the bottle was touched by Larissa, it gains a new meaning and vice versa; because Larissa touched the bottle, she created sound and experience and the phenomenon of condensation. And even without touching a bottle, she intra-acted with the different water levels of the bottles as she observed them and the other children. Therefore, both bottle E and Larissa are active agents in intra-action and jointly produce something new; they are the cause as well as the effect of the newness.

The bottles and children in their intra-acting afford "the conditions for the emergence of certain bodies and not others" (Pacini-Ketchabaw, 2012, p. 158). Drawing on Duhn (2012) to understand this newness, such assemblages between child and materials "…can be understood as a human-nonhuman multiplicity with qualities that emerge through the interactions" (p. 104). Intra-action through this lens emphasizes that bodies *become through* the joint activity, rather than being individual entities with fixed boundaries. Together they constitute something new, but they also each constitute themselves in a different way. With the bottle, Larissa is able to engage with the science phenomena of sound, and with Larissa, the bottle does the same. This intra-action taking place during the sequence is a joint one, structured and afforded by its participants.

10.6.2 Conjoint Activity as an Agentic Intra-action

Applying a materialist lens to the examples above supports our understandings that the bottles' attributes would not manifest themselves in intra-action without the children. Their properties, such as how they make different sounds depending on the amount of water or whether they are blown into or tapped against, would not have been revealed. The human and non-human bodies might not need to be analysed separately or juxtaposed but instead should be positioned as conjoint participants in the unfolding intra-action. Theoretical understandings from materialism mediate understanding what is happening *to*, *with* and *because* of bottle E and enables seeing benefits of a multilevel and multi-theoretical analysis.

Diffractively reading the results of our initial, as well as emergent, analysis enabled us to recognize the multiple layers to understanding how Larissa and bottle E jointly met the objective of the lesson in the 2:14 min sequence by producing sound. Further, Larissa adopted a leadership position when distributing bottles to the other children, as she smiled and nodded in encouragement to her peers and the bottles. Bottle E and Larissa together produced sound and condensation. This was mutually constituting, as all occurred in unstructured time and space open for investigation and intra-action, albeit in a school setting. Through our analysis grounded in perspectives of agency, difference and materiality, the performative aspect of the materials is revealed (Fenwick, Edwards, & Sawchuk, 2011), and it can be understood "how things function within a particular context and in relation to the bodies they encounter and their own variabilities" (Taylor, Pacinini-Ketchabaw, & Blaise, 2012, p. 82). Hultman and Lenz Taguchi (2010) have reconceptualized pedagogy at the early childhood level as a practice that is intra-active, material and discursive. In this process, Taylor and Hughes (2016) argue that "agency, meaning, and thus potential transformation are produced in the intra-actions between children and the material 'things' with which they are engaged" (p. 82) and this is particularly relevant for science education practices with young children. Blowing, tapping and distributing can be positioned as autotelic practices (Rautio, 2013) as Larissa is evidently doing something for the sake and reward of doing it.

10.6.3 Agency Through Autotelic Practice

Rautio (2013) understands agency as the "allocated space in between children and their environments, arising in complex encounters" (p. 396); thus material has "(intra-)agency" (p. 404). We have gained new understandings through our analysis of agency as consisting in part of the space that is taken, in addition to the individual and collective capacity to act. We argue that agency happens in intra-actions and shifts for each body depending on the constellations. Concurrently, agency is not something purely human-natured, but rather it can involves the materials – in this case, the bottles on the table.

Thus, the intra-actions constitute agency for both the human and the non-human bodies (de Freitas & Sinclair, 2013). Applying this lens to the data allows us to appreciate the agency of both (agentic becoming of) the bottle and the child but foremost as something that arises and is shaped in, and through, the intra-action. When agency is something that is constituted in intra-actions, we argue that bottle E and the other bottles on the table are somehow inviting, whispering, demanding and offering themselves to Larissa and the other children. They have agency, and that agency is *extended to*, *constituted by* and *continued by* the child who intra-acts with the bottles and other materials at hand. Thus, the bottles have "(intra)agency" (Rautio, 2013, p. 404). Furthermore, the human body is merely a "follower of some action initiated by his/her material surroundings" (Rautio, 2013, p. 399), when engaging in autotelic practices, characterized by the fact that there is no outer reward or external incentive.

10.7 Implications for the Field

Through our diffractive analysis of this activity, we examined how human and non-human bodies *became for one another* in and through intra-action. Drawing implications for research practices in early childhood education from this work, it becomes obvious that not only human bodies but also non-human bodies provided space and possibilities to make meaning from, and with, science phenomena. The intra-actions between children and materials in the above excerpts demonstrate that the human and non-human bodies afforded each other and we have added to our understandings the ways in which non-human bodies are a central part of working towards agentic practices with young children. All participants, human and non-human, in these intra-actions structured what happened. The role of bottle E, for example, moved beyond the initial purpose of producing sound to include producing condensation; thus, the role of the bottle complexified. Larissa's engagement with bottle E shifted her role from one of investigation to also one of leadership and support of the other group members.

This chapter has implications for teaching science as well as researching learning. We end with a newfound emphasis in our perspective, stating that scientific encounters in informal classroom settings can be fostered with the aim of making-meaning in free learning situations such as the sequence explored herein. This work emphasizes the value in providing an *in-between time/interval space* (Haus, 2017) for open-ended explorations between materials and children. Larissa and bottle E moved together beyond the teachers' objectives to produce sound, as they engaged with the phenomena of condensation and also facilitated Larissa's group leadership role. Agency became distributed across the human and non-human bodies, and the investigations of science phenomena go deeper than initially defined by the teachers' objectives. Place and space become an assemblage which ought to be reconsidered as pedagogy (Duhn, 2012), and we argue that it is important to think about how classroom science lessons are structured. There are no "hard-and-fast" rules that determine how these materials should or should not appear (Duhn, 2012). Rather, in the informal spaces of investigation, agency can be afforded and emerge from the intra-actions between materials and children in new ways that provide deep opportunities for engaging with science at the early childhood level. Therefore, making the space for those opportunities could turn out to be a benefit for (science) education and research practices.

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Chapter 11
From Lab to Lecture? Science Teachers' Experiences Translating Materiality in Lab-Based Research Experiences into Classroom Practice

Nancy P. Morabito

11.1 Introduction

The activities in which scientists and engineers engage have received substantial attention in recent documents shaping science education in today's K-12 classrooms in the United States, perhaps most visibly with the Next Generation Science Standards (NGSS Lead States, 2013). Indeed, in outlining the three key dimensions used to form each of the NGSS standards (i.e., practices, crosscutting concepts, and disciplinary core ideas), the role of the practices of science and engineering is described as follows:

> The practices describe behaviors that scientists engage in as they investigate and build models and theories about the natural world and the key set of engineering practices that engineers use as they design and build models and systems. The [National Research Council] uses the term practices instead of a term like "skills" to emphasize that engaging in scientific investigation [and/or engineering design] requires not only skill but also knowledge that is specific to each practice (Three Dimensional Learning section, para. 2).

Given this emphasis, we must consider how the K-12 teachers responsible for developing learning experiences centered on the practices of science and engineering might themselves develop meaningful understandings of these practices, including the vital role of the apparatuses with which scientists and engineers engage while doing their work. This study describes one medium for supporting teachers' understandings of the role of apparatuses and materiality in science and engineering, as well as for considering how such understandings might relate to classroom practice in K-12 settings.

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11.2 Materiality in Science and Engineering

In their seminal work *Laboratory Life: The Construction of Scientific Facts*, Bruno Latour and Steve Woolgar (1979) began their exploration of the work of scientists with an excerpt from observer field notes that transcribed the verbal exchanges and actions of several workers in a laboratory over a 5-min period of time. This excerpt was followed by a brief "observer's story" that summarized the course of a typical day in the same lab (pp. 15–17). Likewise, Latour (1987) introduced his subsequent examination of the activities of scientists, *Science in Action: How to Follow Scientists and Engineers Through Society*, by providing brief vignettes that described the work of researchers in three different, yet related, lab settings. Through such introductory accounts, these authors provided readers initial glimpses into the world of laboratory work often unseen by outsiders, which were then expanded upon throughout the remainder of the two texts. Latour explained his intent to study "science and technology…through the back door of *science in the making*, not through the more grandiose entrance of ready made science" (p. 4, emphasis added) in order to more fully understand scientific activity.

One particular aspect of science and engineering activity problematized by Latour (1987), among others, is the role of instrumentation in the production of scientific knowledge. Ronald Giere (2002), for instance, drew upon Edwin Hutchins' (1996) description of distributed cognition, which posited that knowledge is not maintained solely within the mind of an individual; instead, it extends among and beyond humans, including the physical tools that are used when carrying out a task. Therefore, Giere observed researchers' interactions both with one another and with instruments used to conduct their investigations and concluded that "to understand the workings of the big cognitive system [of scientific research] one has to consider the human-machine interactions as well as the human-human interactions" (p. 292). Karen Barad's (1998) work further addressed this precise issue through her framework for agential realism, prioritizing "an understanding of the role of the human and nonhuman factors in the production of knowledge" (p. 89). More recently, her focus on agential intra-action (Barad, 2003) has provided additional focus for considering the role of material instruments in the everyday activity of scientists and engineers. According to Barad (2003):

> Apparatuses are constituted through particular practices that are perpetually open to rearrangements, rearticulations, and other reworkings. This is part of the creativity and difficulty of doing science: getting the instrumentation to work in a particular way for a particular purpose (which is always open to the possibility of being changed during the experiment as different insights are gained). Furthermore, any particular apparatus is always in the process of intra-acting with other apparatuses… Phenomena are produced through agential intra-actions of multiple apparatuses of bodily production… That is, it is through specific intra-actions that phenomena come to matter—in both senses of the word. (pp. 816–817).

Therefore, an understanding of the agential intra-actions among scientists, engineers, and apparatuses is fundamental for fully comprehending the notion of *science in the making*.

One potential approach for building understandings of science in the making and agential intra-action is to provide pre- and in-service teachers with opportunities to actually participate in authentic science and engineering practices. Given that teachers may not necessarily be provided with the chance to engage in such practices during their own educational experiences and training, numerous programs exist that are designed to address this need. One of the most pervasive programs in the United States aimed at engaging teachers in science and engineering research is the National Science Foundation-funded (NSF) Research Experiences for Teachers (RET) professional development programs, which are housed at universities nationwide in a variety of fields within science, engineering, and computer science. The case addressed in this chapter describes the research experiences of three high school science and engineering teachers who participated in a summer RET in Engineering program, specifically focusing on the teachers' agential intra-actions with apparatuses through their work, as well as the ways in which they carried these intra-actions back into their classroom teaching.

11.3 Methods

11.3.1 Study Context and Participants

Participants in this study applied and were selected to take part in a 6-week summer RET in Engineering Professional Development Program designed for middle and high school science, technology, mathematics, and engineering (STEM) teachers. Teachers were matched with university faculty based on alignment of their classes taught and the faculty member's research, as well as the teachers' overall interest in this research. Teachers then collaborated with researchers to work on small-scale projects related to the professor's ongoing work. According to the NSF (2007):

> [The] Research Experiences for Teachers (RET) in Engineering program supports the active involvement of K-12 teachers and community college faculty in engineering research in order to bring knowledge of engineering and technological innovation into their classrooms. The goal is to help build…collaborative partnerships between K-12 science, technology, engineering, and mathematics (STEM) teachers, community college faculty, and the NSF university research community by involving the teachers in engineering research and helping them translate their research experiences and new knowledge of engineering into classroom activities. (Synopsis, para 1).

In order to maximize the teachers' involvement in research, participants spent most of the 6-week program working in labs on their projects, with 3-day introductory and concluding periods bookending the research experience. During the final days of the program, RET participants were asked to create a curricular unit based on their research experiences, which was to be enacted during the following academic year in a science or engineering class.

Among those teachers who were selected for participation in the iteration of the RET program addressed here, a total of six were first-time program participants with minimal previous experience in science and engineering research. These first-time program participants were identified for study in an attempt to isolate the impact of this type of professional development program. Of these six teachers, three teachers from three different schools were selected for focus in the case study presented here. Ryan, who had been teaching for 32 years prior to participation in the RET program, taught physics and engineering in a private K-12 school. Joshua taught physics in a public, suburban high school and had been teaching for 8 years prior to participation in the RET program. Finally, Sarah, who taught life science, biology, and anatomy and physiology, had only been teaching for 1 year prior to her participation in the RET program. She taught in a public high school in a different suburban school district from the one in which Joshua taught. Therefore, a range of teaching backgrounds, school contexts, and content areas taught were represented across these three study participants. Additional information about the criteria for their selection, as well as detailed information about the lab settings in which study participants conducted their RET work, can be found in the case description that follows.

11.3.2 Data Collection and Analysis

Data for this case study include documentation of participants' research experiences during the 6-week professional development program, as well as the teaching of their RET-based curricular unit during the subsequent school year. During the RET program, study participants were asked to keep detailed records of their daily research activities, including the purpose of their role in and the roles of any other individuals with whom they interacted in each activity. Although these logs were generated on a daily basis, completed logs were submitted at the end of each day or week, depending on the preference of the study participant. In addition to their daily activity logs, study participants wrote brief reflections at the conclusion of each week considering what they learned and its potential impact on their classroom instruction.

In order to verify and discuss in greater detail what was recorded in participants' activity logs and weekly reflections, I conducted individual, semi-structured interviews with each of the study participants during the first, third, and fifth weeks of their research placement. These interviews were conducted in or near the lab space in which each participant worked during their research placement and were scheduled at the teachers' convenience. Each teacher's activity logs and weekly reflections were available during his or her interview in the event that further explanation or clarification about their contents was needed, such as verification of the roles of the individuals with whom they interacted during their research and/or more detailed descriptions of what the teachers were physically doing during their research placement. Each interview lasted approximately 15–30 min and was recorded and transcribed for analysis.

During alternating weeks (i.e., weeks 2 and 4 of the research placement), I observed study participants directly while they worked in their labs at a time of their choosing, which was indicative of their typical research activities in order to obtain a better understanding of the settings in which they worked and their day-to-day activity. Each visit lasted approximately 1 hour, and I recorded field notes during all visits. These interviews and lab visits were designed to triangulate data provided through study participants' daily activity logs and reflections.

Following the conclusion of the 6-week RET in Engineering program and the study participants' return to teaching, I conducted observations of lessons taught as part of the curriculum unit designed by each teacher during the conclusion of the RET program. These curriculum units were intended to reflect a student-appropriate version of the content and nature of the scientific work in which each teacher had engaged while completing his/her research placement. Although agential intra-action was not an explicit focus of the RET program, nor a consideration for curriculum unit development, the lessons developed as part of these curriculum units were of interest because they provided the best opportunity to reflect each teacher's unique experiences with material resources in the lab in his/her own classroom instruction. Therefore, the selection of the three focal teachers discussed here was based on the fact that the curricular units that they developed were longer in duration than those of the other first-time RET participants. Hence, I was able to observe the focal teachers' RET-related instruction more frequently (i.e., five times each as compared with only three times for other first-time participants). This allowed me to obtain a more complete picture of each focal teacher's instructional approaches as exemplified by the RET-based curriculum unit, particularly the extent to which his/her research experiences with material resources were carried back to the classroom. Each observation lasted approximately 50 minutes, although some class periods were longer or shorter, depending on a particular school's schedule. During all lessons observed, I generated field notes to document the instructional strategies employed (e.g., lecture, inquiry-based activities, class discussions, textbook work), the social organization of these activities (e.g., individual work/small groups/whole class, directions provided, roles of students and teachers, materials provided), and the nature of the content communicated (e.g., discipline-specific information versus interdisciplinary content as expressed both verbally by the teacher and through course assignments). When possible, these lessons were also video-recorded so that I could review certain elements of each lesson as needed. Artifacts collected during observations were limited primarily to materials provided by the teachers (e.g., handouts, worksheets) and were intended to ensure a thorough record of the instruction that took place during each observed lesson. Teachers were asked to provide copies of any materials distributed and used by students during these lessons, particularly those used as a basis for discussion or group activities, so that I could more effectively follow the progression of each lesson and provide a richer qualitative description of each study participant's instruction.

A grounded theory approach (Strauss & Corbin, 1998) was used during analysis of all data to support the exploration of the cases presented here. According to Yin (2014), "the distinctive need for case study research arises out of the desire to understand complex social phenomena" (p. 4). Therefore, I define the "case" in this study to be the agential intra-actions experienced by teachers through a summer research program and their translation to the classroom.

11.4 Findings

In order to describe the case presented here, I will first draw comparisons among the study participants' experiences with science in the making through agential intra-action while conducting research in their lab placements. This is intended to highlight the breadth of opportunities provided for teachers through such programs. Following this, I will consider the ways in which study participants brought these experiences to bear on their own classroom instruction.

11.4.1 Material Intra–actions in the Lab

Contexts for Research Although all teachers were placed in laboratories within the School of Engineering with which the RET program was affiliated, Ryan, Joshua, and Sarah worked in separate labs and on vastly different projects. Ryan worked in a lab focused on medical image processing for real-time use in surgical interventions for neurological disorders. He developed his own project, which centered on computer modeling of electric fields in the brain during stimulation by implanted electrodes, in consultation with his cooperating principal investigator (PI), and was able to develop and follow his own research methods while working toward his project goals. In his daily activity logs and bi-weekly activity interviews, Ryan indicated that he interacted frequently with a range of university research personnel, including research faculty other than his PI. Approximately halfway through his research placement, Ryan had the opportunity to observe a surgical procedure that drew upon the research of the lab.

The lab in which Joshua was placed explored the medical applications of mechatronics. Rather than contributing to the overall research goals of the lab, his project focused on the redesign and development of a haptic paddle device used in undergraduate and graduate courses at the university (Fig. 11.1 shows a haptic device.). Joshua was able to devise his own methods for the device redesign, but he was also able to consult frequently with graduate students in the lab when needed. While placed in the lab, Joshua attended weekly lab meetings, as well as a multi-lab meeting that brought together several labs for discussion of their ongoing work.

Sarah assisted in the preparation of bone samples for mechanical and imaging-based testing in order to help advance the lab's work on medical imaging for the evaluation of human bone strength. In completing her project, Sarah worked closely (often side by side) with a graduate student in the lab. She also had the opportunity to attend a conference about medical imaging hosted at the university, as well as a seminar related to her lab's work.

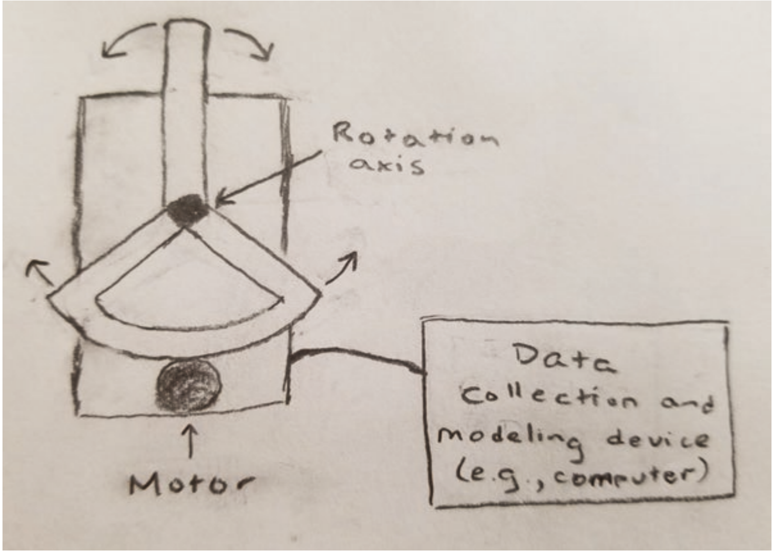

Fig. 11.1 Haptic device

Use of Apparatuses in Research The different research projects on which each study participant worked did, of course, provide varied opportunities for interactions with a range of apparatuses. For Ryan and Joshua, their projects allowed frequent intra-actions with computers, as well as other apparatuses relevant to their particular research. The majority of Ryan's work took place on a computer, as he focused primarily on writing code to improve the effectiveness of the computer-based models. Ryan's observation of a lab-related surgical procedure provided him the opportunity to witness directly the potential impact of his work in a clinical setting. In an activity interview following his observation of the surgery, Ryan explained that this experience enabled him to comprehend the existing surgical procedures, including the ways in which the surgical team used the information from the lab's computer models to guide their implantation of electrodes within a patient's brain, and how the work he was doing would ultimately help expedite and improve the efficacy of the process (Ryan Activity Interview #2). Therefore, he not only engaged in agential intra-actions through his computer modeling activities, but he also observed the ways in which medical professionals engaged with the computer-based models to physically manipulate surgical instruments most effectively.

As noted previously, Joshua's project was not intended to further the overall research goals of the lab in which he worked. In spite of this, he had opportunities to engage in agential intra-action through his redesign of the haptic paddle device. In fact, the haptic paddle itself was intended to serve as an instrument to facilitate human/computer intra-action. As Joshua described, "the overall device, this haptic paddle, is to simulate…virtual space. So if you see something happen on a computer screen, the idea's that you feel it through this paddle" (Joshua Activity Interview #1).

Joshua initially spent a great deal of time interacting with and researching existing haptic paddle devices to help him develop plans for the redesign of the device. Ultimately, this led Joshua to generate computer-based models for the redesign, revise these plans, write computer code to control the haptic paddle, and source parts for the device with the aim to construct a prototype of the redesigned paddle. For this reason, of the three study participants, Joshua appeared to have the most multilayered, direct experiences with agential intra-action during his research placement.

Unlike Ryan's and Joshua's research experiences, Sarah's research did not involve computer-based work. Instead, her material intra-actions primarily involved the tools and instruments used to prepare bone samples for the evaluation of their physical strength via mechanical testing and medical imaging, as well as the bone samples themselves. In order to prepare the samples for testing and imaging, Sarah worked alongside a graduate student to clean the samples, often using a scalpel to remove soft tissue and/or the marrow from the bone, and then use a diamond saw to cut the bone into smaller pieces (Sarah Lab Visit #2). Although the ultimate intent of Sarah's project was to participate in mechanical testing and medical imaging data collection, that point was not reached during her time in the lab, as the apparatus for preparing the bone further for these processes had yet to be developed. Nevertheless, the very issue of instrumentation was problematized for Sarah by her inability to test the bone samples due to this lack of the required apparatus.

