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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

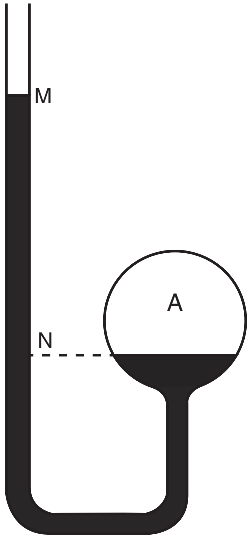

Fig. 2.3 An image of one of Guillaume Amontons' air thermometers. Amontons used mercury to block a bulb of air, which expanded, pushing on the mercury

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

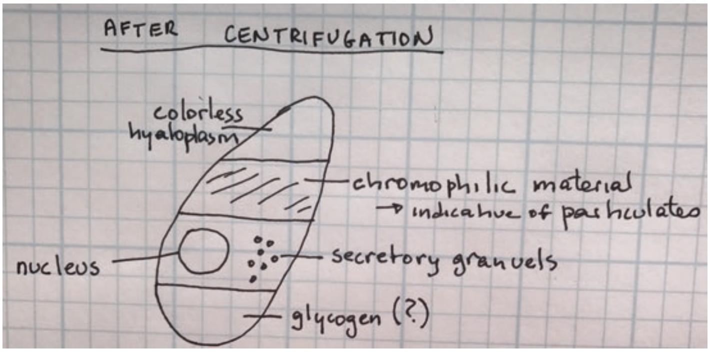

Fig. 2.4 Ultracentrifugation resulted in different differentiated layers, but the internal structure of the cells was destroyed. The "chromophilic material" indicative of particulates was particularly interesting to scientists