As is evident from these accounts, the opportunities for agential intra-action during these teachers' research placement varied widely. Ryan's experiences were confined primarily to the computer; therefore, the products of his work were relatively less tangible than those of the other study participants. However, it is worth noting that the intangible nature of his work did not preclude Ryan from intra-action with matter beyond the computer itself, as these intra-actions merely took virtual form. Using the computer to model the human body allowed Ryan to visualize and interact with structures that were otherwise inaccessible to him, thereby shaping his understanding of the modeled system and, ultimately, his coding of the model. These recursive intra-actions reflect how "participants and their technology become entangled and both the participants and the technology are changed as a result" (Milne, 2015, p. 320). Furthermore, Ryan had the unique chance to see how the modeling on which he was focused could be translated to more tangible apparatuses in clinical practice. Joshua's project did not provide him with much contact with the apparatuses used in the lab's ongoing research, but he worked with computers in several capacities (i.e., researching devices and sourcing materials, generating models for the redesign, and writing code to control the haptic paddle device), as well as with the haptic paddle device itself. This hybridized experience provided Joshua with the most direct connections between computer-based intra-actions and intra-actions with other apparatuses. Finally, although Sarah's project as intended may have provided a similarly hybridized experience, the lack of a required apparatus prevented this from occurring. Instead, her experiences were confined primarily to the instruments used to clean the bone and make the initial rough cuts to the samples in preparation for more fine-tuned cutting/shaping for mechanical and imaging-based testing.

11.4.2 Material Intra-actions in the Classroom

Lesson Overviews As noted previously, all three study participants were observed during the teaching of five lessons, all of which were part of the curriculum units they developed during the RET program. Ryan, the only study participant who taught in a private school, developed a series of lessons that tied closely to the topic of his own research. This curriculum unit asked his students (grades 9–12) enrolled in his engineering class to work in groups to develop a museum exhibit explaining and demonstrating computer-guided surgery in the brain intended to alleviate the symptoms of Parkinson's disease. Throughout the unit, which spanned several weeks in length, students first worked in small groups to research different aspects of the disease, surgery, and related medical imaging, sharing their brainstorming products through online document-sharing services; students then shared their expertise with the other groups in the class through presentations utilizing PowerPoint, online videos and simulations, a student-constructed model of an electromagnet, and accompanying printed materials. The students subsequently met in new groups to develop models and other exhibit materials that would explain the surgery to museum patrons. One group, which was focused on describing the surgical procedure itself, was provided with a sample device (called a "platform," which was loaned to the class by researchers at the university) that could be placed on a patient's skull to help guide the placement of the electrodes/leads to be inserted into the brain. Another group worked on running computer programs to display MRI brain images and consulted with a computer programmer in doing so, while yet another refined the electromagnet model. Students consulted with one another through informal discussions and roundtables in order to solicit feedback as they prepared their final contributions for the museum exhibit.

In her anatomy and physiology class for students in grades 11 and 12, Sarah introduced a lesson that also related to her research experiences quite clearly. Her curriculum unit, focused on bone structure and formation, presented her students with a scenario in which she asked them to diagnose the condition (i.e., osteoporosis) of a hypothetical patient who had fallen and broken her hip. Sarah provided students with the results of a DEXA scan to assist them in their diagnosis and also asked them to determine possible causes for the condition. Finally, the students were asked to identify potential preventive measures that the patient and/or her descendants could take moving forward to minimize the risks of the condition. Ultimately, students were asked to work in groups to make a public service announcement about the condition presented in the scenario. In learning about the skeletal system, osteoporosis, and the risks of this condition, students worked in groups to take on the role of travel agents to create travel brochures for the human skeletal system, listened to lectures addressing bone formation and provided written responses to questions reviewing the lecture's content, and engaged in a station activity in which students reassembled a disarticulated skeleton, used x-ray images to locate a break in a bone, and used a microscope to look at slides of bone samples. During the concluding lesson of the unit, students worked in groups to generate their public service announcements by creating a poster or a video, using classroom computers to do so as needed.

Unlike Ryan and Sarah, whose RET-based curricular unit topics were reflective of their research, Joshua's lesson topic departed quite radically from his research focus. Rather than using his work with the haptic paddle as the basis for his lessons, he instead asked his 11th- and 12th-grade physics students to collaborate in groups to determine whether it might be possible to replace a ruptured Achilles tendon. In so doing, students used computers to research current treatment plans and their limitations and submit their findings to a shared online space; engaged in a lab activity exploring Hooke's law, spring constants, and elasticity by hanging weights from springs and measuring displacement; conducted computer-based research on materials to be used as a replacement for a ruptured Achilles tendon; and created a PowerPoint-based sales pitch designed to convince orthopedic surgeons to use the selected replacement material and that they could "defend…on physics principles" (Joshua Classroom Observation #4).

Apparatus and Language Use During Instruction Although all three study participants provided learning opportunities in which students interacted with material resources during their RET-based curriculum units, the extent to which these experiences mapped onto the teachers' research experiences varied widely. In spite of the fact that Ryan's agential intra-actions most directly involved computers while working in the lab, his unit addressing deep brain stimulation (DBS) surgery provided students with an array of material resources, including the surgical platform and leads used during DBS, and materials to construct an electromagnet. In these ways, Ryan appeared to draw heavily upon his experience observing a surgical procedure during his time in his research placement, as he tried to provide students with the most authentic experience with these materials as possible within the constraints of the classroom. Further mirroring Ryan's agential intra-actions in the lab, students were encouraged to use computers for multiple purposes, from conducting online research to manipulating medical images and computer-based models, much as Ryan himself did during his research placement.

Consideration of "the conjoined material-discursive nature of constraints, conditions, and practices" (Barad, 2003, p. 823) through analysis of the types of language employed in Ryan's classroom during these lessons provides additional insight into how his lab-based agential intra-actions carried into his instruction. While engaging in the instructional activities noted above, classroom discussions echoed the technical language that Ryan used in the lab setting. That is, both the teacher and students used clinical terminology related to brain anatomy (e.g., subthalamic nucleus, substantia nigra); the physiological basis of, impacts of, and treatments for Parkinson's (e.g., dopamine, tremors, and L-dopa, respectively); medical imaging techniques (e.g., the role of electromagnets in MRI); and the materials and procedures of DBS surgery (e.g., platform, leads). Although Ryan did not engage students in computer coding as he had done during his research placement, he provided students with code that he had written for them and that aided them as they selected and manipulated brain images (Ryan, Classroom Observation #4). This process, too, introduced students to language associated with such computer-based models (e.g., volume, slice) which, in other contexts, takes on very different meanings. The adoption of language by both Ryan and his students throughout this unit of instruction underscores this material-discursive nature of matter, as all classroom constituents used technical, context-specific language to construct their understandings of the material resources with which they intra-acted. Furthermore, although some relevant terminology was initially raised by Ryan as he introduced the unit of study (e.g., MRI, computer-guided surgery), most language use emerged and was refined as students conducted their independent and group research and, in some cases, constructed physical models of related apparatuses.

Sarah likewise provided students with a variety of learning activities related to her research placement. However, given that most of her lab activities focused on cleaning and cutting bone samples using a diamond saw, it is perhaps not surprising that the agential intra-actions with material resources that students experienced in these lessons did not closely reflect her own experiences. Sarah's students did have opportunities to manipulate bone models, much as Sarah manipulated bone samples, as well as to attempt to interpret x-ray images, which would have connected to the imaging work that had been planned for Sarah's project. She also included opportunities for students to interact with other apparatuses in her curricular unit, such as their use of microscopes to look at slides of preserved bone material. Again, while Sarah herself did not utilize these particular apparatuses during her research experience, she made a concerted effort to allow students to engage with apparatuses through experiences related to her research placement, even if tangentially.

Like Ryan, Sarah introduced technical terminology related to her research from the outset of her curriculum unit. The initial challenge posed to the students asking them to diagnose the fictional patient's condition included clinical language and acronyms such as DEXA scan and BMD (i.e., bone mineral density). Subsequent lessons in the unit introduced students to the scientific names for different bones of the human body (e.g., "patella" rather than "kneecap"), as well as bone structure and development (e.g., spongy and compact bone, epiphysis, osteocytes, ossification). Although activities earlier in the lesson sequence, such as the creation of a travel brochure for the human skeletal system, did not directly reflect the activities in which Sarah engaged during her research, they did encourage students to transition to the regular use of the language that Sarah encountered during her time in the lab. When introducing new vocabulary during a lesson presentation on bone development, Sarah pointed out certain terms that related to the students' challenge of diagnosing their "patient." She also integrated such language use during a bone lab activity (i.e., looking at slides of bone tissue, examining x-rays of bone fractures, and reassembling a disarticulated skeleton), as well as when students created their final public service announcements at the end of the unit of study. For instance, as students examined an x-ray of a fracture to the calcaneus during the bone lab, they used the x-ray image to visualize the damaged bone and simultaneously referred to the answer key provided to reinforce the notion that *calcaneus* is the scientific name for the heel bone. During this same lab session, students conversed to reassemble a disarticulated skeleton using the technical language associated with each skeletal structure. In addition to using terms such as *phalanges* to describe the bones of the fingers and toes, the students also utilized common clinical abbreviations such as

C1 and *C2* to refer to different cervical vertebrae in the model skeleton (Sarah, Classroom Observation #4). In terms of language, the prevailing focus of this curriculum was on anatomical and physiological terminology rather than apparatuses used for measuring bone mineral density (i.e., the DEXA scan) or other forms of medical imaging (e.g., x-rays). Therefore, the material resources with which the students intra-acted were incorporated into the curriculum unit to support their developing understanding of lesson content, especially relevant vocabulary; meanwhile, this developing understanding simultaneously facilitated their intra-actions with such materials.

Unfortunately, despite his numerous experiences with agential intra-action during his time in the lab, Joshua could not find a way to relate his work to his courses effectively, and his departure in his unit topic reflects this disconnect. It is worth considering whether this was reflective of the fact that he did not work on a project aimed at advancing the research goals of the lab but instead focused on refining materials (i.e., the haptic paddle) used in undergraduate and graduate coursework. Perhaps, had Joshua had the opportunity to delve into the field of mechatronics research, he may have found a clearer connection to the classes that he taught. Conversely, one might argue that his work with the haptic paddle to be used in university classes provided a natural opportunity for Joshua to bring such an apparatus into his own classroom. However, given that this was not possible, Joshua created a curricular unit more directly related to his course content. This unit, focused on proposing a material to replace a ruptured Achilles tendon, largely centered on student intra-action with computers as they conducted their research but also allowed them to interact with materials such as weights, springs, and measurement instrumentation as they explored Hooke's law. Although not related to Joshua's research, students were afforded some opportunities to experience the agential intra-action that permeates science and engineering research.

Despite these affordances, the language used throughout Joshua's curriculum unit primarily focused on physics principles deployed to support students' reasoning for their suggested materials to replace the Achilles tendon. That is, students were expected to take certain principles, such as Hooke's law (specifically spring constants), into consideration when they explained the viability of their proposed material. Like Sarah's students, Joshua's students had the opportunity to draw upon language (e.g., fibrin, collagen fiber, graft) from related fields (i.e., anatomy and physiology) as it arose during their research into potential replacement materials, but most discussion centered on content directly related to broader physics course objectives. In fact, Joshua encouraged his students to focus their attention on such content when he reiterated that "All we're looking for is for you to be able to defend it on physics principles, not necessarily medical… We chose it because of this law, this principle" (Joshua, Classroom Observation #4). Therefore, it appeared that the types of agential intra-actions that Joshua experienced during his research experience were more difficult to reproduce in his own classroom, perhaps given the tenuous connection between his research experience and the focus of his curriculum unit.

11.5 Conclusion

As Barad (2003) stated, "We do not obtain knowledge by standing outside of the world; we know because 'we' are *of* the world" (p. 829). This statement underscores the importance of engaging teachers and students alike in the agential intra-actions that characterize science and engineering. Taken together, the research experiences of the three teachers described here reflect the varied opportunities for agential intra-action, to be of the world of science in the making, by participating in professional development programs aimed at providing authentic science and engineering research experiences. Furthermore, the ways in which such intra-actions were carried back to the classroom were inconsistent, at best, with respect to how classroom instruction reflected the role(s) and form(s) of such intra-actions.

With respect to the classroom implementation, the inconsistency of translation to the classroom may well have been due, at least in part, to constraints impacting teachers' ability to reproduce their lab experiences in the context of a K-12 classroom. For Joshua, curricular constraints prevented him from drawing upon the content related to his research experience. In relating her research experience to the classroom, Sarah had to reconcile the material resources available to her in the classroom with those that she used in her research, thereby shifting the focus of her curricular unit to work within such constraints. Ryan appeared to be the most adept at translating his agential intra-actions into a classroom-appropriate version for his students. This could have been influenced by a number of factors, including his extensive 32-year teaching experience, the context in which he taught (i.e., a well-equipped private school), and/or the alignment of his courses with the focus of his research placement. Indeed, it is possible that Ryan's engineering course naturally lent itself to exploration of such a vast array of material given the breadth of content that he deemed relevant to the course, from the physiological basis of Parkinson's disease to the mechanics and clinical applications of medical imaging. In comparison, Sarah and Joshua addressed content linked more traditionally to their courses (i.e., bone structure and development for Sarah's anatomy and physiology class, physics of elasticity for Joshua's physics class) despite the fact that both approached these topics through the lens of a clinical problem or issue.

As Barad (2003) noted, "On an agential realist account, discursive practices are not human-based activities but rather specific material (re)configurings of the world through which local determinations of boundaries, properties, and meanings are differentially enacted" (p. 828). Due to a number of factors as described above, Ryan's instruction appeared to be subject to fewer curricular boundaries, which may have provided a more robust ground for the (re)configuration of meaning through his students' agential intra-actions during classroom instruction. This suggests that further research is needed to explore what structures and/or resources need to be in place to support agential intra-action in K-12 settings most effectively. Meanwhile, in order to more fully immerse teachers and students in the practices of science and engineering as called for in the NGSS, the role of including agential intra-action as described by Barad must be made explicit both in teacher research experiences and the classroom.

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Part IV
Technoscience Matters

Chapter 12
Sociomaterial Relations in Asynchronous Learning Environments

Shannon M. Burcks, Marcelle A. Siegel, Christopher D. Murakami, and Rose M. Marra

12.1 A Journey Toward Materiality

My coauthors and I (Shannon) decided to engage in experimentation with materiality because we were curious to see how this perspective could help us make new progress in terms of equitable science assessment practices. We view equitable assessment as assessment practices that support all learners (Siegel, Wissehr, & Halverson, 2008) while meeting diverse learners' needs (Siegel, 2014) and valuing their identities (Murakami & Siegel, 2017). This study provided a unique context within which to explore how sociomaterial perspectives can inform theory and practice in equitable science education. As the instructor of an online unit on experimental design within a course for preservice science teachers, I was interested in describing the role of material elements in equitable assessment practices. While analyzing the data from this unit, I noticed a conglomerate of material and human elements. These material and human elements seemed to drive discourse, not just what is said but what *could* be said (Barad, 2007). The collection of technological tools in the asynchronous learning environment was designed with the intention of enabling students to fully participate in science practices outside of a face-to-face or laboratory setting. The research team consisted of three science education assessment researchers (myself, Marcelle, and Chris) and a technology-enhanced learning scientist (Rose). In collaboration with my coauthors, all with interests in designing equitable and inclusive learning environments and classroom assessment, we explored the data collected from this unit using theoretical perspectives that were new to us. In this chapter, we explain our interpretation of theorists that influenced our ideas including Paul Leonardi (2012), Martin Müller (2015), Gilles Deleuze, and Felix Guattari (1987), Bruno Latour (2004), Tara Fenwick and Paolo Landri (2012), Wanda Orlikowski and

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Susan Scott (2008), and Karen Barad (2003, 2007). We chose to describe the entangled material and human intra-actions in an online science unit. The human element consisted of 12 teacher education students working in teams of 2 to conduct authentic science practices. Furthermore, following Deleuze and Guattari's (1987) ideas of assemblages and Fenwick and Landri's (2012) lead regarding the *sociomaterial*, we chose to call these assemblages sociomaterial to emphasize the social nature of human and nonhuman materials surrounding student learning. This analysis opened up opportunities to discuss sociomaterial relations in online learning environments. We also studied the intertwined roles of materials and humans in online learning in terms of equitable science assessment practices. We suggest that the agency of sociomaterial assemblages affect student learning in online courses, and those involved with online education may want to consider this agency as a way to help ameliorate the marginalization of some students in this context.

12.2 Materiality in Practice

12.2.1 Theoretical Foundations

Materiality is a perspective that focuses on instruments, artifact properties created by instruments, and ways people use those artifacts (Leonardi, 2012). Using this perspective, we explored and discussed the "conjoined material-discursive nature of constraints, conditions, and practices" (Barad, 2003, p. 823) where practice is socially shaped in a community and activities are negotiated (Leonardi, Nardi, & Kallinikos, 2012). The aim of this chapter is to explore and discuss the implications of materiality in practice in the context of examining the intra-actions (Barad, 2007) between educational technology tools and social practices in science classes using a sociomateriality perspective, where intra-actions represent a conceptual shift from interaction to include the material (Barad, 2007). Furthermore, Paul Leonardi, Bonnie Nardi, and Jannis Kallinikos and Orlikowski and Scott (2008) used sociomateriality to focus on the use of technological tools within a specific social context and examine the practice in which the technology is embedded.

In this chapter, we first explain how we used the theories in this study regarding sociomateriality and related current literature to establish the context for this research study. To explain our study, we begin at the level of phenomena. We were influenced by Fenwick and Landri's (2012) explanation of phenomena where:

> Phenomena are understood to be hybrid assemblages of materials, ideas, symbols, desires, bodies, natural forces, etc. that are always active, always reconstituting themselves. Sociomaterial studies shift the conversation from issues defined by the personal and the social to *questions about these assemblages, how they move, and how they produce what may appear to be distinct objects, subjects, and events. How and why do certain combinations of things come together to exert particular effects? For example, what knowledge is produced through patterns of assemblage? How do some assemblages become stable, and what force do they wield? How can more oppressive assemblages be interrupted and weakened?* [italics ours] (Fenwick & Landri, 2012, p.3).

Furthermore, we considered Barad's (2007) agential realism framework that asserts, "phenomena are the ontological inseparability of intra-acting agencies" (Barad, 2007, p. 206). Additionally, similar to Barad's (2007) explanation that agency emerges through intra-action, we found Latour (2004) further encouraged us to understand sociomaterial assemblages as an inseparable new entity of material and people that has agency, for the reason that agency is present only *because* the people and materials are in this inseparable relationship. Moreover, Barad's (2007) explanation of entanglements—where entanglements consist of intra-actions as the mingling of people and things with the ability to act *because* they are within this relationship—encouraged us to emphasize this idea that what is important is the action performed by this new entity. In essence, we found that our interpretation of sociomaterial assemblages with agency aligned with our interpretation of Barad's (2007) description of entanglements and corresponding intra-actions. Our interpretation is that sociomaterial assemblages are one type of entanglement that involves intra-action with the mingling of people and things (see Fig. 12.1). This interpretation helped us think about the sociomaterial assemblages we observed and to think beyond artificial boundaries, allowing us to "rework the boundaries between the 'human' and the 'nonhuman'" (Barad, 2007, p. 65). We chose to view phenomena as hybrid assemblages (Fenwick & Landri, 2012) consisting of intra-acting agencies (Barad, 2007, p. 206). We visually represent our interpretation in Fig. 12.1.

Because we chose to view sociomaterial assemblages as an entanglement, it made sense for us to use diffractive reading where diffraction is "about the entangled nature of differences that matter" (Barad, 2007, p.381). We describe our diffractive reading (Barad, 2007) regarding the insights of Barad, Deleuze and Guattari, Aditya Johri, and Latour as well as other theorists through one another in an effort to advance this account. Specifically, diffractive reading enabled us to describe the entangled phenomena. We chose to privilege the technology's role while also considering how the users perceived the technology. Specifically in our analysis, we identified properties within the material, which enabled or limited practices in this context. Furthermore, since this post-humanist theory does not exclude the human, we chose to also consider how the users perceived technological features built with a specific intention in mind and how its actual properties determine how the technology can be used (Norman, 2013). We found Johri's (2011) idea of *sociomaterial bricolage* based on Baker and Nelson's (2005) "making do" helpful for considering this human element within the sociomaterial assemblage.

Finally, after describing sociomaterial assemblages by considering both the material and human elements, we felt the need to understand the consequences of these assemblages. We chose to consider Barad's (2007) agential cuts that are "… agentially enacted not by willful individuals but by the larger material arrangement of which 'we' are a 'part.' The cuts that we participate in enacting matter" (Barad, 2007, p.178). We interpreted agential cuts as a way to define an entanglement, which is a result of the material arrangement and includes us. We based the slice of entanglement, our agential cut, on the agency we observed. These sociomaterial assemblages enabled us to define the boundaries of the entanglement, and therefore we were able to "peek" inside a phenomenon (Barad, 2007). Furthermore,

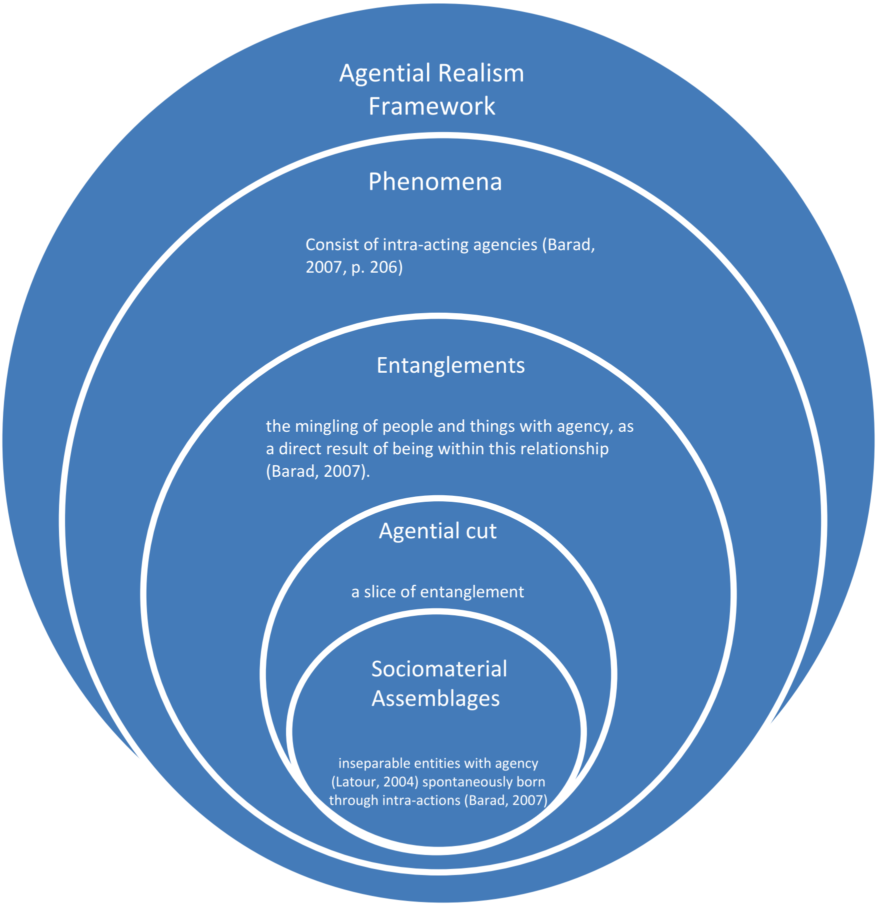

Fig. 12.1 Agential realism and sociomaterial assemblages

following Fenwick and Landri (2012), we used these agential cuts to focus on how these assemblages can be oppressive. Considering the agency we observed as agential cuts allowed us to describe these sociomaterial assemblages, and we began to see phenomena that seemed to be spontaneously, and at times shockingly, born through these intra-actions. We hope to bring awareness of fundamental problems embedded within these assemblages and possible alternate understandings within these assemblages. We aim to help clarify how to interrupt and weaken oppressive assemblages and inform theory and practice toward more equitable science education.

12.2.2 Our Study

In this pilot study, we describe sociomaterial assemblages and study intra-actions (Barad, 2007) among the materials and 12 preservice science education students. This asynchronous learning environment occurred as a unit within a face-to-face science teaching methods course. This practice-focused course expected students to complete one online asynchronous unit by working in teams of two to conduct authentic science practices via an online learning system. The learning activities were designed using online technology-based cognitive scaffolds meant to support meaningful collaboration and learning. Following Barad (2007) and Deleuze and Guattari (1987), we label the intra-actions of the technology and social practices associated with collaboration and learning sociomaterial assemblages because they constitute a new creation formed when multiple social and material factors work together (Müller, 2015). Therefore, we asked the research question (RQ): What is the nature of assemblages in asynchronous learning environments? Our analysis focuses on the post-humanist aspect of materiality through Barad's (2007) diffractive analysis, and while we felt this post-humanist analysis helped us understand the role of instruments and artifact properties created by instruments, we needed another tool to comprehend the human element. We chose to influence our diffractive reading through the humanist lens offered by Johri (2011) and Baker and Nelson's (2005) work. Merging these ideologies enabled us to understand assemblages that formed and included both material and humanist aspects. Furthermore, we chose to discuss intra-actions as a means to describe the practices that emerge from the sociomaterial assemblages.

We accepted that our study afforded us opportunities and responsibilities for "thinking deeply about the relationships between issues such as power and knowledge, power and privilege, and power and identity in the construction of research narratives and arguments" (Milne, Siry, & Mueller, 2015, p.1065) while at the same time seeking to consider the nuances and complex intra-actions (Barad, 2007).

12.2.3 Identifying and Exploring Assemblages Through a Sociomateriality Lens

We felt that the best way to explore the nature of assemblages in this asynchronous learning environment was to examine evidence that would allow us to observe assemblages involving students, technology, course documents, and student reflections. We considered how the material element's properties determined how it could be used and how the human element perceived technological features built with a specific intention in mind (Norman, 2013). These properties of material objects (Fenwick and Landri, 2012) can also be identified as affordances (Dickey, 2003); they affected the sociomaterial intra-actions we observed in the assessment materials and student work.

12.2.4 Who We Are as Researchers

As mentioned above, our collaboration included colleagues who identify as science assessment researchers and technology-enhanced learning scientists. We all have an interest in designing equitable and inclusive learning environments. Our individual roles are described below.

Shannon Burcks I am a doctoral candidate at the University of Missouri and assessment researcher. I am concerned with formative assessment for science learning and the larger assumptions regarding teaching and learning with technology, particularly online. As a researcher, I am interested in how the material factors associated with online science learning combine with the human element and affect all aspects of formative assessment in this context, including issues regarding social justice. Additionally, I aided in the development of this online unit and served as the instructor in the pilot study. Furthermore, I was involved in experimental design and data analysis, and I am first author.

Marcelle Siegel I am a faculty member with a co-appointment in Science Education and Biochemistry at the University of Missouri. My research interests intersect with this study via teacher development and equitable assessment. I have a strong social justice stance, but I am inquiringly new to materiality and the perspectives we explore in this chapter. My role in this research as coauthor involved codesigning the pilot study, developing materials, and aiding in NGSS alignment. I was also involved in the recruitment of students, taught during the pilot, collected data, and aided in data analysis.

Christopher Murakami I am a science education scholar interested in equitable assessment, and I work at the Assessment Research Center for the University of Missouri. I am particularly interested in social justice issues in education, designing inclusive learning environments, and viewing assessment issues through a sociocultural lens. As a newcomer to poststructural perspectives and materiality, I became involved in this project after the data collection to support analysis and writing to learn how to think with post-humanist or poststructural perspectives to inform social justice and equitable assessment issues.

Rose Marra I am a faculty member in learning technologies at the University of Missouri. I am interested in designing technology-supported learning environments that are student-focused and help students to engage in meaningful learning outcomes *with* technology as a "partner" as opposed to learning *from* technology. This research is based in a project that uses technology tools to support one of those meaningful learning outcomes—meaningful collaboration as part of hands on science labs. In this study, my role included coauthor and aiding in the description of the project design.

12.2.5 Teacher Education Students

Other human elements of our study included 12 undergraduate teacher education students enrolled in a practice-focused face-to-face science teaching methods course participating in an online asynchronous 5-day unit. This unit was not a normal part of the class and had a different instructor (Shannon). Six of the students were completing a combined degree in biological sciences and secondary science education, while the other six were studying secondary science education only. Students received a small incentive for participating in the study.

With the support of the course instructor, we were able to introduce an instructional element that required students to work in pairs to complete a "kitchen" lab-type science experiment at home and to collaborate using an online collaborative space we called the supporting collaborative inquiry labs (SCIL). We designed the environment to support meaningful collaboration and science lab learning between lab partners working at a distance.

12.2.6 SCIL Materials

The SCIL environment had the goal of supporting learners in authentic science problem-solving with technology-based cognitive scaffolds specifically designed for that purpose. SCIL worked in conjunction with the Canvas learning management system, which was the course management system used for all courses at the institution. Following Lev Vygotsky (1978), David Wood, Jerome Bruner, and Gail Ross (1976) coined the term "scaffold" and defined it as assistance from experts that enables learners to achieve what is beyond their ability to accomplish independently. Scaffolding can have multiple functions including engaging, motivating, and challenging learners, drawing attention to critical features of the problem at hand, demonstrating techniques, and reducing frustration (Wood et al., 1976), and the technology-based cognitive tools we developed in our SCIL system had that precise purpose. One other feature of scaffolding support is that it should gradually decrease as learners become more capable.

Students entered SCIL using a link from Canvas. Each student lab pair had their own SCIL space on Google Drive. Within each pair, each student also had an individual space on Google Drive for individual portions of the lab assignment. Other students in the class did not have access to any other pairs assigned spaces; however, instructors could look at each pair's folder and could comment on, or monitor, each group's progress along the way.

The lab activities implemented in SCIL followed the 5E learning cycle model (Bybee, 2006) (see Fig. 12.2). Note how the student pairs could move through the lab activities using SCIL and how those activities instantiate the 5E method. As students moved through the lab activities, the SCIL environment provided them with technology tools to scaffold and support their thinking and to allow them to

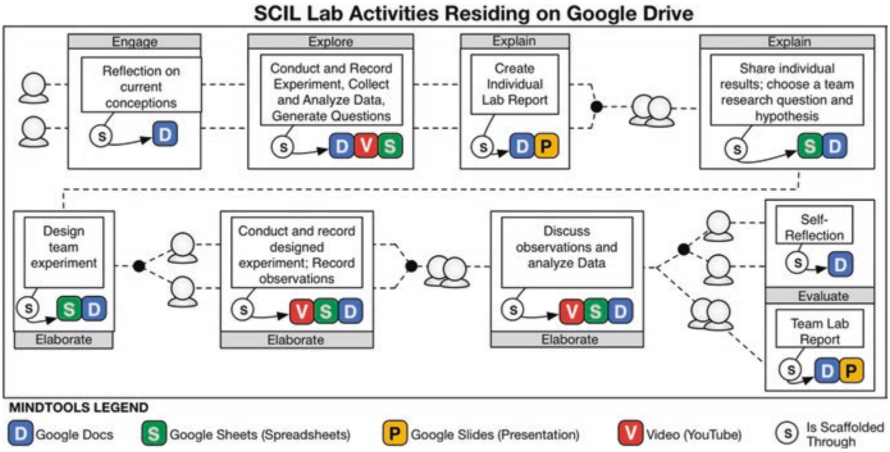

Fig. 12.2 Student path through lab using SCIL and Google apps as scaffolding cognitive tools

represent and share their learning with their lab partners. The colored letters in Fig. 12.2 identify the different technology tools that students could access in order for them to document, reflect upon, analyze, and communicate their data and results with their partner and the instructor.

In setting up the SCIL environment to support the participants' laboratory activities, we randomly created student pairs. Student pairs provided an opportunity for students to collaborate on a research project; collaboration is an important feature of scientific knowledge creation that we wanted students to experience and understand. Additionally, we created the workspaces for each pair on Google Drive and populated those workspaces with the scaffolds and tools in Canvas to prompt and guide students through the lab activities.

Students were required to work remotely in pairs on the lab over a 5-day period. During the face-to-face class on the first day of the activity, we came to class to obtain student consent, train the students on the SCIL environment, distribute physical equipment needed for conducting the lab (e.g., Petri dishes), and answer any questions students had about the SCIL environment or the lab itself. Rather than the goal of learning science content, the lab activity and SCIL scaffolds modeled alternative teaching methods (e.g., online teaching) for the preservice teachers and have them reflect on these teaching methods. With these purposes in mind, we chose a simple lab on growing bacteria. Because of the relatively short duration of the pilot and the time required to grow bacteria, the students in the pilot only completed the elements of engage, explore, and explain encompassed in the first four steps of the SCIL environment (see Fig. 12.2). This meant in practice that the students first individually completed engage, explore, and explain steps and then worked in pairs for an elaborate step. During the elaborate step, students discussed and reflected upon both experiments and developed a new research question. Students were supposed to work together to complete an experiment, which answered the second co-constructed research question. The SCIL environment encouraged students to share their ideas and support them to evaluate their actions.

Students completed these activities over the 5-day period, and partners worked in separate locations of their choice, such as dorm rooms and apartments, to gather data for the experiment. As they progressed through the lab, students in each pair intra-acted through the online SCIL environment and created and stored lab activity artifacts in their shared SCIL workspaces.

Students were instructed to record their results from their daily observations on their individual experiments in a shared lab workbook that resided in their shared SCIL workspace. For example, this is an excerpt from one of the student's lab workbook, "Day 2 – The Petri sample from the dishwasher clean dish is unchanged; the sample from the dirty dish is beginning to grow grayish spots; see accompanying photos." Materials in the SCIL environment (see Fig. 12.2) included Google online tools to support the ability for both pair members to do real-time editing on their shared workbook and to see and comment on each other's progress. These shared notebooks included text entries as well as photos that students used to record the progress of their experiments.

Students used threaded discussions in the SCIL environment to develop a research question that was only constrained by the materials to which each student had access. Students could design their experiment as they chose. The actual structure of the study each pair conducted could involve each student completing the exact same experiment and comparing the results each obtained, or pairs could identify variables to explore with each team member investigating a different variable. As each member of the pair was completing the experiment, students recorded their results from their daily observations in a shared lab workbook. These shared notebooks included text entries as well as photos that students used to record the progress of their experiments.

12.2.7 Students Collect Data on Bacteria, While Researchers Begin to Describe Sociomaterial Assemblages

With our focus on sociomateriality, we recognized the importance of collecting data with the aim of describing possible assemblages, which included students and the technology. Students collected the data over the course of one 5-day unit.

Our primary data sources for this case study included all the material elements, which encompassed the discussion posts and asynchronous communication through artifacts students created in the SCIL environment, as well as post-lab surveys. Students used the technology tools in the SCIL environment to create text and image artifacts that we could use to guide our analysis to describe the sociomaterial assemblages. We began by observing student ad hoc use of the cognitive tools from the SCIL environment that they were encouraged to use during the SCIL online bacteria lab activity.

12.2.8 Data Analysis and What We Learned

We first describe our data analysis influenced by the ideas of Barad (2007), Johri (2011), Deleuze and Guattari (1987), Fenwick and Landri (2012), and other theorists. We provide raw data in the form of course descriptions and technology features and student comments made within the context of the course. Through our data analysis, we eventually comprehended sociomaterial assemblages and describe limitation as the agency exhibited by these assemblages. We then describe the sociomaterial assemblages that are shaping discourse in asynchronous learning environments and explain how "making do" is a central theme within the intra-actions of these assemblages.

Additionally, we felt the need to comprehend the nature of these assemblages, to address our research question, and to honor the opportunities and responsibilities for us to think deeply about power, knowledge, privilege, and identity (Milne, Siry, & Mueller, 2015) regarding these assemblages. Therefore, we considered agential cuts within these entanglements to identify intra-actions present in these sociomaterial assemblages. We chose to take the reader through a narrative of our data analysis by providing specific examples of raw text alongside a discussion of the agency of these assemblages.

12.2.9 Discourse

According to Barad (2007), discourse consists of what constrains and enables what can be said rather than what is actually said. The struggle to communicate and collaborate demonstrated the challenge the students and instructor experienced because of sociomaterial limitation assemblages. Our data analysis began by diffractively reading discourse considering student pairs' experiences in the context of the online course tools (e.g., a threaded discussion) in an attempt to describe sociomaterial assemblages. We chose to first privilege the technology and try to describe how the technology could drive discourse while also describing how the human element was entangled within the assemblage.

Let's start with thinking about Nancy and Cole, a student pair in this study. Our data analysis consisted of diffractively reading the materials and their experiences in an attempt to describe the assemblages that entangled Nancy and Cole. We first focused on identifying sociomaterial assemblages (Latour, 2004) created as a process of intra-actions (Barad, 2007) between the material and the human elements. This first data set took place in an online asynchronous threaded discussion in the context of an assignment to co-create a scientific research question. The students, Nancy and Cole, were part of this assemblage, and we considered how they contributed to this assemblage by focusing on how they each (1) made do with what they had available, (2) used the resources they had to the best of their ability, and (3) used existing resources for new purposes (Baker & Nelson, 2005). In this case specifically, Nancy's partner, the reliance on the SCIL environment infrastructure for communication, and the physical materials all created a unique situation where Nancy was required to be innovative (make do with what she had available) to complete the assessment. The assignment requested Nancy and Cole to develop a research question about bacterial growth. They communicated through the asynchronous threaded discussion session, using this resource to their best ability. After developing a research question, they were supposed to send that research question to the instructor for approval. However, a web of intra-actions inhibited the intended goal. Cole's online comments in the threaded discussion did not specifically address the assignment at hand, had a tone of joking and possibly sarcasm, and could seem condescending to Nancy. We drew this inference from a subsection of the raw data which included Cole's note in the threaded discussion "'Hey, global warming is becoming a bummer, could you do some science and find a way to fix that?' Scientist – 'Yeah.'" This comment, located within this material technology-centered context, could be interpreted in multiple ways, including sarcasm. Cole's discussion in the assignments was limited to comments that were difficult to interpret. Cole's actions, evidenced by his comment about global warming, suggest that he used the resources available to the best of his ability to what appears to be an innovative, yet very negative for Nancy, way. As a result, Cole did not benefit from the learning activity, nor was Nancy able to benefit from the assignment as intended. Additionally, our data of the discourse (where discourse is considered to be what constrains and enables what is said, rather than what is actually said between Nancy and Cole) includes an exchange where Nancy asks, "So, anything in particular you want to try?" Cole responded, "No." Next, when Nancy offered to compare clean dishes to dirty dishes, Cole responded excitedly, or perhaps sarcastically, "Wait… wait wait wait. Are you telling me that we can test dirty dishes versus clean ones? H-E double hockey sticks yeah. I am so down for that. What dirty dish should it be? Tacos? Sandwich? Or maybe even spaghetti? Let me know. I'm psyched." This comment was the last contribution by Cole for the rest of the unit. In this context, we identified a sociomaterial assemblage we decided to refer to as a limitation assemblage. This assemblage constrained and enabled what both Cole and Nancy could say. Furthermore, a closer examination of limitation assemblage revealed limitations imposed by the materials. The materials enabled Cole to communicate in this way, and the materials drove how Nancy and the instructor did or did not react to statements, as well as what these students learned. This sociomaterial assemblage resulted in a negative learning experience for Nancy.

This limitation assemblage highlighted how this entanglement of intra-actions could constrain the potential for both the material and human elements to support learning. Furthermore, this sociomaterial assemblage formed among multiple students to entrap more than one set of students. Another example of a limitation assemblage consisted of the sociomaterial assemblage that entrapped Jim and Kathy, another student pair. Our analysis began by first considering the context of the material elements that drove the discourse between them. The assignment required them to design their experiment together. We considered how these students navigated the imposed discourse by the material and how they were each able to "make do." This activity again occurred in a threaded discussion where Jim wrote in short, incomplete sentences with confusing comments. Kathy had to read these statements in the online discussion board, and initially she responded with questions that asked for clarification. However, eventually she took the lead on the assignment when Kathy stated, “So let me clarify, we would swab our hands under these conditions.” Then Kathy detailed the specifics of the research project, Kathy “made do” with what she had available and used the resources she had to the best of her ability attempting to navigate the intra-actions imposed on her through the materials and Jim. Jim affirmed using the same incomplete and confusing language. This incomplete and confusing language could be considered the use of the existing resources for a new purpose, to participate minimally in the project. Interestingly, Kathy also used the resources for a new purpose; she reluctantly took the lead on this project, possibly due to the lack of clear communication using this technology.

To understand the nature of this limitation and sociomaterial assemblage and deriving inspiration from Barad’s (2007) agential cuts, we chose to focus on the assemblage slice surrounding Nancy and Cole and Kathy and Jim. We considered how the assemblages we describe could be oppressive. In this process, we aimed to bring awareness to the fundamental problems embedded within these assemblages with the intention to understand how to interrupt and weaken oppressive assemblages in asynchronous online courses. By considering agential cuts with the influence of Fenwick and Landri (2012) where we were encouraged to consider how these sociomaterial assemblages move and produce what may appear to be distinct events and why these combinations exert particular effects (Fenwick & Landri, 2012). Together, these analyses led us to a realization that the male students demonstrated behaviors with the course materials that made it more difficult for the female students to succeed at doing science. We found it interesting that one interpretation of these behaviors could be a refusal by the male students to work with the female partner and develop a viable research project. The materials associated with these assemblages afforded the males the described opportunity and supported this web of oppression. Often subtle inequalities go unnoticed in traditional classrooms, resulting in caustic climates for women and LGBTQ (lesbian, gay, bisexual, transgender, queer) members of the science community (Scantlebury & Baker, 2007). In the online SCIL environment, intra-actions became visible when we chose to influence our perception using the ideas of assemblage (Fenwick & Landri, 2012) and agential realism (Barad, 2007). Our description provided an opportunity to make what could go unnoticed as a subtle inequality more blatant, enabling us to further investigate how to dismantle these assemblages.

In online courses such as the SCIL environment, conversations between students in threaded discussions may occur at any time, with complete conversations occurring between instructor intra-actions, and conversations may have limited instructor input or oversight to student intra-actions. Similarly, in a face-to-face class, instructors commonly use techniques to investigate engagement and civility issues yet these can still be limited. It is not possible for teachers to hear every conversation students have within groups or on the side. Online environments have another challenge of disinhibiting student behavior due to anonymity, perceived lack of instructor authority, and the feeling that actions are not happening in real time (Suller, 2004). People may feel they can act differently online than they would in a regular classroom. The mild civility issues that we noticed in this study involved males in two separate pairs. While gender may play a role, we cannot rule out other possibilities. For example, one researcher found that eye contact quells online hostility more than lack of anonymity (Lapidot-Lefler & Barak, 2012). We should also note the technology and assessments they were using. These were threaded discussions within the context of the SCIL environment embedded in an online learning management system; yet since this was not a normal part of the class with a different instructor, they may have felt this activity was less formal and took it less seriously. Additionally, it is important to note these are preservice teachers, so learning how to help students behave in traditional and online courses is important for them to learn.

Identifying the needs of students, understanding when students need support, and building relationships can be difficult in face-to-face (Pellegrino, Chudowsky, & Glaser, 2001) and online learning environments (Kelly, 2014). For example, a teacher could adjust the technology, better understand the diverse needs of students, or adjust scaffolding of the scientific content based on how they interpret when students did not complete the assignment. In this case, the first challenge is for the teacher to recognize a limitation assemblage and then choose effective actions to interrupt it. However, recognizing this occurrence during the course can be difficult even for experienced teachers because the teacher is part of and enveloped within the assemblage. The materials and the social elements shape the communication and actions the teacher can take. We suggest using the materials to help weaken these assemblages by introducing increased scaffolding in the form of netiquette, self-monitoring opportunities, and the addition of specific questions to discuss with a partner to aid student intra-actions. Furthermore, if a partner does not interact appropriately, we suggest a two-pronged approach. First, the instructor contacts that student directly using a tool such as an email to follow up with ways to aid student learning. Second, we suggest an investigation into the assemblages that enable this behavior to identify, modify, and disrupt oppressive learning environments. Additionally, there is a need to inform instructors of common student tactics and actions that exclude and marginalize other learners' contributions in the online context. Instructors could also use help developing tactics for challenging and confronting these actions. Informed instructional designers can also address assemblages that change the culture of online courses and support an equitable online classroom.

12.3 Implications of Materiality

Based on these findings, we suggest that understanding these variations of sociomaterial assemblages can help address how materiality matters to science learners and how understanding the sociomaterial relations might aid equitable assessment and ameliorate the marginalization of students that may not attend traditional face-to-face science courses.

12.3.1 Why Materiality Matters to Science Learners

In this study, we chose to focus on a SCIL environment instructional unit on experimental design for senior-level undergraduate preservice science teachers. Our analysis described the agency of the sociomaterial assemblages that formed in this context.

Technology tools can create learning environments that help learners gain increased access to knowledge resources of a learning community. In studying technology-guided learning environments, we argue that it is important to attend to issues of power and access (Giroux, 1992) and consider that material elements affect these issues as well as the human element. Often, the perception is that learning technologies, such as online learning environments, act as a way to enhance accessibility for learners, not bound by the traditional limitations of synchronous, face-to-face courses. It is similar to online learning environments where material resources and the student digital interface might appear at its surface to be free of bias, oppression, and other messy social factors (Kelly, 2014). It is important to note, however, that these learning environments cannot be sufficiently understood in their material terms (word processors, computer, websites) but must be conceptualized in light of the ever-present sociomaterial intra-actions. While this might seem trivial, recognizing and negotiating a role within sociomaterial assemblages that impact practice in technology-enhanced environments are both increasingly important for more teachers and exceedingly more challenging than in face-to-face courses (e.g., Kelly, 2014; Siegel, 2012). Our present study focuses on the assemblages entrapping students and the learning tools in a technology-enhanced environment. We hope to continue a critical discussion about freeing both the human and material elements entangled in oppressive assemblages. To this aim, we suggest considering how to support and engage diverse and historically marginalized learners in digital science classrooms.

As with all technology, there are associated trade-offs to balance in the complex process of instructional decision-making and curriculum design (American Association of Colleges for Teacher Education, 2014). For teachers in online learning environments, it is important to note that the digital material environment may make the presence of oppressive sociomaterial assemblages harder to identify and easier to ignore and as a result can silence the voices of learners who do not participate in the conventional activities of an online classroom. At the same time, we bring attention to the idea that blank spaces on worksheets, or what instructors might otherwise label as excuses, provide valuable information about the accessibility of a learning environment. With digital learning environments, there are new sociomaterial phenomena in the cultural practices of science education. We suggest that what once was, the dog ate my homework, has become the app was not working on my phone. Both occurrences, when not viewed through a deficit perspective, provide valuable feedback on the accessibility of a learning environment, the social contexts that students are experiencing, and provide cues to the assemblages at work in that context. However, there is an ongoing conundrum for teachers to try to tease apart what intra-actions are creating challenges students face and what should be accommodated while also considering what is critical data, suggesting the need for increased scaffolding or the redesign or reconceptualization of a particular assignment or task. The culture of technology-enhanced science learning environments shares many of the same conventions and practices of more traditional science classrooms, but there needs to be an ongoing study of the new sociomaterial cultural practices in online learning environments.

We also suggest that perhaps more important is attempting to understand how issues of gender or racial bias might manifest and/or be perpetuated in online learning environments. Especially for asynchronous, remote courses, the inability for students and teachers to develop or act on biases because there is a dearth of superficial social or cultural information about learners might be viewed as a possible benefit. While there might be some assumptions made in terms of gender, race, and ethnicity based on students' or instructors' names (normally readily available), it is possible that online learning could support the formation of sociomaterial assemblages which offer some refuge for historically marginalized learners. While a strictly material view of online learning environments may support these views, sociomaterial perspectives would problematize some of these assumptions. A sociomaterial perspective we used in this study highlights gender as one example of this occurrence.

In our analysis, there is evidence that online learning environments and digital tools just provide a different context in which identity issues of gender, class, and race can create inequities. Detecting these issues of marginalization presents a special challenge. Jean Lave and Etienne Wenger (1991) discuss this notion of identities representing the combination of humanist characteristics developed in conjunction with practice and tools. Furthermore, Wenger (1998) explains that making meaning of practice and tool usage play a role in shaping identities. Identities, just like knowing (Orlikowski, 2002), only make sense in the context of practice. Additionally, we find it interesting to think about whether or not identities are transferable between communities of practice/context, that there is some core or natural identity that we are born with (Gee, 2001), or if they are always embedded in practice and how the material can drive discourse around identity. In this study, intra-actions within sociomaterial assemblages may help support certain types of identities (i.e., male science ability), make oppressive structures/practices more visible, and limit learners' notions of the type of person they are/or can be (e.g., Nancy).

We suggest future studies could also explore the extent to which gender bias is manifest in online learning environments. An additional question that could be addressed is in what ways can technology and the material elements support more equitable learning environments and equitable assessment practices. Online learning and technology-enhanced environments require access to certain tools that might be prohibitively expensive for many learners and create uneven starting points for students, thus increasing digital inequalities. Take, for example, some students who may have inadequate or limited access to high-speed Internet or a smartphone. In our study, there were students who did not adequately complete the assignment for a variety of reasons, some of which may include access to resources and tools.

In addition, the Matthew effect—that gaps widen over time—is a danger given studies that show achievement gaps widening with the introduction of technology that is beyond the means of certain students (Stanovich, 1986). We conclude it is important for teachers to note that technological literacy (awareness and ability to use technology) is yet another way that students may vary in ability (Kelly, 2014). Additionally, teachers' technological literacy differs and can influence student learning in technological environments (Bell, Maeng, & Binns, 2013). Finally, we want to emphasize the importance that material elements have in driving discourse. These material elements can entrap students and teachers in complex sociomaterial assemblages that drive learning determining what can be learned, how learning can occur, and even if learning is possible. Thus, we show, even in virtual worlds, the relevance of Barad's (2003) statement, "It is vitally important that we understand how matter matters" (p. 803).

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Chapter 13
Affordances Offered by the Material Nature of a Website Designed for Teacher Learning

Paul Davies and Shirley Simon

13.1 Introduction

The use of technology in education is not new, but its emergence and development has radically changed the way that data are used and managed. The future of the use of technology is predicted to become even more digitized (Johnson, Smith, Willis, Levine, & Haywood, 2011), and, according to Aditya Johri (2011a), we stand at a cusp of fully integrating technology, both in terms of theory and practice, into the repertoire of how teaching and learning is understood. This chapter explores a research project where science teachers interacted with the design and development of a website focused on teacher development to use argumentation in science lessons. As such, the project considered two key areas of teacher development: one, the relationship between teachers and web-based materials in their own learning and, two, teacher change. The project included two aspects of teacher participation: first, a group of teachers worked with researchers to design and teach lessons to be video-recorded for the website; second, other teachers were involved in developing the website using the edited videos. A focus for the second group was professional learning arising from their participation. A framework for teacher learning arising from the relationship with web-based materials is outlined in this chapter and further elaborated in Chap. 14. This chapter first introduces perspectives of how learning technologies have been viewed in the past through the lens of technoscience and individual affordance. It then considers an alternative perspective by examining the

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complex interactions between the material and social aspects of how learning takes place with, and through technology. Key to this is how is learning with websites a function of both teachers' current and evolving practices and is embedded in the everyday actions of teacher development. Using the research project as an example, we explore how teacher design of web-based materials within personal contexts brings meaning to the technology, through interactive practices.

13.2 Technoscience and Learning Technology

The word technoscience was first introduced by Gaston Bachelard in 1953 as a term used to describe how science and technology are situated within social and historical contexts but, importantly, becomes functional through interaction with both human and nonhuman agencies. Typically three levels of the concept of "technoscience" can be examined. The descriptive-analytical level is concerned with the relationship between how scientific advances relate to and change technology and the impact that knowledge development has within the wider society. The visionary level is concerned with how technology and science are evolving and how this may change perceptions of what is meant by "technoscience" and examines how the emerging fields of "technoethics" and "technoetics" will affect the future use of science and technology. The deconstructive level is concerned with a critical analysis of the supposed objective nature of research and work within and with science and technology. The two most important strands of the deconstructive level take either a sociological approach (e.g., Latour, 1987) or a scientific (scientism) approach (e.g., Barad, 1998). As we explore below, the last two of these levels are most important to our work as they recognize the material nature of human-computer interaction and situate technology within a social context, recognizing the interplay between social interaction and technology development and use, something which Sismondo (Sismondo, 2004) argues for in terms of a "new vision" of technoscience.

13.3 The Materiality of Websites

A typical description of a website will state that it is composed of a series of web pages that exist within a signal "web domain" that are hosted through a web server. They have specific "addresses" called Uniform Resource Locators (URLs) and are composed or normal (plain) text and images, supported through a special programming language such as Hypertext Markup Language (HTML). Access to a website normally happens through the Internet, although it is also possible through a Local Area Network (LAN). The language that is used when talking about websites is interesting and helps us to think about their material nature; take the two sentences above. The terms "site," "domain," "hosted," "address," and "access" all pay reference to the "space" aspect of websites. By "space" we mean that websites exist in a form which is tangible, though virtual, and have both spatial and temporal dimensions. But these types of description pay no attention to the designer or user of the website, or the social plane in which these types of technology exist. To better understand what websites are, how they come into being, and how people interact with them, we need to consider three ideas: What is the Internet? How do websites exist within the Internet? and Where is the *social* when thinking about the nature of websites?

Fully answering the question "What is the Internet?" and subsequently "How do websites exist within the Internet?" is not easy. Relating these questions to thinking about the *materiality* is even harder. Ulrech Beck, Anthony Giddens, and Scott Lash (1994) describe the formation and rise of the Internet as being part of the process of globalization and the development of post-traditional methods and approaches to organization (Slevin, 2002). They argue that the Internet was never "designed" in the purest sense but emerged, something which was possibly an accident but also inevitable within the world globalization landscape of the 1960s onward. However, the Internet is not a "thing" in the sense of how most people think about real objects, and neither is it a concept or abstraction of reality; it is slippery and a mixture of many things, its form and function shifting depending what questions are being asked of it.

In its early conceptions, the Internet, and note the significance of the demarcation of the word as a proper noun, was first described as a network of networks (Braden, 1989). The image that this phrase invokes is not far away from how most people think about the Internet – as an invisible web of billions of computers linked to one another. The Internet carries information, resources, and services between, among other things, computers, mobile devices, hyperlinked documents, and electronic mail programs. So, at this level Internet can be thought of as material in the sense that it is made of things: computers and other devices (which themselves are composed of different materials), metal or fiber-optic wires, electrons or photons of light traveling along these cables, radio waves traveling through the air in wireless transmission, and servers which sit like super computers sorting and referencing billions of bits of information per second. What of websites?

Websites form part of the Internet, within the domain called the World Wide Web (www), a section of the Internet, very specifically defined as using Uniform Resource Locator (URL) technology. URLs are composed of a protocol, that is, a special set of "rules" that allow communication between different devices, and a domain name. The domain name is key to the functioning of websites and is formed from a link to the host server (e.g., www), the organization (the second-level part of the domain name which identifies its affiliation), and the top-level domain name which is the final part of the name (e.g., .com or .org). The top-level domain name provides a category to which the website belongs (e.g., .org mean "organization"). The URL is thus more than an "address' but a signal to the user of the affiliation and function of a particular website.

Being composed of text, images, media, and links to other parts of the Internet, websites are highly plastic environments. Behind the so-called interface, that is, the page that the user sees, there are layers of computer programing or code which turns a binary language of numbers and language alien to most people into things that people recognize and can relate too. However, views of the Internet and websites that take the position of their tangible nature as explaining them completely neglect the user and user-technology interaction. James Slevin (2002), in the publication *The Internet and Society* recognized the importance of this when he wrote that understanding the Internet and its role in society only comes about through considering that "the symbolic content and online interaction are embedded in social and historical contexts of various kinds" (p. ix). In the same publication, Niels Brügger (2002) said that what is missing from this statement is the "material being" of the Internet and websites. Here he argues that the material being considers both the way that websites are set up (content, interactivity, links) but also, crucially, the way that the use of the website "affects its being." He summarizes this "The material being … is therefore both condition for and result of actual use" (p. 14) and goes on to argue that key to understanding the material nature of the Internet comes through understanding the nature of, and relationships between, the "material components," by which he means the machines, technology, objects, and artifacts of websites and bodies of the users.

We agree with this and consider that examination of these components is central to fully appreciate how websites are used and are involved in learning. This chapter does not provide enough space to explore all these aspects, and so we will concentrate on those that are most important to the arguments we are forwarding and briefly summarize the key features of those which are less relevant.

As discussed above, the computer (and other "hardware") aspects of the Internet are things, they are connected to one another by things like cables, and they communicate with one another through a shared, computer language. It is here that we see that their material nature is divided into their physical being consisting of things such as metal, plastic and moving parts but also electricity or light and their physical being in terms of how communication or data are processed and filtered, through the nature of how the electricity or light is sent, received and transformed between the hardware components of the system; what Brügger (2002) called the immateriality of the Internet.

More crucial to us is the role that the user plays in their relationship with technology. Websites contain objects and artifacts, for example, images, media, text, and blogs which are produced through human interaction with the website interface, and it is through this interaction that we start to see the intertwining of humans and technology and then begin to realize the full nature of this "unit" of materiality. Leonardi (2012) provides a useful example to compare how human interaction affects the materiality of technology by considering the differences between the way that a social blogging site differs in its behavior, potential, and spatial-temporal existence, compared to an email program. A blog site is a dynamic space, with the user sharing ideas, possibly uploading media, and contributing to discussions or "threads" cumulatively. These actions are stored and saved, available for later retrieval and reediting at later times, giving rise to both spatial and temporal existence for the data and the user. In contrast to this, an email program, where user editability is impossible once the message has been sent, and the message can be shared quickly to a large number of, possibly, unknown users, offers alternative communication strategies. So, when people are engaging with technology of this type, they accept that the materiality of the technology, what it does and not does allow, influences how it is received and the possible actions that follow.

This notion of shifting or changing materiality is also true of websites. Websites are complex spaces and have a range of functionality. In their simplest form, they present content, which the user interacts with in a fairly passive way, being the "receiver." For example, a government webpage designed to provide information about library services offered in the local area. A different type of website might have a chat room or blog associated with it or opportunities for the user to load and share media. Here the interaction between website and user is more dynamic with the user shaping and molding the nature and form of the website, in both a spatial and temporal plane.

These types of interactions are important for us if we are to understand both the materiality of the website but also its affordances. To do this demands a reexamination of the notion of materiality of technology. The traditional view of this takes the primary focus as one of three things: the technology, the user, or the technology user. In our work, we argue for there is a need to consider technology users through both the perspective of materiality *and* also the *social*. This is especially the case when considering the nature of learning with technology, and it is which we go on to consider in the next section.

13.4 An Emerging View of Learning with Technology

The emergence and then rapid rise of technological development were, in the middle part of the last century, heralded as a potential panacea that would lead to a broader and deeper education for all (Scanlon, 1959). In this way, technology was perceived as a "solve all" because it allowed access to content that had never been available or imaginable before. For example, the rise of television meant information could be "beamed" directly into people's home. This, coupled with the perception of how "better" education could take place at low cost, seemed to be the answer to many of the problems that were facing, and still face, education across the world (Johri, 2011a). Viewing technology as a tool for education in this way follows an "efficiency model" of its use in that it sees technology as simply, as Johri (2011a) puts it, a "vehicle" used to achieve a predetermined goal and, in doing so, takes a deterministic view of how technology supports learning. Earlier work in the sociology of technology focused much of its attention on the social construction of technology (Pinch and Bijker, 1984) and actor-network theory (Latour, 1990). With these foci came a recognition that design comes about through, what Paul Leonardi (2012) calls, "contestation and negotiation" and that there exists important power relations and shifting positions of authority and interests (Callon, 1991). Bruno Latour (2005) has gone on to argue that the distinction here between the materiality of the technology and the social world is illusionary and only useful in terms of discussing the complexity of the relationship, rather than recognizing them as distinct. As Leonardi (2012) points out, Karen Barad (2003) has gone further in arguing that the relationship between the material and social is loose and flowing, that is, not predetermined, and is "enacted" through one's work. This idea of the boundaries being "constructed at the moment" (Johri, 2011a) is central when considering the place of user in learning with technology and, as Leonardi (2012) recognizes, echoes Wanda Orlikowski's (2007) ideas that when considering technology, the material social are entangled. Here, neither one (humans or technology) are privileged nor are they seen as a single entity. Instead, they are "inextricably related – there is no social that is not also material, and no material that is not also social" (Orlikowski, 2007, p. 1437).

In response to this, the term sociomateriality has become important when thinking about technology and users of technology. Clearly, this term is an attempt to being together both the social and material aspects of technology, but that is not to say that technology is, in itself, sociomaterial. Instead, it demands that technology is recognized in terms of how it is embedded in what the user does with it, that is, the affordances of the technology (Sørensen, 2008). We think this definition of technology offers important perspectives in understanding its development and use in learning.

In our work, we concur with both Johri (2011a) and Orlikowski (2002) who both argue that by examining the use of technology *in practice* the meaning that "users attach to technology and the meaning that technology achieves through these enactments" (Johri, 2011a, p. 208) is revealed. But what does it mean to say "in practice"? There have been various concepts put forward to explain the idea of practice, for example, Lave and Bourdieu. Whatever the differences that these authors identify, they recognize that practice is not the same as the activity of an individual but the collective activities within a set of norms with a specific setting. For Lave this means shared practices within a community (Lave, 1988), while for Bourdieu (1977) it is where subjective experience and objective reality are "played out" (Leonardi, 2012). With specific regard to technology, Leonardi (2011) develops a perspective on *practice* which draws together human agency, in terms of developing and working toward goals, and material agency, where nonhuman digital-associated artifacts influence human behavior. Take as an example the authors typing this text. They have agency – a knowledge of the words they use to convey a particular message – and this is expressed through the material agency of the computer hardware (keyboard, monitor) and software (program and computer language). So, while we make decisions about what keys to press as we type, we do not have influence over *how* the "computer" interprets and processes this information, other than the words we see appearing on the monitor. Also, as Leonardi (2012) points out, here we see that the materiality of the computer does not change either spatially or temporally, i.e., we expect the word-processing program to work in the same way for different people at different times, but what we do with it and through it, will – so, what the technology *is* does not change, but what it *does* will change.

The view that sociomateriality is intertwined with practice can be taken further by augmenting this theoretical perspective with what Johri (2011b) describes as sociomateriality bricolage. In our research, we postulate that the notion of sociomateriality bricolage is a useful theoretical position to adopt when considering how teachers use and learn from web-based material because, as Johri (2011a) argues, it places the user at the center of technology. Bricolage is an idea that was first put forward by Levi-Strauss (1967) within the concept of people "making-do." He argues that *making-do* is how most people use the tools that are available to them. In terms of teacher learning, this would mean that instead of completely changing their practices as new or innovative ideas are introduced to them, teachers incorporate these into their current practices to make them fit with pre-existing modes of teaching. The relationships between this and how teachers might be involved in designing and using technology are immediately apparent. If technology is introduced to teachers at a level which is far removed from their own modes of teaching and learning, it is unlikely to be useful. Much better is to allow teachers to assimilate the new ideas into their existing mode with change coming gradually. A good example of this is observed in participatory design of software where the "user" is fully involved in the process, from initial ideas to trialing alpha and beta versions of the finished program. Price et al. (2014) describe such a project where beginning teachers took on the role of participatory designers in developing a smartphone-hosted app (called GeoSciTeach). The app was originally conceptualized by the project leaders as allowing teacher and students to explore plants at a botanical garden through geospatial positioning (GPS) technology. The beginning teachers supported the development of the app through initial ideas, linking the functionality of the app to their own experiences of teaching science in high school and through trialing with their students. This model of iterative reflection and development resulted in the final app being radically different from that imagined by the project leaders and supported teaching and learning of the curriculum in a much more focused way. The finalized app was also designed to be embedded within the teachers' practice, and not seen as an "add-on" or novelty tool, but instead an integral part of how the teacher used different strategies in their practice. It is in this final idea that we see a clear echo of the "making do" bricolage of Levis-Strauss, with the new technology becoming very much part of the teachers' "social consciousness."

13.5 Teacher Learning Through Website Design

In this section we consider how taking a sociomateriality bricolage perspective is useful with regard to understanding learning technology through the examination of a research project focused on teachers designing a website. The project was concerned with supporting teachers' use of argumentation within the science classroom. Argumentation as a pedagogical approach has become well established in the Science classroom (Erduran & Jimenez-Aleixandre, 2008) and, through encouraging analysis of data and peer discussion, has been shown to lead to enhanced conceptual understanding (Venville & Dawson, 2010). However, research has shown that teachers often find it hard to learn and master argumentation practices and find their implementation a challenge (Osborne, Simon, Christodolou, Howell-Richardson, & Richardson, 2013). The goal of our project was to work with both primary and high school teachers to develop a website for professional development in argumentation. We were interested in how one group of teachers, acting as participatory designers (Koehler & Mishra, 2005), influenced the design and implementation of an argumentation lesson to be video-recorded and also how another group of teachers contributed to the choice of website materials, layout, learning tasks, and user interface facilities. The focus in this chapter is how the teachers' involvement in this second activity supported their own learning about the use of argumentation in the classroom. The much fuller account of the project design, the participants, and outcomes can be found in Chap. 14; here, we focus on the role that thinking about sociomateriality bricolage plays in understanding the successes but also challenges of teacher learning.

13.5.1 How Do Teachers Learn?

There is a considerable amount of evidence to show that teachers often find it hard to incorporate new teaching and learning strategies into their practice (Zohar, 2009), and this is particularly true when teachers cannot relate their learning to familiar practices and contexts (Hatch & Grossman, 2009). This challenge led us, as the project team, to decide to include a range of tasks and tools within the website that would scaffold learning for the teachers in a staged and manageable way. In order to do this, we considered five key aspects of teacher learning and designed the project to allow the teachers access to these stages of professional learning.

Firstly, we recognized that teachers need to *view new pedagogies as something familiar to their own teaching*, that is, these new pedagogies cannot be so far removed from their everyday practice that they seem alien. In many ways, this resonates with the bricolage ideas of Levis-Strauss (1967) in terms of the teachers "making do" with new ideas within their specific contexts. Secondly, we were anxious to ensure that the teachers were supported in *analyzing their new pedagogies* and felt empowered to reflect on their developing practice. Thirdly, we were mindful of the importance that *collaboration* plays in teacher professional learning (Bell & Gilbert, 1996), both as the teachers worked within the project group and also back in their schools. Fourthly, we considered how *teachers interact with tools or meditational means* that are available to them. As James Werstch (1998) explains, tools come in an array of forms, and part of our research focused on understanding how participation in designing the website allowed the teachers access to new tools and opportunities for internalization and mastery of how these tools could be used in their own teaching contexts (Wertsch, 1998). The final aspect that we wanted to provide to support the teachers' learning was the opportunity to *reflect on their learning and changing practice*, something which has been shown to be of greater important in teacher learning (Zohar, 2009).

Viewing the teachers as participatory designers meant recognizing the authentic nature of teacher knowledge and practice. That is, we, as researchers, were aware that teacher learning is situated within practice of the "real world" (Pea, 1993). Setting the project up in this way meant that it encouraged inquiry, research, and design from the teachers, leading to the development of meaningful artifacts in the form of the website. As researchers, we were keen to keep the project "open ended" so as not to guide the teachers too much allowing them freedom to design a website that worked for them and potentially other teachers. This meant that the teachers were fully embedded in the design process, something we perceived as key to the way that the teachers would then work back in their normal practice.

13.5.2 Teachers as Designers

To understand the process of teacher learning through participatory design, we draw on features of educational design research, which involves the systematic study of the design and development of educational interventions for addressing complex educational problems (Edelson, 2002). For this project, the process involves identifying the challenges related to new practices, offering opportunities for addressing those challenges, and engaging the participants in the direct improvement of their educational practice. Design research thus provides a framework for systematically analyzing the problem, providing a design solution and a design procedure (Edelson, 2002). The approach is especially suited for understanding developing practices which lead to changes from traditional, or deeply held views of teaching and learning, to those which are more exploratory or innovative. In Chap. 14 the implementation of a design research approach will illustrate how participants took part in the analysis of "challenges" teachers face in the teaching of a new practice – argumentation, and developed ways of addressing these challenges through design solutions – strategies to use in the video-recorded lessons and teaching approaches that are accessible through a website, and evaluation of these solutions through reflective accounts, which form the basis of website tasks. Participatory design can serve to establish the value of design solutions that promote changes in teachers' knowledge and practices. Design "cycles" (Nieveen, 2009) can be conducted with the same group of teachers over time as the website develops or with different groups of teachers informed by the first cycle while interacting with the website.

13.6 The Website Design

Basing our project on the five key aspects of teacher learning identified above, we designed an outline to the project, which incorporated these ideas but also allowed flexibility in response to teachers' needs. It is through the teachers' interaction with these aspects of the project that sociomateriality bricolage of the website as a learning space can be seen.

The first, *introducing new pedagogies in familiar contexts*, meant we needed to introduce argumentation classroom strategies in a way that the teachers could recognize. Therefore, we decided on the use of video footage, which is more fully described in Chap. 14. Video is known to be a useful tool to support teachers' reflecting on their own practice, knowledge, and beliefs because it allows the viewer to see how new practice can be embedded in their existing ways of working (Sherin, 2001). During the project, the second group of participant teachers viewed, commented, and modeled behaviors and approaches they observed in the videos and made suggestions about how the videos could be embedded within the website. Here, the teachers were reflecting on their own practice and "imagining" how the new pedagogies would or could fit within their current practices, an example of Clause Levi-Strauss's (1967) "making-do" model of learning. A key feature of the use of video in websites is that is allows classroom interactions to be viewed from different perspectives, something that is not possible in not classroom environments (Brophy, 2004). The teachers were keen to draw on this feature in the website and use the same video clips to emphasize different aspects of argumentation in the classroom. For example, the same clip was used to demonstrate how to introduce argumentation and setup different activities.

It quickly became apparent that video alone was not sufficient for the teachers to recognize and understand the design and rationale "behind" the lesson or "noticing" as John Mason (2002) describes it. For Mason, noticing refers to the process whereby teachers "see" certain practices and activities through their own perspectives. What a particular teacher will notice depends on their values and beliefs about teaching and learning, meaning that other, potentially significant events, might be missed or seen as unimportant. Supporting teachers in recognizing this and refocusing their attention is a key feature of teacher development (Mason, 2002). In our work, noticing is something which the teachers saw as key to helping them to make links to their practice. To support this, the teachers felt a transcript of the lesson should be accessible along with the video clips, allowing the user to pause the video, consult the text, rewind and fast-forward as necessary, and so fully "integrate" the classroom interactions. The research team also felt that the development of tasks to sit alongside the video materials would be helpful in order to support critical engagement with both the classroom strategies being displayed but also trialing of the strategies by the teachers in their own contexts. Supporting the development of these tasks, the teachers returned to their schools and used the tasks to frame their own experimentation and, in doing so, *analyzed their developing practice*. The provision of tasks thus became an important aspect of the website to both guide the learner and support in-practice experimentation.

The project was designed to fully support *collaborative* learning approaches; during the workshops, the teachers worked in teams based around the age of children they taught and experience. When trialing ideas back in school, the teachers also worked within their school teams, sharing ideas and supporting one another's development. As part of the website design process, the teachers argued that tasks that encouraged this would be useful and that the provision of online sharing activities (blogs etc.) could also be useful, especially for those teachers who feel more isolated.

The teachers felt that *tools* should be central to the website design, in terms of tangible materials such as worksheets, card sorting activities, and other paper-based classroom resources because these tools allowed them to conceptualize how the new teaching strategies might be used in their own practice and gave immediacy to their learning, especially when the resources were linked directly to the video clips on the website. In the wider sense, tools also encompass the other aspects of the website, such as the embedded media, text, and tasks – what Wertsch (1998) describes as *meditational means*. These were crucial in terms of the teachers' own learning, because they provided scaffolding as the teachers shifted in their views of teaching and learning.

Opportunity for *reflection* on their own learning was an essential element of the project, with the teachers trialing activities in school, producing reflective journals and notes, and discussing their evolving ideas within the group. They felt that this element of personal learning was an important part of their "learning journey" and wanted this embedded within the website – something which came about through specifically designed tasks and an area on the website focused on the process of embedding argumentation strategies in the classroom through lesson plans and schemes of work.

13.7 Conclusion

The example of the website project demonstrates the aspects of sociomateriality bricolage (Johri, 2011a). Firstly, the teachers (as participatory designers and users of the website) used their knowledge in new ways within their specific context, that is, they were quick to engage with the new teaching strategies and make them workable within their existing practices. Secondly, they "made do" with the resources that were made available to them, incorporated them into their practice, and made design recommendations about how they could be best deployed, and, thirdly, they devised new ways of using the tools and resources at their disposal as their learning evolved. So, here we see that the design of the website and the teachers' development came about through collaborative trial and, in some ways, error, within situated contexts or activities.

Sociomateriality can be applied to all learning, as learning always takes place through the mediation of materiality (Johri, 2011a), something which a focus solely on language does not take into account. The sociomateriality bricolage perspective, when applied to learning technology, is especially powerful because it (1) puts the materiality of the *technology-user intertwining* at the center and (2) recognizes the contextual importance of technology, that is, it does not exist in a separate world to the user and also exists in different worlds depending upon the user. This perspective seems to offer opportunities in understanding learning technology that are only slowly being realized.

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Chapter 14
Teachers as Participatory Designers of a Professional Development Website

Shirley Simon and Paul Davies

14.1 Introduction

In Chap. 13 we outlined our perspective on the materiality of websites, building on Niels Brugger's (2002) argument regarding the material being of a website, that is, the relationship between the material components and bodies of users. The focus of the website development in this project is on the production of a coherent site that results from teachers' engagement with components such as video and teaching resources, and the production of interactive tasks that enable teachers to reflect the outcomes of that engagement. So, what is on the website is produced through human interaction with the material components. This process also resonates with the notion of how the relationship between the material and social is loose and flowing (Barad, 2003) – it is not predetermined but is enacted through one's work. The material and the social are inextricably related; hence, the concept of sociomateriality is an important one in this website design. Moreover, the distinction between material agency and human agency (Leonardi, 2012) is relevant to our work. The components of the website do not change, but what we can do with it does change according to our choices. So the final website has to be designed to have a clear structure that makes logical sense, but with a flexibility that allows for a range of users and their needs.

The original version of this chapter was revised: figure 14.1 was published without permissions from the original publisher which has been removed now. The correction to this chapter can be found at https://doi.org/10.1007/978-3-030-01974-7_18

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In developing the website, we took the position that video material alone is not sufficient for teacher learning, as to ‘notice’ (Mason, 2002) aspects that can be related to their own practice teachers need to understand what is behind the lessons. Thus the video has to be accompanied by tasks, resources and collaborative reflection. In this project videos were developed with one group of teachers to show argumentation pedagogy, and these formed the basis of the website designed with a second group of teachers from both primary and secondary contexts. The aim was to plan tasks within the website that would be useful to teachers engaging with it either as individuals in schools or groups supported by a professional development programme. Although the video clips allow behaviour to be observed, the sociohistorical aspects of production are hidden – the viewer does not know how the lesson was planned or how the video extracts were chosen. The aim of the website is to embed the video within a structure that optimises teacher learning, building on the sociohistories of the teacher and researcher designers of the lessons filmed, and on the sociohistories of the new users of the videos and tasks. Specific tasks were developed to accompany each video that were designed to elicit a number of different responses from the observer. To understand teacher learning, we consider the sociohistoric context of the individual to explore:

1. How they navigate their learning through interaction with the website components.
2. How they may or may not change their teaching practice.

Key to the nature of teacher change that we observed, were teachers’ personal perspectives on teaching and learning, the school contexts in which they worked and their reflective abilities. By considering these aspects through the role that the teachers played in designing the website, we are able to shed light on this emerging and developing mode of teacher learning.

14.2 Argumentation Pedagogy and the Use of Video

The focus of the video and website development was the need to enhance the practice of teaching argumentation in both primary and secondary schools. The importance of argumentation in science education has become well-established and has been the focus of many international research studies (Erduran & Jiménex-Aleixandre, 2008; Khine, 2011). Yet enhancing pedagogical practice with argumentation can be challenging as teachers do not readily engage students in scientific argumentation in the classroom (Osborne, Simon, Christodolou, Howell-Richardson, & Richardson, 2013; Simon, Erduran, & Osborne, 2006; Sampson & Blanchard, 2012). To advance this field requires an examination of the specific features of argumentation pedagogy that teachers can focus on in their initial practice with using argumentation activities. These can then be central to professional development that will enable teachers with limited experience in argumentation to build their pedagogical strategies. From studies on teaching argumentation, we focused on addressing the management and organisation of groupwork and the role of the teacher in a lesson structure that includes introducing argumentation, small group discussion and a classroom plenary in professional development for argumentation.

The management and organisation of groupwork is an essential first step in getting argumentation activities working within a classroom setting. Studies of students engaging in group discussion or collaborative argumentation show that they have difficulties in making those discussions productive (Evagorou & Osborne, 2013; Sampson & Clark, 2008), as it can be difficult for students to find evidence to support their claims in constructing arguments (Bell, 2004). Teachers need to structure group discussion for argumentation in such a way that students take stances and have access to suitable evidence that enables them to produce reasoned arguments. There are a number of strategies that can be adopted to provide such opportunities which can form the basis of video material. Through initiating groupwork strategies in practice, teachers can reflect on student outcomes and build their knowledge of argumentation pedagogy.

Many teachers do not engage students in scientific argumentation as they focus more on explaining concepts (Weiss, Banilower, McMahon, & Smith, 2001) or have limited knowledge of how to encourage argumentation processes whilst students are involved in argumentation activities (Simon et al., 2006; Zohar, 2008). Teachers can develop a role that involves scaffolding argumentation processes through providing a rationale for students, modelling argumentation, and/or asking appropriate questions (McNeill & Pimentel, 2010). Video material can be particularly helpful for teachers in developing their role at various stages in an argumentation lesson: introducing the activity that involves explaining the purpose, modelling argument and setting up appropriate groupwork integral to the purpose; positioning in the class, questioning styles and scaffolding discussion during group work; and drawing on the outcomes of argumentation to consolidate learning. All these aspects of the teacher's role require an understanding of how argumentation contributes to science learning through reasoning (Sampson & Blanchard, 2012).

In order to capture video material that was not contrived but showed teachers working with students in 'real' contexts (Grossman et al., 2009), we worked with three teachers, from two different schools, to develop lessons which demonstrated a range of teacher-student and student-student interactions focused on argumentation and groupwork activities. These teachers were well versed in the skills needed to establish and maintain effective argumentation activities in science lessons and were familiar with much of the literature and resources that support this pedagogy. The process of planning thus took on a design approach (Edelson, 2002) as participant teachers and researchers analysed the potential challenges faced by teachers in adopting a new practice and focused on strategies to show on video that might help users to address these challenges.

The planning of the lessons to be filmed occurred in two stages; this helped provide some flexibility with the outcome of the exact nature of the lessons and the final video clips. Initially meetings took place with each class teacher and the researchers to discuss the aims of the project and to initiate the lesson planning process. During these discussions key ideas were raised to prompt and encourage the teachers to think about activities in the lessons which would be useful, for example, the teacher grouping the students, students working in small groups and students moving between groups. At the same time, the teachers made suggestions about the lesson design, sometimes specific to the nature of the class or innovative ideas in addition to those of the project leaders; these discussions allowed for the most appropriate lessons to be devised. Thus planning was determined by the sociohistoric positions of researchers in terms of argumentation pedagogy, and teachers in terms of science lessons and knowledge of students.

The final outcome of this planning was the development of three lessons aimed at 11–12-year-old students, which contained a mixture of content-specific and generic argumentation, groupwork strategies and teaching approaches. The lessons were then taught by the teachers in normal classroom settings and filmed by a production company that was experienced in working in naturalistic classroom settings. In order to capture the material required to show a real teaching context, it was important that the lessons 'flowed' so the filming continued uninterrupted. The filming involved whole class teaching, teacher-focused and student-focused episodes and teacher-student interactions.

Having footage of complete lessons, with extensive material from all aspects of the lesson, requires careful editing as an important stage in order to guide and focus potential observers as to what they should notice (Koehler, Yadav, Phillips, & Cavasos-Kottke, 2005). Editing of videos took place in three stages. Initially a complete transcript of both teacher and student dialogue was made available to the project team. This allowed for the identification of footage that would be potentially useful in demonstrating how the three teachers operationalized argumentation pedagogy, including how they organised small group discussion and scaffolded argumentation. The process of editing of short sections (ranging from under a minute to a few minutes) of footage then took place, focusing on the particular activities that are significant in teachers' development of argumentation classroom strategies (group management and teacher-student dialogue to scaffold argumentation). The researchers viewed the clips and made detailed notes focusing on the actions of the teachers and students, the dialogue relevant to argumentation, and resources use. Following some minor editing, the final videos were shown to the teachers and students involved in the filming to gain their approval before any of the material was made publicly available. The sociohistoric positions of the researchers regarding ways in which teachers might build their knowledge and practice from viewing the video informed the editing process and subsequently the order in which the videos were situated within the website structure.

14.2.1 Video Focus 1: Groupwork Strategies

The teachers and the researchers planning the lessons for filming built on their teaching and research knowledge regarding groupwork skills. Students need to develop sound skills of listening carefully to each other and taking it in turns to respond to each other before they can fully engage in argumentation. The first groupwork skill, called verbal tennis, is very simple and easy to manage as a teacher and engage in as a student and was designed as a starting point for groupwork by one of the teachers being videoed. The students develop skills of listening and responding to each other in pairs. In the first two video clips, the teacher introduces the task, and then in each pair, one student begins by naming an animal, and the other student has to respond with another animal. The task then becomes more focused, the students have to listen more carefully and think of an animal that is related in some way. A transcript of the first video is as follows:

> The first activity we are going to do is called verbal tennis. And the way that works is, you are going to talk to the person next to you, so you two will talk as a pair, you two will talk as a pair, not the person opposite. So that's who you are going to talk to, the person next to you not opposite. And this is what I want you to talk about. For about a minute, one person in the pair is going to start talking about animals that they know then the other person is going to start talking about animals that they know and bounce the ideas off one another. So you might start off saying dog and the other person might then say cat, then you might say worm and they might say snail and I want you to try and name as many animals as you can. So one person says one, then the next person says one, then the first person says one and the next person says one. We will do that for around about a minute. Does every one understand what to do?

Following verbal tennis comes a slightly more complex group format, called speed dating, which involves students thinking more about specific animals and their features and interacting with more students. Subsequent video clips show groupwork activities that use specific resources, such as evidence cards or concept cartoons, to engage students in discussion of evidence and argumentation to make decisions. In addition, the context becomes more complex in terms of the science, for example, using evidence about animal features to classify them as fish, amphibians or mammals. Building even more complexity into groupwork skills, the use of jigsaws or envoys is then incorporated in the lessons. In envoys one member of the group takes the group's decision and shares this with another group. He or she finds out what the other group decided and takes back their arguments to the original group for further discussion. The lesson plan and video extracts therefore reflect how the teacher and researcher see simple groupwork as a precursor to using these skills in more complex activities in terms of both groupwork skills and science content. This progression of ideas is part of the sociohistoric aspect of both researcher and teachers, in how they view learning groupwork pedagogy as an outcome for other teachers watching the video and how they see students' skills developing. The outcome for teachers viewing the video will be highly varied as it will be dependent on their own contexts, stages of understanding of argumentation and perceptions of learning. For most teachers, the simple strategies they observe in the video will have some familiarity and thus be assimilated into their existing repertoire, reflecting the notion of bricolage (Levi-Strauss, 1967), as teachers 'make-do' with the tools afforded by the video.

14.2.2 Video Focus 2: The Teacher's Role

Once teachers and students are confident with groupwork strategies that can be used in argumentation activities and have assimilated these into practice, teachers can consider more deeply their own role in an argumentation activity. Lesson structure is a familiar aspect of a teacher's repertoire – teachers often plan three phases, how a topic is introduced to the students, what happens whilst students work in small groups and how the activity is finished. Adopting argumentation pedagogy involves teachers considering how to fit new aspects of their role within this familiar structure or 'make-do' with the new ideas. Taking on an effective role and deciding what to say to students relies on moment-to-moment decision-making within the lesson structure, for example, deciding when to question for justification, when to provide information or when to stand back and monitor the discussion without intervening. The video clips illustrate some of the ways in which the teachers interacted with their students, how they asked questions, how they responded to students and how they provided scaffolds to help student thinking, for example, writing frames. Video clips of different kinds of teacher-student interactions were edited to highlight different teacher roles for users to view. In the following example, the teacher asks questions that help students to think about information that could be used to support a claim that the dolphin is either a fish or a mammal.

Teacher: Well what do you think?
Student 1: We think it is more like a fish because it lives under the water and it has a fish like tail and fish like features.
Teacher: OK, what would those fish like features be?
Student 1: Well, it has a fish tail and fins,
Student 2: It swims under water and lives there most of the time.
Teacher: Right, when you say most of the time where does it live the rest of the time?
Student 2: Sometimes it comes out of the water and jumps

In a whole class format, the teacher encourages the processes of argumentation whilst students are working as envoys:

> I want you to think about why your evidence is the best for the decision you have made and why their evidence isn't so good. You call that a counter claim or a counter argument. You are arguing against what someone else says. So you are arguing for yours and against their idea at the same time. So its decide fish, reptile, amphibian or maybe you can't decide. And then it's choose which bits of evidence really support your decision and thirdly it's think about how could I counter someone else's argument.

The decisions about what to say and when in the argumentation classroom are a combination of how the teachers understand the pedagogy, how they have discussed their role with the researcher prior to filming and how they make moment to moment decisions based on their experiences as teachers. Editing the video to show different kinds of interactions was more complex, as it involved judgements about how these clips could be used by teachers viewing them.

14.3 The Participant Designers and Their Engagement with Website Components

The study was carried out with eight teachers working in schools in a large city: four from primary school (5–11 years) and four from high school (11–18 years). The teachers met together for three one-day workshops over a 3-month period. Each workshop was focused around one aspect of argumentation pedagogy and was designed to engage the workshop participants in watching the videos and carrying out activities based on the strategies observed. Much of this work was carried out through group discussion which allowed individual evolving ideas and beliefs to be revealed through the development of a collegiality within the group (Servage, 2008). After each workshop, the participants were encouraged to develop and trial argumentation strategies in their schools. The direction for this was deliberately kept open to allow the teachers flexibility in their design but also to encourage them to critically consider which approaches would be most appropriate for the topics they were currently teaching. The participants were also encouraged to share their experiences of the workshop with colleagues in their schools.

As the workshops developed into the website design, evaluations and choices by teachers helped to determine the tasks and layout of the website to optimise teacher learning for new users. Data regarding the responses that the teachers had during the workshops and the nature of their discussions were collected through a combination of teachers' written accounts and researcher field observational notes. An initial questionnaire focused on their teaching experiences, ideas and beliefs about the use of groupwork and argumentation in science teaching, hence their sociohistoric positions, and expectations of their own learning through the workshops. A summary of these positions is presented in Table 14.1.

Subsequently, teachers were asked to explain and reflect (both written and orally) on their responses to the activities that they completed during each of the workshops and on their use of different groupwork and argumentation strategies in their own schools. In addition, the teachers were asked to record their thoughts as they trialled different classroom approaches through reflective journals captured on flip cameras (small, digital cameras with straightforward usability).

14.4 The Construction of the Website with Video and Tasks: Examples of Sociomateriality Bricolage

Previous research on teachers' responses to changes in the curriculum or to new innovations has shown that teachers do not easily make changes in practice that are needed to address new goals (Zohar, 2009), particularly when teachers cannot relate learning to familiar practices and contexts (Hatch & Grossman, 2009). For teacher development to be effective, new practices need to be reflected upon analytically and shared between colleagues working together collaboratively (Bell & Gilbert, 1996; Clarke & Hollingsworth, 2002; Hoban, 2002). In this project, with teachers acting as participatory designers, their choices and contributions regarding the

Table 14.1 Sociohistories of participants

	Experience	Teaching focus	Expectation
Pritti	Secondary <5 years, good science degree	Students gain correct scientific knowledge and ability to justify the right explanation	Build on argumentation practice already strong in her school, learn new ideas
Emma	Secondary <5 years, good science degree	Students gain correct scientific knowledge, group discussion	Develop existing skills for managing group discussion
Mike	Secondary <5 years, good science degree	Students produce correct scientific explanations	Build on existing strategies for teaching science, new strategies for critical thinking
Tim	Secondary 11–15 years General science background	Students' independent learning and thinking	Gain ideas for more teaching strategies
Judy	Primary <5 years (second career) No science qualification	Less focus on correct scientific knowledge, more on justifying ideas	Ideas for extending learning, gain confidence, create teaching plans
Jane	Primary <5 years Science Degree Science coordinator in her school	Students gain correct scientific knowledge, but not always possible, focus on justification	More 'hands on' skills for group work and argumentation. Develop confidence to share knowledge with colleagues, raise profile of science in school
Kate	Primary 6–10 years Sport science and geography degree. (second career) School science leader	Less focused on correct scientific knowledge, more on justification	To improve understanding of strategies to teach science, share ideas with colleagues at school
Serina	Primary < 5 years No science qualification	Less focus on correct scientific knowledge, more on justifying ideas	Extend her ideas to help children work well in groups

website materials, together with their practices and reflections, enabled them to advance their learning of argumentation pedagogy according to how they 'made do'. In Chap. 13 we identified five key aspects of professional learning, which will be exemplified in this chapter:

- Viewing new pedagogies as something familiar to their teaching.
- Having support in analysing their new pedagogies.
- Collaborating (Bell & Gilbert, 1996).
- Interacting with tools or mediational means for internalisation as mastery – adopting what they see and/or appropriation – making it their own (Wertsch, 1998).
- Reflecting on learning and changing practice (Borko & Putnam, 1996; Zohar, 2009).

The video clips and some preliminary website tasks were presented to teachers in three workshops where they viewed the videos and provided insights into the kinds of website tasks that could work within the website for professional learning.

14.4.1 Viewing New Pedagogies as Something Familiar to Their Teaching

In Chap. 13 we pointed out that the teachers were keen to use the video clips to plan their own teaching; however, to explore their thoughts about how they viewed these pedagogies, we asked them to note down aspects they found useful and also concerns they had whilst watching video clips. The teachers' comments demonstrated how they noticed different aspects of practice to which they could relate. They commented how resources were introduced and used, how the teachers positioned themselves whilst questioning small groups, where teachers stood or sat in relation to students, how they directed questions, how much time they gave students to respond to questions and how ideas were gathered on the teaching white board. Some were concerned about how to include all their students whilst working with the envoy strategies. They also made suggestions on different ways the lessons could be ended. In summary, all the teachers focused on strategies that they felt were important to take note of in their own planning, and differences in these comments showed that individual sociohistories were guiding the process of noticing. These teacher commentaries were useful in contributing to the web design. Most teachers wanted to see the transcript of the lesson discourse so that they could go over what was said by teachers and students. Thus transcripts were included in the website next to video clips.

14.4.2 Having Support in Analysing Their New Pedagogies

The research team felt that the development of tasks would be helpful to support teachers' critical engagement with strategies on video and also their own implementation of new strategies. To prompt individual analysis of experiences, the flip camera recordings and feedback tasks in subsequent workshops were used, and these provided evidence of how teachers analysed their practice. It was clear that teachers needed guidance on what to focus on in their reflections, and the materiality of that guidance by way of written tasks, thus tasks to focus on analysing strategies, was also included as artefacts in the website, for example:

> Plan an argumentation activity for a class and identify how you will introduce and finish off the lesson as well as your role in facilitating your students' argumentation.
>
> Ask a colleague to observe you teach an argumentation lesson and ask him or her to write down the questions you used to facilitate your students argumentation? Reflect on how these could be improved.

Further on in the website where whole lesson plans are included and linked to video clips, teachers are asked to be analytical:

> Look back at one of the lesson outlines and read the commentary that accompanies the outline. Consider the teacher's intentions and the decisions they made in designing the lesson the way they did. Why do you think they made the decisions that they did? Were they good or bad decisions, why? If you were planning a similar activity, would you do it in the same way?

14.4.3 Collaborating

The work with teachers was designed to promote collaboration. In workshops, teachers were provided with group tasks and were encouraged to plan lessons together drawing on strategies and resources they noticed in the videos. The workshops also provided a forum for sharing experience and discussion. Teachers were also encouraged to collaborate with other colleagues once back in school. From their contributions, it was clear that collaboration was valued more by some than others and that encouragement in this aspect would be advantageous. Collaboration was also difficult between teachers who had different agendas, and who thus 'made-do' in different ways. For example, Kate and Jane (Table 14.2 below) were both primary teachers but had a different focus on how to activities; Mike and Tim worked in the same school but worked independently; and Judy and Serina also worked in the same school and planned everything together. A successful partnership developed between Pritti and Emma, who were from different schools and worked independently at first, but then more collaboratively as they gained confidence. In the light of this, teachers suggested online sharing activities could be useful in the website design.

Tasks that would encourage collaboration in future planning included:

> For a topic you will be teaching in the future, design a lesson using all of the ideas you have considered …. Share your ideas with colleagues and, as a team, consider how you will embed this into your existing planning for this topic.

14.4.4 Interacting with Tools or Mediational Means for Internalisation and Mastery

Teachers felt that access to the resources used by the teachers in the video lessons was essential for them to be able to see how they might adopt the argumentation strategies in their own practice. In the workshops, all these resources were made available to the participant teachers, for example, lesson plans written by the original teacher designers, evidence cards and concept cartoons used. Teachers' experiences in this regard were essential for the final section of the website, which focused on designing activities and creating lesson plans. This part of the website introduces a variety of different resources and activities that are linked to the videos on the

Table 14.2 Participants changes, collaborative working and reflections

	Changes in practice	Collaborative	Reflectivity and learning
Pritti	Tried new argumentation activities and strategies. Tentative at first but confidence grew to try different ideas	Nervous and non-collaborative in workshops initially, bonded with Emma and supported by collaboration at school	Very reflective. Internalisation as mastery and appropriation
Emma	Practice included new group work strategies and argumentation activities, transferred ideas to new contexts	Non-collaborative initially but bonded with Pritti in workshops and gained confidence to disseminate at school	Reflective. Internalisation as mastery and appropriation
Mike	Extended his use of existing strategies	Non-collaborative in school with Tim, some collaboration in workshops	Limited reflection. Internalisation as mastery, little appropriation
Tim	Tried a few new activities and strategies	Non-collaborative in school, limited in workshops	No evidence of reflection. Limited confidence with new ideas, little internalisation
Judy	Tried many group work strategies and transferred to different contexts, used argumentation activities to promote reasoning	Very collaborative with Serina (same school). Reticent at first in workshops, contributed more as confidence grew	Reflective. Internalisation as mastery and appropriation
Jane	Tried new group work strategies, transferred to other disciplines	Reported sharing with colleagues in school, potential collaboration with Kate but limited follow-through	Reflective in workshops. Gained confidence in using tools, internalisation as mastery, beginnings of appropriation
Kate	Tried simple group work strategies. Planned activity for argumentation, but focused on naming forces rather than using evidence	Willing to collaborate with Jane but had more content focus so collaboration limited, learnt from sharing ideas in the workshop	Reflective but in a superficial way. Used the new tools in her practice, little evidence of internalisation
Serina	Tried simple group work strategies. Developed questioning and prompting across different science contexts	Very collaborative with Judy. Contributed in workshops as confidence grew	Limited reflectivity. Limited evidence of internalisation

website where they can be seen being used by teachers and students; other examples of activities are also provided. The tasks in this section of the website focus on lesson features that support argumentation and groupwork and link to lesson plan outlines with accompanying commentary which reveals the rationale behind their design.

The website task for teachers to interact with encourages them to build on the ideas presented in this section of the website:

> Choose a lesson you have taught before and change the plan and resources to provide an opportunity for argumentation to take place. Consider: the activity, the group work strategy and how you will introduce, facilitate and finish off the lesson. Will you need to develop students' group work skills before the lesson?

14.4.5 Reflecting on Learning and Changing Practice

Reflecting on learning was a key element in the project, as teachers were encouraged to reflect using the flip camera recordings, when sharing their experiences in the workshops, and whilst writing individual commentaries in the workshops. The website was structured to encourage reflection in all sections as follow-up tasks were included after groupwork strategies. In the teacher's role sections, teachers were encouraged to try out strategies in practice and then reflect on the experience. In the final section on creating lessons, the observation task cited above was followed by a prompt to reflect:

> After the lesson, reflect with a colleague on what happened and how what you did could be improved.

14.5 Teacher Professional Learning Through Participatory Design

The teachers taking part in the website workshops were participatory designers as they analysed challenges that might be addressed as the different sections and foci of the website evolved. To determine how these teachers may have changed in their beliefs and practices during engagement with the workshops, data were collected from a range of sources, including simple questionnaires, flip camera recordings, workshop contributions and finally post workshop interviews. All these data were analysed in terms of:

1. New practices implemented as a result of video and workshop tasks.
2. Collaborative working.
3. Reflectivity.
4. Indicators of internalisation of argumentation pedagogy.

A full analysis of the outcomes of these data analysis is reported elsewhere (Simon and Davies in preparation). Table 2 provides a summary of this analysis for all eight participating teachers.

In terms of changes in practice, it can be seen that of the four secondary teachers, Pritti and Emma not only tried out new ideas more extensively but transferred ideas to different teaching contexts, unlike Mike and Tim for whom 'making-do' was restricted to extending existing strategies or trying out a few new ideas. Collaborative working, which has been shown to be important in bringing about real changes, was also different for these pairs; Pritti and Emma became more collaborative as time went on, unlike Mike and Tim.

Though relatively quiet in workshops, Pritti was highly reflective through her flip camera recordings, of which she made many, and in her interview. To supplement her own reflections, Pritti sought feedback from the class about how she organised activities. She considered carefully how the roles of the students reflected their abilities and confidence, and her reflective comments showed how she continued to learn about the efficacy of certain strategies for supporting low-ability students to help them engage in discussion, such as the use of prompt cards. Initially, Emma's reflections were on the composition of groups and how this worked rather than about her personal learning. Her reflective stance was stimulated greatly by watching the video clips, also hearing and discussing with others in the second workshop, and she became more overtly reflective of her practice. The material nature of the website components prompted her to 'notice' practices that she herself could undertake; such interaction with the website is unique and personal to each teacher. Personal development became more apparent as the workshops progressed, and Emma felt more confident and empowered as a result of changes in her practice and sharing outcomes with others. Emma became much more eager to accept ideas as the workshops progressed and also more eager to reflect on her own thinking about teaching and learning. Mike's reflections showed him to have valued the development of 'skills' and ideas for supporting the learning of science, but little reference was made to the role that argumentation has to play in student learning. For Mike, the position of the teacher was central with students, as he put it 'being trained' to understand science, an approach which shifted little throughout the project. Like Mike, Tim was reluctant to reflect on activities in any more than an organisational way in terms of what the students did, with limited reference to what was learnt. Having said that, he did report that, as the teacher, planning and using the activity had encouraged him to think about the types of questions he might ask and how to 'facilitate what the students were doing'.

Professional learning for these teachers through the lens of sociomateriality bricolage is therefore seen as a way in which their sociohistories influence their interactions with the video and other website components that results in a certain 'making-do' as they try out new ideas. The subsequent willingness by some teachers to engage in collaborative, reflective working with the website components shows how the sociomateriality of an interactive website can enhance professional learning for teachers. The need to scaffold these interactions through professional development programmes is apparent for teachers for whom collaboration and reflection comes less readily.

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Chapter 15
Learning Matter: The Force of Educational Technologies in Cultural Ecologies

Cathrine Hasse

New technologies are one of the most radical cultural influences that create change in people's lives. New technologies are changing habits, values, trade knowledge, and institutional life in general. Technologies, such as educational technologies, however, also reinvent, stabilize, and reinforce cultures in subtle and unpredictable ways. When the physicist and feminist Karen Barad says that "mattering is simultaneously a matter of substance and significance" (Barad, 2007, p. 3), she is challenging an instrumental view of educational technologies. Theories of new materialism open for us new insights into the performative processes of mattering matter in school ecologies, which forcefully evolve through various forms of frictions leading to expulsion as well as espousing. These dynamic and complex processes emerge analytically through a diffracted reading of anthropological theory, postphenomenology, feminist materialism, and cultural–historical activity theory. The theoretical lighthouses of new materialism all discard representationalism and instrumental and mechanistic matter. Instead they light up different areas of stabilization as well as transformation of materials in learning processes forming what I term "cultural ecologies" defined as "a practiced place teeming with vibrant and frictioned materials" (Hasse, 2014, p. 24). I begin with a story of how tablets became a major force changing the material constitution of Danish educational habitats. In 2011–2015 I was a member of a group of researchers that followed a process of transformation in a number of Danish primary schools in a project named *Technucation*. During this time we followed how tablets and interactive whiteboards began to replace books and blackboards, form new bodies and subjectivities, and simultaneously reinstated old learning theories.

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15.1 The Story of Agentic Tablets

Educational systems are in a process of economic and technological transformation. Many politicians desire to manage education and expect technologies to be helpful in guiding the efficient learning of children – without clearly defining what learning is. Instead they place their hopes in new kinds of material artifacts replacing older educational technologies, which through the use of algorithmic devices claim to improve and measure the quality of education. Giving all children the same electronic device, e.g., a tablet, makes it possible to work with the same software devices and from this communal platform follow each pupil's individual progression. The Technucation project visited 13 schools, most of which had purchased new technologies for educational purposes within the last 2 years. When we first arrived, these primary schools were physical environments with amalgamations of pupils, teachers, and rooms with chairs and blackboards, chalk, books, and papers. Between the years 2011 and 2013, many Danish municipalities bought tablets for all pupils and teachers, some schools removed the old blackboards and replaced them with interactive whiteboards, and some schools introduced both interactive whiteboards and tablets. The tablets were introduced as new invigorating tools for learning, expected to open up for innovative ways of teaching twenty-first century skills (see www.technucation.dk for more about the Technucation project and its findings).

In many Western institutions, there is a friction between teachers who prefer blackboards and chalk and managers and teachers who prefer to use interactive whiteboards, tablets, and cameras in the classroom. Educational technology can be broadly defined as "goal oriented problem-solving systems approach utilizing tools, techniques, theories, and methods from multiple knowledge domains, to: (1) design, develop, and evaluate, human and mechanical resources efficiently and effectively in order to facilitate and leverage all aspects of learning, and (2) guide change agency and transformation of educational systems and practices in order to contribute to influencing change in society" (Luppicini, 2005, p. 107). Educational technologies are in other words physical media designed to support teaching situations and learning processes. They are also commercial merchandise that becomes agents of change in education. The need for technology literacy among teachers and pupils derives from the fact that although new electronic educational technologies are often defined as the solution to learning problems in schools, many teachers lack skills in dealing with these new technologies, and managers increasingly perceive this as a problem. There are constantly new and commercial technologies introduced to the school market that demand training of the people who will use them. This makes it difficult to follow suit (Roblyer, 2005, p. 193) but also raises the question of how we are to understand technology as a cultural force transforming the identities of teachers and pupils as well as the ongoing learning in the cultural ecologies of schools.

The philosopher Albert Borgmann has stressed that on the one hand we can understand new technologies as hardware and software equipment produced by engineers, designers, and programmers but on the other hand these designed machines work as a cultural force that transform our social life (Borgmann, 2006, pp. 352–353). When we choose to replace familiar instruments, such as blackboards, with new ones, we can rarely predict their effect of teaching and learning. A good example of this is the friction between the intended Danish educational reform – and the introduction of tablets that unnoticed threatened to undermine the explicitly formulated political educational goals. In 2014, Denmark introduced a new school reform, which, among other things, had the stated aim of creating more physical movement into the school day including ensuring that children and secondary school pupils were moving more about in the school area. It was emphasized that movement and exercise should be one of the driving forces to create a new school environment. While the need for the use and understanding of IT technologies were also highlighted in the reform, educational technologies like tablets were seen as separate from the need for movement and exercise (Antorini, 2014; Danish Ministry of Education, 2013). Though many kinds of tablets were available, most tablets introduced to Danish schools in 2011–2013 were iPads (due to a number of Apple investments in Denmark). The iPad was perceived as an educational tool that created new innovative opportunities for learning if the teachers could understand how to use them (Grönlund & Genlott, 2013; Jahnke & Kumar, 2014) not least through the many available software programs for learning purchased in Apple's so-called App Store.

The project Technucation found that many teachers lacked technological awareness and skills in relation to the operation and evaluation of the new technologies (such as interactive whiteboards and tablets) and were confused by the technologies' impact on the relationships between teachers, pupils, management, and parents. Many teachers did not understand why these technologies were purchased by the municipality and introduced into the school. Fewer teachers reflected more generally about how these technologies evolved and profoundly changed existing professional disciplines. The Technucation project's research showed that there was a difference in how much teachers, educators, and children knew about the iPad as a tool in advance of its implementation. Many teachers expressed uncertainty facing even simple operations of the new device and formulated the following questions in our laboratories, "How do you turn on your iPad? How does it run on current? Should iPads replace textbooks? What is the difference between an iPad and a computer?" (Hasse & Brok, 2015).

In the existing school ecologies, teachers had developed habits of working with well-known devices and procedures connected to books and blackboards. iPads were plunged into these habitats overnight (in many places the iPads were delivered to all pupils and teachers on the same day) and stirred things up. In most places, they were introduced without any educational training course for teachers to make them aware of tablets possibilities and effective use. In many educational settings, management was surprised by the teachers' reluctance to invent new teaching practices with iPads. They had assumed that as educational technologies, the iPad was such an intuitive tool that they did not have to invest in massive learning experiences for teachers. Though some teachers voiced their discontent, others explained to the Technucation researchers that they were afraid of explicitly voicing their lack of confidence in the new teaching tools as they expected managers would find them stupid. Furthermore the new material artifacts disrupted the stabilized identities between teachers and learners in schools as many pupils showed more proficiency in handling the technical aspects of iPads than their teachers.

Tablets are platforms for a variety of applications and, as such, offer many new opportunities to rethink teaching. Because the technology is portable, it can challenge the stationary classroom and move it outside and around the countryside. But when teachers' learning with technology does not follow suit, because there is a focus on technology's imagined obvious benefits and not on the complex human–machine entangled relationship, many of these options were not exercised in practice. Furthermore, since there is no focus on the human–machine relationship, tablets are often allowed to be the controlling cultural force transforming cultural ecologies in unacknowledged ways. After the reform pupils were expected to move around more than before in and between classes. However teachers experienced that pupils instead of playing in the school yard simply disappeared. They found them hiding under staircases and behind shelters deeply engaged in playing games on their portable devices. As an agent of change, iPads opened new accesses to app-based games (downloaded from the iPad App Store), and these applications also took up a disproportionate amount of time in teaching situations as pupils engaged in gaming and messaging activities instead of the activities envisioned by the teacher. An iPad invited play-actions through its design – and both older pupils and younger pupils (age 7–15) responded by playing both in class hours and leisure time. After a while the teachers responded by introducing iPad restrictions. Several teachers and educators at the schools visited by the Technucation project began to demand that the newly purchased iPads were put away completely when classes were to begin, to ensure that they had the pupils' attention. When pupils were unruly, troubled teachers began to take recourse in old reward–punishment systems and promised pupils that if they would sit still and do their work quietly for 45 minutes, they would get 15 minutes' reward with iPad gaming. Rather than to be used for new and innovative pedagogical–didactic reasons, iPads were used as "sweets" or rewards following an (often unrecognized) otherwise long since left behaviorist learning theory.

In addition to the reinstating of what was thought to be outdated learning paradigms, it also appears as if iPads changed children's play patterns. Children previously played more physically in the school yard, but iPads in school created new bodily patterns of bending over screens engaging in virtual games. iPads can in this sense be said to work directly against the intention of the school reform, as more pupils could tell in interviews that they were playing less physically and moving less than before they got iPads (Schilhab & Hasse, 2015).

15.2 New Materialism and Techno-Cultures

In the Western world, we are increasingly living in an electronic- and algorithm-based techno-culture. In the vast majority work with technological tools, we are users of technology both in private life and at work, and many of us live by distributing technology to others through organized technology transfer. Our technology-mediated existence penetrates ever deeper into our social and physical being. Even so, the history of philosophy has been since Plato struggled with an adequate definition of technology, and that has proven to be a very comprehensive concept. "Technology" is often defined broadly as a goal-driven process and a product that aims to improve conditions and streamline processes. No technology can be said to be value-neutral (Franssen, Lokhorst, & Van de Poel, 2013). Underlining the product side of technologies, technologies could be said to be material artifacts created by humans for a purpose. The link between technological artifacts, their functions, and purposes are, however, rarely a one-lane highway. People will always seek to adapt technologies for their own purposes; however, both purposes and objects can change because technologies are not passive entities that mold to the people's needs but also influence and change those needs.

The blackboard and chalk in the school are technologies that can be used in a myriad of ways. The teacher can write a tribute to fascism, an algorithm, or share a poem written by Shelley on the blackboard surface. Even if the blackboard and white chalk were never passive entities, the process side of technology seems to be going toward a more black-boxed complexity with tablets and interactive whiteboards. These material artifacts are far from the passive impregnatable instruments perceived by school managers but highly agentive artifacts. When put to use in practice, data from the Technucation project show that the interactive whiteboard is constantly forcing the teacher to relate to the board's effects, such as placing the blue and red pen in the right color storage boxes on the interactive whiteboard. Failure to do so risks making a fool of a teacher when the teacher claims to want to write in red and the color appears as blue. The interactive whiteboard has many other functions (that the blackboard does not have) that call for an increased attention to the technicality of the board and its functions. The board "remembers" notes, different pupils, formerly used Internet pages, and their connection to a planned teaching event. Many teachers in Technucation tell us they feel pressured by the complex and demanding learning processes tied to the product, and many give up and use the board as they would use a blackboard. Technology has become products that are bought and sold without necessarily meeting a demand or meeting people's needs or taking account of frictioned complex human–machine entanglements.

This massively felt presence of new technologies may be what has made educational studies aware that new theories accounting for the force of materiality are needed.

The different lights cast by new feminist materialism, postphenomenology, and cultural historical theory each help with new diffracted insights into what we should pay attention to in the analysis of these new human–machine relationships. Diffraction creates patterns that illuminate boundaries as undetermined and shifting, when new light is cast over dark regions, and new shadows emerge in what otherwise appeared as bright (Barad, 2003, p. 803).

New materialism can be seen as a pragmatic turn away from the strong focus on linguistics termed *The Linguistic Turn* by Richard Rorty in 1967 (Rorty 1967). *The Linguistic Turn* with strong contributions from, e.g., Michel Foucault and Rorty himself, opened up new discussions of the relation between discourse, power, ideology, and language. The new focus on materials (always inherent also in the linguistic turn) brings to the forefront the agency of materials on the constitution of cultural ecologies. Though language is indeed powerful, both "positivism" and social constructionism share the desire to turn materiality into cultural representations.

One of the prominent figures in new feminist materialism, who most clearly criticized this linguistic emphasis, is the physicist and feminist Karen Barad. Barad's discussions highlight that "language has been granted too much power" in relation to matter:

> Language matters. Discourse matters. Culture matters. There is an important sense in which the only thing that does not seem to matter anymore is matter. (Barad, 2003, p. 801)

Positivism underlined the representation of nature in language. Social constructivism on the other hand emphasized the signification of representations and the power. With Barad's concept of "intra-action," she shifts the focus from the representationalism engaged in discussions of dichotomies such as nature versus culture and social constructions of culture toward a performative focus on matters of practice and activity.

Barad does not abandon a focus on discursive practices but reformulated how words do not represent preexisting things. Neither do words have the power alone to determine the real. She contests "the habits of mind" that have privileged representational power in settling ontologies. She suggests diffraction instead of the reflection of the nature-culture mirrors caught in an endlessly recursive mirroring of each other. What appears as bounded representations will in a diffracted approach illuminate the boundless and ongoing performative processes of boundary making. Barad challenges the taken-for-granted ontology that representations captured as words mediate between already existing individuals. In her performative approach, subjects and objects emerge within intra-actions – they do not preexist performativity.

15.3 Broken Glass

Returning to our example of the tablets in schools, it is clear that the discourse in the reform text formulated by the Danish Ministry of Education (Danish Ministry of Education, 2013) about a school reform that underlines movement and exercise is neither a mirror of the actual practice in schools nor do the reform words in themselves create new boundaries shaping practices of moving bodies in schools. Something that is not put in words in relation to movement and exercise seem to influence pupils' movement patterns much more than the reform's explicitly formulated discourse. This unnoticed "something" is the materials that have tied the pupil's bodies to be seated in hallways and under stairs bending over flat pieces of aluminum, wires, and glass. This presence of materials materialized as belonging to school ecologies through the boundaries set by the reform discourse (tablets as innovative educational technologies) exercise their own power in unexpected ways once implemented. The performed boundaries are not performed by words alone, or by materials alone, but by the performative practices in which intra-actions constantly form new subjects and objects.

However, other aspects of new materialism theories can deepen the analysis of how tablets create teachers' and pupils' bodies within new boundary-making practices in cultural ecologies. Empirical studies using Barad for analysis have run into problems or "dark areas," which may be illuminated through other new materialist readings.

The human body, for instance, seems to be a constantly reiterated boundary that needs more attention than granted in Barad's performative processes even when acknowledging and considering intra-activity.

A diffracted reading of a new feminist materialism with postphenomenology highlights bodies in technology (Ihde, 2002). Postphenomenologists like Don Ihde, Robert Rosenberger, and Peter-Paul Verbeek share the feminist starting point of dismantling representationalism and mechanistic understandings of matter. What mediates between humans and life worlds are not representations but agentic technologies. Even though postphenomenology acknowledges the agency of matter, it is a matter standing in a relationship with human bodies that come to the forefront of analysis.

Postphenomenology opens for an understanding of technology as a change agent of bodily engagements in cultural ecologies. Technology mediates our access to a world that is becoming anew, with our transformed bodies. Don Ihde discusses four ways the "I" (or the embodied being) and the surrounding world is mediated through technology. The first is an embodiment relation, where a body merges with the technology, so the surrounding world appears in new ways. When we get new glasses or hearing devices, we see and hear a lifeworld anew, just as the telescopes and ultrasound scanners moves otherwise invisible phenomena within bodily range. The second body–technology–world relationship is the "hermeneutic relation" where technology merges with an environment that next can be decoded by a human embodied being. An example here is the weather balloon that captures moisture in the air, converts it into algorithms, which can then be decoded by scientists. The third is an "alterity relation" where the human body is directly engaging with a responding technology, e.g., when a human is engaging in a dialogue with a robot or a virtual meeting. The last relation is a "background relation" where a surrounding world and a technology react on each other without a human body being involved, as when the thermostat on the heater aligns for temperature fluctuations (Ihde, 1990). Peter-Paul Verbeek has expanded Ihde's original discussion, under the influence of Bruno Latour, proposing what he calls cyborg intentionality in human–machine relationships (Verbeek, 2008). Contrary to Latour, Verbeek considers it erroneous to suggest that mediated agency is a property of the artifacts in themselves, not of the relationship between humans and artifacts (Verbeek, 2005). "Postphenomenology is the practical study of the relations between humans and technologies from which human subjectivities emerge, as well as meaningful worlds" (Rosenberger & Verbeek, 2015, p. 12).

Tablets and interactive whiteboards are both new kinds of alterity and hermeneutic relations. More complex than the blackboard, both new technologies open up and mediate the world in new ways. For instance, by giving direct access to virtual skype encounters with teachers and pupils all over world or direct contact with weather balloons dataset. This potential however depends on the teachers having learned to operate the new devices – it is the human-machine relations that make realities come about. Reality is not given in representations but in the relations humans have with it.

The implicit workings of educational technology both stabilize and disrupt established relations in seemingly unexpected ways. In one school we worked with in Technucation, we did a number of living laboratories with teachers who wanted to learn to deal with the felt force of the material agency of iPads. Together we created a new program for teaching involving alternating using books and iPads making use of the different material qualities. However in the new cultural ecology, the force of the iPads expelled books from the cultural ecology. When we presented the new strategy of interchanges between books and iPads, management informed us that this option was no longer possible. The material stability of iPads' glass covers, together with the usual comportment of school children, had created a new demand on the schools' budget. Repair of broken iPad screens were costly and were considered first priority. Subsequently, school management had delegated the next year's budget for books to the replacement of iPad glasses (in 2015 the municipality spent 800.000 Danish kroner on renewal of iPad screens). This decision was not formed by the iPads in themselves but in co-creation with a management that perceived books as "old" and iPads as "new." In all instances new boundaries are created in co-creation through human-machine relations. This however begs for a deeper understanding of why we find systematic patterns of preferences for the stabilization or destabilization of certain relations in cultural ecologies.

15.4 Cultural Conceptualization

Even if postphenomenology and new feminist materialism share a taste for dismantling mechanistic and representationalist views of matter, these philosophies have a hard time accounting for the culturally diverse patterns of processes of transformation in cultural practices. It is not enough to point attention to human–technology relations nor the agency of technology nor the claim that "human," "subjects," and tablets' are iteratively performed, when we cannot account for why some iterations and relations are preferred systematically over others.

In another part of the spectrum of the neo-materialist theory, we find a materialist rereading of the Vygotsky-inspired cultural historical learning theory, which unlike new feminist materialism places emphasis on human collective and culturally shaped learning processes through mediating artifacts. The approach is referred to as both "cultural–historical theory" and "cultural–historical activity theory," depending on which direction one follows. Both focus on relations between human learning processes and the surrounding mediating artifacts. Barad's intra-agential framework admittedly goes further than the Vygotskyan in dissolving the idea of a separately bounded subject–object interaction as she replaces these fixed boundaries with agential entanglements in which human and artifacts intra-act constantly shifting boundaries. And postphenomenology has a better understanding of the human body in human-technology mediations. However the Vygotskyan framework has a better grip on practices as cultural and collective stabilizations. The nature-culture dichotomy criticized by Bard is in some interpretations of the Vygotskyan framework transformed into a culture-culture diversity tied to differences in performative practical activity. Representations are in this line of thinking, as in Barad, no less material than the things they purport to represent and tied to local cultural agency (Cole, 1996, 117). There is an attention to psychological (rather than "cognitive") processes that are shaped with material artifacts: human thought, emotion, and attention. Everyday learning processes tied to concept formation connect materiality and sociality in ways that transform subjects, relationships, and bodily movements as well as material boundaries in practiced places (Hasse, 2014).

Humans are generally considered preexisting entities moving about in material worlds and sometimes in a collectively shared cultural consciousness. Materials are both the physical representations (e.g., war memorials) and words that act as material anchors for the constantly transforming processes of concept formation. The new material reading of Vygotsky makes it clear that cultural historical theory was never about representationalism, but about how we ascribe meaning to the world (Derry, 2013). The practices, which remain somewhat shadowed in postphenomenology and in Barad's work, are here tied to learning the work from the outside into persons through the formation of concepts that form new and shifting meaningful boundaries anchored in materials like words. Though cultural historical theory too easily takes "the human" for granted, it is a human engaged in cultural practices that are both normative (and thus have directive force) and diverse (in so far these directive forces differ) in cultural ecologies. Though cultural historical theory does not operate with iterative object-subject boundary making intra-acted within phenomena, the analytical approach highlights a diversity in the perception of materials tied to more or less collectively practice-formed complex networks of synthesized normative connections and relations. Thinking in concepts is not abstractly removed from reality but rather anchored in reality:

> Only when we recognise the thing in all its connections and relations, only when this diversity is synthesised in a word, in an integral image through a multitude of determinations, do we develop a concept. According to the teaching of dialectical logic, a concept includes not only the general, but also the individual and particular. (Vygotsky, 1998, p. 53)

Adding to the Vygotskyan theory of concept formation, we can from a cultural perspective see these processes of synthesization not just as culturally normative but as culturally diverse processes of normative connections. Going back to Barad, we may now realize that boundaries have normative histories, even if we accept the situatedness of practices and find the intra-action a nice step away from representationalism. The iterative processes of "intra-actions" are not formed in a vacuum but could be seen as formed in a materialized collective consciousness.

It is not accidental that tablets and interactive whiteboards, despite material and discursive diversity, move with the same culturally directed force tied to the conceptualization of new innovative educational technologies overruling both school reforms and individual goals in school ecologies. This is not a discourse formulated as explicitly as the school reform. It is rather bits and pieces found here and there: material words, artifacts, and subjects which are systematically and over time included or excluded in school ecologies.

Taking matter seriously (Barad, 2003) does not imply a direct correlation between the emergence of iPad and the disappearance of books in educational setting; only that in a cultural ecology, some materials at certain times exert more power over human than other material. The entangled connection between iPad screens and books involved many other entangled entities including discourses of tablets as “innovative learning tools,” inviting candy glimmering software application, children playing with iPads instead of footballs, teachers lacking technical skills, and the children’s evolved embodied iPad skills. In the school ecologies, we furthermore found books side by side with iPads, so even if budgets prioritized iPad screens, books were still around. Even so, it seems we find a systematic pattern of replacing books with iPads and blackboards with interactive whiteboards even if those who are going to use them sometimes object and even if these technologies (contrary to the official discourse) reinstate old learning paradigms. It is not old versus new (Selwyn, 2011) but a particular lack of understanding of how the old (e.g., learning paradigms) is entangled with the new. Humans learn on an everyday basis either to leave or to cope with the new materials spilled out in the environment as a materialized consciousness following the materialized direction of how school ecologies evolve.

Cultural historical theory notes that the breakdown and renewal of boundaries is an ongoing but never accidental process in cultural ecologies. New practices and materials are historically developed through reworking of older materialized collective consciousness. When materials are changed, our anchors for thinking are transformed as well. However the “old” may well emerge in new ways as transformed mattering matter. The presence of iPads is reinforced because they have the power to expel educational technologies such as books. The presences of old (historically speaking to-be-replaced) technologies create the possibility for new boundaries between new and old subjects and objects. New educational tools create new both “innovative” and “unskilled” teachers and “new creative” pupils (and interactive whiteboards can expel blackboards and old-fashioned teachers using them for the same reason) yet also reinstate “old” learning paradigms without any apparent explicated wish to do so.

Through learning in material ecologies, we over time come to expect and take for granted the presence of what once we called “new” technologies – and that now entangle “old” and “new” practices in reiterated intra-agentic ways. Putting materials to the forefront creates an awareness of the agentic force of materials embedded in a cultural historical consciousness which regardless of educational discourse and individual desires moves history in the direction of more electronic algorithm and traditional learning paradigm-based educational technologies while expelling former types of educational technologies such as blackboards and books from the cultural ecologies of schools.

15.5 Conclusion

Culture, as thinking and materials, matters when educational technologies are transforming practices of education. Cultural ecologies always allow for some material presences while excluding others. The new demanding technologies are a massive force in the daily lives of schools that often overrule any explicitly enunciated school discourse. In brief “digital technology is not bringing about the changes and transformations that many people would like to believe” (Selwyn, 2011, p. 716). However, we are in need of better theoretical frameworks to understand why this is so.

The linguistic turn that has long dominated the social and the educational sciences have been challenged by theories of new materialism. Those mentioned in my diffracted readings could have been supplemented with many more that all share a new concern for our world as a material yet not mechanistic world – and new perceptions of humans as less individualized, more collective and more material in our embodied entanglements with living and moving materials. All of these new theoretical perspectives refer to the situated practices of research. Though new feminist materialism and postphenomenology discard representationalism and emphasize bodies and boundaries and cultural historical theory overlooks bodies and boundary making but highlights collective historically materialized matter, they together cast shadows and light over our school experiences.

What matters to me here are theories that help me understand the force of iPad in our empirical studies of schools in Denmark. I place these studies in front and find variation patterns across the agency of teachers, pupils’ management, tablets and whiteboards, books, and blackboards. Tablets do not just change human-technology relations in schools but also how we think about educational technologies spilled out as materialized collective consciousness. This is how they push their transformative power through all kinds of human enunciations of the need for books and exercise. Their force is historical and political as well. They become integrated in the practices and bodies they perform with, yet performativity is not without historical underlying desires flowing through bodies in cultural ecologies making some iterations more likely than others. Cultural ecologies as the frame of analysis informed by such theoretical underpinnings serve the twofold purpose of making us aware that iterative processes are not just tied to materials but to historical processes and that discourse and materials may align or be expelled in different ways in culturally diverse settings. New products may expel other products as well as discourses and theories through linguistic and material performances synthesized in concepts that connect what is seemingly separate (broken glass, learning theory, and iPads as innovative). Together these material processes of inclusion and expulsion may be seen as what create the cultural futures of educational ecologies beyond discourse, representationalism, and intentionality.

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Part V
Ending Matters

Chapter 16
Communicating Through Silence: Examining the Unspoken, the Unsaid, and the "Not Done" in Science Education

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16.1 Role of Silence in Feminist Research

Most science education research privileges the verbal and written production of knowledge. That knowledge may focus on which pedagogical practices are effective to promote students' science learning, their positive attitudes toward science, or students' science conceptions. Data can be collected through surveys, interviews, video and audio recordings of classes, cogenerative dialogues, student work, teachers' plans, and reflection and comments on what it means to teach and learn science. But that research rarely examines the silences that exist in the data collected, the unasked questions, or the informants who chose not to participate. Moreover, when examining students' science learning, teachers' pedagogical practices, or the context of learning science, researchers may privilege different types of knowledge, such as western science over indigenous science knowledge. There remains a strong ethos that science is value-free and thus the sociocultural context does not influence the teaching and learning of science. In particular, categories such as gender, race, socioeconomic status, religion, or first language and how these contribute to learning experiences and one's interpretation of those experiences do not contribute to knowledge production in science teaching and learning.

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Feminist research methodologies focus on women's experiences and are concerned with ethical questions that guide research practices. Feminist research problematizes face-to-face interviews and other interactions between researchers and the researched focusing on the power imbalance between participants (Oakley, 1981). Christina Scharff (2010) examines researcher silences and discusses the implications for research when participants chose not to speak. For example, researchers can enact silences when they do not completely disclose all aspects of a study to the participants. A second silence can occur when a researcher acknowledges that asking questions about specific theoretical constructs or ideals (e.g., what is feminism?) may place the participants at a disadvantage if they do not know what the word or terms mean, raising the questions as to whether the researcher should move into "informant/lecturer" mode and provide the information to the participant.

Interviews typically assume that by giving participants the opportunity to voice their perspectives that this event "present(s) the truth and reflects the meaning of an experience," as Lisa Mazzei and Alecia Jackson write (2009, p. 4). While using what is defined as an authentic approach to research/evaluation that highlights the importance of voice, one might infer that researchers using this approach view silence as a deficit (Guba & Lincoln, 1989). Moreover, research methods such as interviews, cogenerative dialogues, and/or reflections are based on the assumption that voice is important. While researchers have power in framing, conducting, and communicating a study, participants' power is through various avenues, such as declining to participate in the research project, denying researcher's access to information, providing false information, or refusing to answer questions (Scharff, 2010). Scharff (2010) suggests that paying attention to the silences can increase our understanding of the extent to which "differences" impacted the research process or, in Baradian terms, examining whether those differences matter. For example, researchers could examine whether participants answer questions or are silent about specific questions, and if so, which questions? What are the reasons for that silence? A poorly worded question? A question on topics about which the informant has little or no knowledge? Or could the informant feel unsafe, threatened, or nervous in offering an answer to the question?

Thirdly, silence within the process can occur when a researcher chooses not to challenge participants' comments or perspectives, for example, when a participant makes racist or sexist statements. Fourthly, participants can silence researchers through their body language (e.g., looking away), expression of boredom with a particular topic by shrugging their shoulders, refusing to answer, or providing monosyllabic answers. These particular practices could suggest to researchers the need to examine the questions being posed and that possibly the material-discursive practices being produced.

16.2 Silences in Science Education

In the following sections, we introduce several concepts from Barad's theoretical framework, namely, diffraction, agential cuts, material-discursive practices, apparatus, phenomena, and spacetimemattering, to further explore silence and discuss its implication for science education research. We discuss how participants' and researchers' silence could impact research, and finally the silence from science education research on how matter and materiality influence the production of knowledge through the role of the body and how instruments can influence research.

16.2.1 Baradian Theoretical Constructs

> Diffraction is not about any difference but about which differences matter. (Barad, 2007, p. 378)

> intra-actions enact agential cuts, which do not produce absolute separations, but rather cut together-apart (one move). Diffraction is not a set pattern, but rather an iterative (re)configuring of patterns of differentiating-entangling. As such, there is no moving beyond, no leaving the 'old' behind. There is no absolute boundary between here-now and there-then. There is nothing that is new; there is nothing that is not new. (Barad, 2014, p. 168)

Barad's (2007) theory of agential realism challenged "classic" dichotomies, such as nature/culture and subject/object, to propose that these entities are not independent but come into being through their entangled intra-action with each other. These intra-actions produce material-discursive practices. Matter has agency. Building upon arguments first posed by Haraway, Barad notes that diffraction is "marked by patterns of difference" (p. 71) and examines the relational and notes its effects. In the following sections, we consider how silence may be a criteria for an agential cut and whether the differences that are generated through those cuts matter.

16.3 Participants Being Silenced

What are the different contexts for when and why participants may be silent? For example, participants may practice silence if they do not understand a culture or as a dichotomy with discourse. Alternatively, participants may lack the agency to challenge and change the power structures that are operating within the research context. Silence can also be an agentic act. Participants may understand the culture and its practices and recognize the implications if they engage with the culture and thus choose silence. In this discussion, we show how silence does not exist on a dichotomy with noise.

16.3.1 Silence Because of Not Recognizing Something as a Cultural Trait or a Dichotomy with Speech/Discourse

In a study with science majors, all of the interviewed women addressed the corresponding question about being a woman in physics. But some male participants in a study about the culture of physics were effectively silenced when the interviewer asked them about their experience of being a man in the physics world.

I: How do you experience being a man in the physics world?
Tor: [long silence] What do you mean?
I: It's a question I… Is it something you've reflected upon?
Tor: Being a man in a physics world?
I: Yes
Tor: … Well, obviously, as most physicists are men, it fits."
(Graduate physics student)

This silence may be interpreted as Tor never having encountered the idea that masculinity may be considered a cultural trait within this particular context; constructions of masculinity are not present within his discursive understanding of physics. This is a silence that is not due to a lack of men/masculinity in physics but the opposite rather; the norm of men/masculinity in physics is so pervasive that it has become invisible, rendering the male physics students unable to linguistically address the interviewer's questions. In this context, Tor was rendered silent. Yet, his silence can offer insights into how participants have different perspectives on the culture of physics.

16.3.2 Silence Because of Understanding Culture, Being Silenced Because of Power Differentials, and Participants' Lack of Agency Prevent Engagement with Power Structures

Science can silence others because its participants do not problematize the practices nor examine how the culture is exclusionary and foreign and/or unwelcoming to others who are not "seen/viewed" as a scientist. As a discipline being unaware or blind to key issues, Barad (2007) noted science studies scholars were silent on "gender-in-the-making" (p. 82) with technoscientific practices. Teachers can also silence students through their practices. For example, a preservice teacher recalled her school science experiences:

> The teacher put his lecture in Natural Geography at a far too high level which made it difficult for us, the students. The teacher continued at this same level throughout the lecture. No one stopped him, although there were many opportunities to do so, for us students, for he often asked the question "Do you follow?" Afterwards, when we talked about this a lot of students said that the reason for why no one had answered *no* to this question was because you did not want to feel stupid. (Female preservice teacher)

While this story tells of a teacher's practice silencing students, the power structures in the class operated such that students were uncomfortable to voice their lack of understanding about the lesson. The students could recognize that the teacher presented the material at a level they could not understand. Yet, even when asked, students felt powerless to voice their lack of knowledge. The fear of not "wanting to feel stupid" rendered the students silent. Alternatively, the teacher may have assumed that the learners' silence was an indication they understand the concepts and had no questions.

In another example, teenage culture combined with science culture silenced a female preservice teacher about her aptitude and ability in science:

> [Science] was very easy for me [in school], as in chemistry and math and such. But that was nothing you would admit in school. Instead you complained about how difficult it was, even though it wasn't. For that was how the culture was. (Female preservice teacher)

Despite increasing participation of girls and women in science, the subject retains a masculine image, which only the "smartest" students can succeed in (Scantlebury, 2014). And recent studies show that this challenge becomes exacerbated when other social categories such as race and class are considered. Science remains the purview of the white, middle-class male (Archer, et al., 2012).

16.4 Researchers Being Silenced

Researchers may enact silence to protect students/informants' perspectives (Nordstrom, 2015). For example, students may withhold their permission for researchers to share their perspectives about the teaching they have experienced with the instructor. The students may not feel safe and think there would be repercussions from faculty if the critique of science courses and the associated teaching practices were shared.

Researchers can be silenced if participants/informants do not understand the researchers' interview questions and thus do not respond. For example, when researchers ask questions about specific theoretical constructs or ideas that are unknown to participants (e.g., what is feminism?). Does the researcher become an "informant/lecturer" and provide a description of feminism? Or do they remain silent?

Another example of silenced researchers can occur when a participant provides a perspective, opinion, or view that may challenge the researchers' values. For example, in the following quote, the informant shares essentialist views about his stereotypic gender roles:

> S: Well I have three children, so there is a vast difference between me and my wife for example. She in all cases, all senses is a better mother. She wins on that. Even though I… even though I were the best father in the world, I would always loose. Cause… nature is in such a way. At least in her case.

A feminist researcher may be placed in an ethical dilemma; the context and content of the participant's comment could be accepted without challenge or further inquiry. For example, the researcher may disagree with the informant's perspective that mothers are by "nature" better carers for children than fathers, but the interview context is not the place to challenge this perspective, and thus the researcher is silenced.

16.5 Silence from the Research Field/Discipline of Science Education

Science education research is dominated by a focus on the psychological, in particular, using dominant learning theories to identify and understand learners' ability (or failure) to understand science concepts (Roth, 2010). But Wolff-Michael Roth (2010) has problematized conceptual change research in science education because the role of the researcher in the process is not acknowledged and often the researcher's interpretation of what an informant has said remains uncritiqued. Furthermore, this research agenda ignores other facets that contribute to one's learning and understanding, e.g., the role of emotion. Although not relating his observations to Baradian concepts such as diffraction and agential cuts and differences that matter, Roth (2010) clearly shows that failing to clarify an informant's intentional language, ignoring the emotional, and decoupling the informant from the social context are examples of agential cuts. The question Barad poses is do these cuts matter? The various chapters in Roth's (2010) edited book argue that by ignoring sociocultural science education research, researchers are limiting the knowledge production about the teaching and learning of science. Tobin (2010) also noted how research in science education focused on whether students learned and understood science concepts because ensuring that students learned science was valued by scientists, but how they learned science, why some students did not engage with science, or the different patterns of students engagement with science remain secondary.

Kathryn Scantlebury and Sonya Martin (2010) problematized science education research in its lack of addressing this inequity, especially with the field's focus on conceptual change research that often has an interviewer questioning a participant on her/his understanding of a science concept. The role of the researcher and the disparity that emerges between knowledge of participant and that of the interviewer are not considered in this research approach. Further, they note that studies conducted in areas within science education research, for example, pedagogical content knowledge, never considered how gender and other social categories may provide different insights into the field. In this regard, we would argue that the agential cuts in science education research that disregard gender are a difference that matters and the silence this generates is an understudied area.

16.5.1 Ignoring Bodies, Ignoring the Material

Another consideration regarding a silent area of research in science education is how the researcher's bodies are engaged in knowledge production and the recognition that data is not passive. Recent feminist critiques have considered the role of the body and materiality in knowledge production (Haraway, 1991). And Barad's theory clearly articulates that discourses and materiality (i.e., body) are not independent but intra-act to produce unique material-discursive practices:

> Neither discursive practices nor material phenomena are ontologically or epistemologically prior. Neither can be explained in terms of the other. Neither is reducible to the other. Neither has privileged status in determining the other. Neither is articulated or articulable in the absence of the other; matter and meaning are mutually articulated. (Barad, 2007, p. 152)

Thus, the discursive is not independent of matter; researchers in analyzing discourse need to examine how the body and other matter are entangled in producing material-discursive practices and the resultant new knowledge. The culture of science and its ensuring practices remain white, masculine, and western. Thus, the gender of participants and interviewers, along with race, ethnicity, and other social categories, plays a role in the knowledge that is produced through interviews focused on students describing their "knowledge" about scientific concepts.

The examination of silences is a reflexive practice, taken from a stance of power and privilege (Ahmed, 2010). Barad (2007) identified the limitations of reflection as a metaphor because it implies that a researcher reflects what is present rather than providing insights; she proposes that:

> diffraction involves reading insights through one another in ways that help illuminate differences as they emerge: how different differences get made, what gets excluded, and how these exclusions matter. (Barad, 2007, p. 30)

Moreover, Barad's theoretical framework explicitly challenges the notion of an "independent researcher," emphasizing that diffraction "not only brings the reality of entanglements to light, it is itself an entangled phenomena" (p. 73). How might this position impact research in science education? For example, if an interviewer assumes that students who are not "typically viewed" as scientists are silent when asked to explain a concept, they may assume the students' silence is because they do not understand the concept, whereas it may be that the students are exercising their power through silence.

Thus, for much of the research conducted in science education, matter has been considered "silent"; its role, its agency is not taken into account. For example, researchers rarely describe the space and matter involved with the interview. Were the interviews conducted in comfortable chairs, with an informal setting, or with chairs situated across from each other with other material objects also as part of the process? Was there an audio recorder? Paper with a list of questions which provided an interview protocol? Or did the interviewer use other devices such as an iPad or a computer? How different is the data collected and knowledge produced if interviews are conducted using video recorders? What entanglements occur with these instruments/apparatus?

Susan Nordstrom (2015) argues that "recording devices used in qualitative research are a taken-for-granted material-discursive practice in which the recording devices are part of and produce objectivist and realist concepts (even as some scholars deconstruct those concepts)" (p. 2). The recording devices are "not mere observing instruments but boundary-drawing practices – specific material (re) configurings of the world – which came to matter" (Barad, 2007, p. 140). She notes four irruptions when using recording devices in her research study: (1) when moving the recording device to minimize its negative effect on a participant, the poor quality of the conversation between the participants in the discussion meant that the researcher did not have a "truthful and accurate" recording of the discourse; (2) when an informant requested the interviewer to turn off the recording device as she was going to share a personal information she did not want to be included in the research study, in a diffracted reading of the data, the researcher noted that while she had not shared the informants information, "the conversation – the words, the photographs and other objects, and the tears – linger in my body to this day" (p. 5). (3) an enthusiastic informant disrupted the usual pattern of establishing the protocol for recording data – she began talking before the researcher turned on the device, generating new and different agential cuts. And (4) irruption occurred when an informant provided material objects and artifacts before the interview and participated and provided extensive answers to the interview questions, thus producing an overwhelming amount of data for the researcher.

The researcher is part of, and emerges from, the intra-action with the world, thus never being apart from the research process, the data collection, and the entanglement with matter – i.e., other humans, recording devices, and tools along with the physical space and time used in the process.

Further entanglements occur when other matter comes into being, for example, transcripts of interviews and subsequent reports of analysis conducted. The undiscovered knowledge located in countless hours of interviews, transcriptions, and video recording have the potential to emerge forthwith.

Researchers constantly make agential cuts when framing, conducting, and interpreting their research. Are there theoretical ideas of what is missed or not understood when researchers make an agential cut to analyze spoken words? Diffractive reading considers how one looks at a text, how one makes decisions about texts that are included or excluded, and, more importantly, what differences in the "results" are made by these choices and the transformations that are the outcomes of the choices. What knowledge is ignored when researchers fail to document the agential cuts that are made in their the process and examine what is knowledge may be lost when their ideas are silenced.

Possibly the silences that are within science education research which are outcomes of agential cuts may not be "differences that matter," but heretofore, we have never considered those silences, so how can we know? Have we tried to understand the silences and examine how they contribute to material-discursive practices and are a part of the phenomena? What influence do silences have on the "world that comes to matter" (Barad, 2007, p. 380). Thus, when silence is ignored or never understood, it produces a view of the world that is different from if it was considered, i.e., how does the world come to matter when a person's silence is taken seriously by researchers. These researchers' agential cuts produce differences, with the potential of differences that matter.

16.5.2 Implications

> Knowing requires differential accountability to what matters and is excluded from mattering. (Barad, 2007, p. 380)

What are the implications for science education researchers for including an examination of silence as part of their practice? How could researchers approach this challenge? Barad's (2007) emphasis on diffraction rather than reflection is important because the process of reflection produces "mirroring and sameness" (p. 71), while the phenomena of diffraction, which are produced when waves move through openings or around obstructions, produce difference. Science education researchers could engage posthumanistic research approaches by using *data into theory into data* to examine the silences (Taylor & Hughes, 2016), identifying the human and nonhuman entanglements in their research and the impact that this acknowledgment has on data collection, analysis, and ethical considerations. Using Barad's concept of diffraction (as opposed to reflection), science education researchers could reexamine data and identify if there are areas of silence in interview data, video records, and other materials and artifacts (See also Areljung Chap. 8). And if silences are identified, what explanations could be offered for the silences, and are there differences in the silences that matter? In qualitative research, coding techniques may be based on what is previously known by the researched and the researcher, which may result in other or new knowledge being ignored or excluded and silenced.

Science education researchers could reexamine the knowledge produced through the use of recording devices such as video cameras, smartphones, and other digital technologies in collecting data. And several chapters in this book, such as Cathrine Hasse's on the use of iPad and Shirley Simon and Paul Davis' work on using websites for teachers' professional development, provide examples where heretofore science education research has "been silent" on the entanglement between humans and the nonhuman.

Further, another area for examination is the silence researchers may experience when conducting their studies. When are researchers silenced by participants? Or effectively silenced by funding agencies whose policies may dictate fiscal support for research? The authority, role, and power of journal editors could also enforce "silence" from researchers, as editors are key personnel in deciding what research is published.

The unspoken, the unsaid, and the silent can refer to the research questions asked, the data collected, and how that data is collected. A deeper understanding of science teaching and learning may result if science education researchers begin to take matter seriously and explore the silences.

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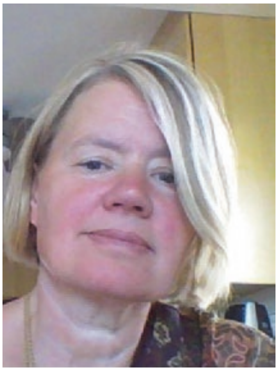

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Chapter 17
Conclusion: Telling Us What to Do. Moving on in a Material World

Catherine Milne and Kathryn Scantlebury

The chapters in this edited book explored the role of material culture in research while also challenging the reader to ask themselves how the material may have been written out of the accounts they have written and whether material culture deserves more attention from disciplines, like science education, than is currently the case. From constructionism and epistemic things to feminist new materialisms-post-humanism, authors of chapters in this book used various perspectives to theorize their adventures with the material. In order to address the question of how can we take matter seriously, the authors explored specific practices that serve to entangle humans and matter in ways that support knowledge production. However, if we have learned anything through the writing of this book, it may be that, like all dualisms, the material and the social are entangled and culture emerges from this entanglement. Barad also challenges the coherent narratives that are used to tell the neoliberal story of scientific progress as the steady refinement of scientific knowledge over time, discoveries that led humans out of the morass, and "the swamp of ignorance and uncertainty to the bedrock of solid and certain knowledge" (Barad, 2010, p. 244). She notes that the history that gets told is really a temporary sedimentation based on the cuts made to establish some form of causation. The lack of absolute boundaries means that what we present as the present is a creation, as is the past and the future. One might expect that there remain specters or ghosts that haunt the constructed phenomena that might become solid if the cuts are made differently (see Barad, 2010, 2014). For us, applying Barad's notion of hauntology means that neither the social (linguistic, immaterial) nor the material (bodies, matter) is privileged,

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opening us to an onto-epistemology in which both the social and the material are non-anthropocentric and non-linguistist (Dolphijn & van der Tuin, 2012). We recognize and acknowledge the challenges associated with questioning the dualisms that populate thinking and doing. For example, it makes no sense to separate the material from the social when considering culture since, as we have argued, any consideration requires both. If we were to adopt one of a dualism to the exclusion of the other, we would be haunted by the possibilities we have missed. However, existing educational worldviews tend to privilege one dualism, the social with its focus on text and language, so our chapters emphasize the role of matter in both ontology and epistemology because the material has been ignored for so long.

17.1 Doing Research

Barad's theorizing materialized through her exploration of the history of quantum theory and the philosophy of Niels Bohr, but her arguments also raise questions for research more generally. In educational research, one is often called upon to provide evidence for the existence of something. In order to do that, we may seek to provide measurements, but for such measurements, we need an apparatus that allows us to engage in the practice of measurement. Barad (2012) argues that such practices are both revelatory and performative. They are performative because they serve to constitute, and are constitutive of, what is actually being measured and it is through this process that they become revelatory. Thus, measuring, like other practices, is intra-active, that is, "agencies of observation" that cannot be separated from what is observed. They bring into being the very phenomena they seek to observe. Our experience with Barad's philosophy highlights how ingrained the Newtonian worldview is in much of science and science education and the difficulties researchers face seeking to break free from its grasp. If we accept that practices, like measurement or asking questions or telling stories, play a constitutive role, then how exploration is conducted also matters. There are no pre-existing phenomena to be measured, which also have implications for rejecting representationalism (discussed below). Rather, through intra-actions involving the living and the nonliving (matter), through "material-discursive practices" (Barad, 2012, p. 7), like measuring and observation, phenomena are materialized through the cuts applied in intra-actions that produce specific phenomena including constructs such as subject and object. Until intra-actions take place, reality is indeterminate, but even with intra-actions, it is only ever partially resolved. Such reasoning suggests that even the material-discursive practice of questioning is emergent and entangled with the context or the spacetime. Our engagement with research means that we are actively engaged in "sedimenting out the world in certain kinds of ways and not others. The past and the present and the future are always being reworked. And so that tells us that the phenomena are diffracted and temporally and spatially distributed across multiple times and spaces, and that our responsibility to questions of social justice have to be thought about in terms of a different kind of causality" (Barad, 2010, p. 69). Thus, research always has ethical and social justice dimensions that need to be acknowledged in any research in which we engage. Each of the chapters in this book takes a position in certain kinds of ways, so that the research and theorizing reported sediment out the world or reduce the degrees of freedom to present a specific sediment based on the cuts made by researchers. These perspectives imply that the phenomena of the research question emerge from the cuts made by researchers intra-acting with apparatus of various forms suggesting the importance of entanglement for initiating this practice.

17.2 Haunting History

In Karen Barad's hauntology (2010), her argument for the liberation we may feel if we are less concerned with "continuity" challenges the assumptions of classical ontology in which objects are distinct, space is a container of specific dimensions, and time is a coherent linear sequence of moments. She uses the example of what it would be like if we walked in the footsteps of electrons experiencing the world as spacetime (re)configurings. Such a challenge leads us to appreciate the possible degrees of freedom associated with the telling of history and the sedimentation that occurs when one history is told. Different choices or different agential cuts will produce different histories because both history and the future are entangled in our present. For example, many of the discovery science stories that are told, based on the cuts made, often privilege one white man as the hero, while the instrument that helped them to make their discoveries is treated as dumb (see Hooke below) and without agency. Exploring the question of how and which cuts are made creates for us also a rationale for strategies such as counter-narratives and culturally relevant pedagogy beyond what Barad (2010) describes as "flat-footed analogies" (p. 240). So we challenge you, as we challenge ourselves, to ask what counter-narrative(s) could be told since Barad assures us that they are without number. The narrative(s) that is told and is accepted becomes part of social-material culture becoming part of an ontology. Counter-narratives also constitute essential elements of culturally relevant pedagogy (Ladson-Billings, 1995). The relationship between hauntology and culturally relevant pedagogy seems to offer a further rich area of study suggested through the scholarship presented by the authors of these book chapters.

Our musings about hauntology, history, and counter-narratives illustrate the need to continue to work with other educators to push for events and reckonings that acknowledge the role of matter and materiality in the teaching and learning of science. This is an underdeveloped area of knowledge production in science education. Rarely, in science education is the material world problematized, and instruments are often treated as "dumb tools" (Milne, in press). Instruments/tools were valued because they extended the capacity of human senses to observe the world, but the tools did not intra-act to change the observed phenomenon (see Hooke, 1665). Numerous authors challenged the neoliberal humanist position that matter is passive (e.g., see Milne, 2018). Following Barad (2007) as educators, we understand that we have a responsibility to give matter its due as an active participant in the world.

17.3 Representationalism and Phenomena

Barad (2007) argues that one strategy humans used to internalize the known was to develop a theory of representationalism that gave power to thinking tools to mirror or reflect in the mind pre-existing phenomena. Representationalism is based on an acceptance of the ontological basis of things and consequently of subjects and objects. Representationalism makes an ontological separation between representations and "the entities to be represented" (Barad, 2008, p. 123). This means that knowledge is constructed as representations of the material world and these representations are accepted as that which is known and the knower as someone who does the representing. With representationalism, the real world exists separately from the knower. The knower is recognized as the subject, with the real world the object of study, and what is known existing in the mind of the knower. As a consequence of this structure, representations mediate the ontological gap between independent entities of the knower and the known. As Barad (2008) notes, with this mediating role come questions of how accurately a representation maps onto the reality of an entity and how accurately language represents this referent. In science, representational forms, such as theoretical concepts, graphs, particle tracks, and photographs, are accepted as providing access to the material world (Barad, 2008) regardless of whether the perspective is one of realism or subjectivism/constructivism and representationalism has a commonsense appeal, which permeates science education. Indeed, the development of theories, such as atomic theory, which presented matter as composed of atoms, then raises the question of what is real, the atoms or the object? Following Rouse (1996), Barad argues that human faith in access to representations over the things being represented is a historical cultural artifact and not a logical consequence of reality.

Representationalism takes the categorization of matter as foundational, leaving unanswered the question of how these categories are linked, a question that continues to bedevil science education as educators seek to develop pedagogical strategies that support learners to move through, for example, various "levels of representation" in chemistry (see Gabel, 1999). Phenomena are differential patterns of mattering [diffraction], and representationalism is not an observation of independent reality and not correspondence, and theoretical concepts are not mere ideations but are materially embodied in apparatus that produce the phenomena being described, so how do we use these ideas to develop a richer understanding of how humans intra-act with matter in ways that science values? Barad (2007) invites us to challenge humanist ideologies noting that "representationalism, metaphysical individualism and humanism work together hand in hand, holding this [humanist] worldview in place" (pp. 134–135). As we have noted, these anthropomorphic forces are so powerful that humans struggle to escape their grip on human thought. For Barad, a performative approach that involves entanglement in material-discursive practice helps us to understand how the notion of subject and object is emergent through the application of agential realism. Entanglement of agentially intra-acting components involving material and the apparatus of observation engenders phenomena via agential cuts that configure subject and object. Reflection works as an element of representationalism because it holds objects at a distance while diffraction, which Barad endorses, requires entanglement with apparatus and matter and is comfortable with a diversity of outcomes eschewed by reflection. Thus, comfort with diffraction as a practice in learning rather than reflection offers a pedagogical strategy for being comfortable with diversity in what and how people learn.

With our exploration through these chapters of matter as active, we are left with the question of how science education could be different if phenomena were the "primary ontological unit" (Barad, 2007, p. 333). As several authors in this book have noted, it is through intra-actions that components of phenomena become bounded and properties can be identified. We are left with questions that invite further exploration, including the question of how matter became passive and immutable when language and culture have their own agency and historicity. We are left asking why do educators continue to hold matter at a distance separating the knower from the known in a way that leaves the human agent as the knower imposing their will on matter. Indeed, representationalism, which can be considered an outgrowth of this separation, is an area that invites further exploration as questions of correspondence between descriptions and reality, i.e., do they mirror nature or culture to matters of practices doings and actions (Barad, 2007, p. 135), can be considered.

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Correction to: Teachers as Participatory Designers of a Professional Development Website

Shirley Simon and Paul Davies

Correction to:
Chapter 14 in: C. Milne, K. Scantlebury (eds.), *Material Practice and Materiality: Too Long Ignored in Science Education*, Cultural Studies of Science Education 18, https://doi.org/10.1007/978-3-030-01974-7_14

An earlier version of this chapter has been published inadvertently including Figure 14.1 without permissions from the original publisher. The figure, its citation and caption has now been removed from Page 212.

The original chapter has been corrected.

The updated version of this chapter can be found at
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