Ownership of Knowledge

Beyond Intellectual Property

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EDUCATIONAL INEQUITIES AND THE DISTRIBUTION OF TECHNICAL KNOWLEDGE: THREE INSTRUMENTS

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This is the story of a banana in a shoebox. The cardboard box has its cover on, but light peeps in through a series of small holes that have been poked in the lid at regular intervals. The numbered holes form a grid into which a thin wooden barbeque skewer, itself calibrated at regular intervals like a ruler, can be dipped. Gathered around the shoebox in a sixth-grade US classroom, children of eleven or twelve are being taught to reveal its contents with repeated thrusts of the skewer. They proceed methodically along each line of holes, recording the depth of each dip onto a waiting piece of graph paper, and as they complete their suspenseful prodding the readings gradually reveal that it is a banana that lurks inside the box—not a potato, not a shoe, not empty space. The banana is, in short, a scientific specimen; the work going on is that of remote-sensing; and the shoebox is a very cheap, very easily maintained scanning probe device: a $4 atomic force microscope (AFM).[1]

How this particular scientific apparatus has come to be known as such, and not as trash or plaything, and the banana known as a research object, not as a misplaced part of someone's lunch, is a worthwhile analytic project for those interested in the ownership of knowledge. Science education in the United States represents a complex project of staged mastery, where learners are meant to encounter increasingly complex, precise—and not least important, costly—versions of "real" instruments as they move in their schooling toward the accumulation of ever more remunerative and prestigious skills.[2] After the shoebox AFM, once in high school, students may encounter a $40 scanning probe instrument made up of LEGO blocks and the sort of pocket laser pointer normally used by carpenters or public speakers; the sample under study might itself be a configuration of LEGO blocks. This more elaborate AFM is accompanied by basic imaging software instead of pencil and graph paper.[3]

Beyond both experiences may come an encounter with a $25,000 AFM in the well-appointed college classroom or industrial training facility, along with the instrument maker's proprietary software, or with a still more expensive system installed in a high-level university or commercial research and development laboratory. Among all the AFMs, only those costing in the tens of thousands of dollars involve the literal mapping of electrons to reveal surface forces of materials at the atomic scale, but in the world of US science education, each of these successive learning experiences moves the aspirant closer to what is understood to be atomic-scale expertise, closer to the comprehensive "sense-making" that is identified as science.[4] But this experience of forward or upward movement, of accreting skill, is not assured to all those present. This chapter departs from other historical studies of science education in suggesting that no singular process of scientific training is occurring in any given classroom. The idea that science education primarily derives from programs of occupational or disciplinary reproduction is challenged as well. Instead, I want to consider, historically, the social instrumentality of occupations and disciplines among *other* possible ways of organizing the epistemic commonalities we know as "science."[5]

THE BANANA IN THE SHOEBOX: MERIT AND THE PRODUCTION OF KNOWERS AS OWNERS OF KNOWLEDGE

The promissory character of contemporary science education for young people—the directionality and continuity that each stage of mastery implies about individuals' potential movements from kindergarten through high school (i.e., progress through the "K–12" system)—reflects deep commitments to the vision of the United States as a meritocratic society.[6] That vision maintains that through the actualization of proficiencies, the student steadily gains access to the next stage of education and, ultimately, to remunerative employment. Meritocratic commitments are, above all, cast in education policy discussions as an automating mechanism of US social life: an individual's innate capacities will differentially yet inevitably lead to achievement, and achievement will yield distributed prosperity.[7] Some students will naturally reach greater life attainments than others, but all have some enhanced future awaiting via education—that is, via actualized competence.[8] The particular actualization of achievement and knowing undertaken by US technical education includes both the enlistment and disciplining of future scientific workers and also, foundationally, the determination of who is eligible for such work at what level—for example, as a manufacturing plant worker, technician, or research scientist, to invoke one customary ladder-like trope. In prevailing discourse around US science and engineering education (the two occupational destinations are conjoined in most recent literature on K–12 education), curiosity about the natural world is cast as something that is to be detected and satisfied in learners through the provision of staged, age-appropriate curricula, with individuals expected to drop out of the science-learning process as they reach the limit of their natural abilities.[9] As Secules et al. incisively capture, each classroom must have a "worst" student.[10]

The twinned ideas that the objects of scientific knowledge await knowing and that such knowledge exists prior to its acquisition together produce a dehistoricizing understanding strongly challenged by this volume. Predicated on a model of education as a process of transmission, or of the "banking" of knowledge in students, as Freire frames it,[11] the proposition of meritocratic pedagogy is especially consonant with the conception of Western science as an enterprise of value-neutral individuals seeking to learn about the world—that is, as a cognitive disposition of "timeless dualist detachment."[12] If there is a singular cosmos to be known, then each person can be understood to know less or more of it, and each individual's particular capacity—how much they know—can thus be gauged and compared with others'. We could say that science makes of the world an instrument for calibrating scientists.

More particularly, empiricism in the context of science education, just as in mature scientific practice, is a technique for sorting *inquiring subjects*, not only or primarily their objects of inquiry, to perhaps extend Barad's formulation regarding scientific discovery to the process of learning to be scientific.[13] This ascription of differing value to individuals' differing cognitive labors does a great deal to hide the ontological operations of capitalism in the United States. In this chapter I will account for the ways in which the twenty-first-century science classroom cospecifies the activity of effectual remote sensing (in contrast to improper conduct) and the effectual remote sensor (versus the improper actor).[14] Such sorting of learners is required in a setting such as the US, where work and economic security, for which education prepares young people, are comprehensively stratified; the outcomes of teaching and learning must map individuals onto a range of capabilities, must establish divergent and legibly hierarchical personal endowments, if the labor needs of capital are to be warranted as democratic.[15]

In the United States, the history of scientific merit is thus a history of the belief in the multiplicity of human intellectual endowments, a timeline of change and continuity in distributive understandings of racial, gender, and other forms of identification. Scholars have shown that this multiplicity of endowments historically has justified differential life circumstances as people of different ascribed identities proceed through schooling into adulthood and working lives, part of a broader Euro-American take-up of heritability in depictions of human cognitive attainment now understood as a racialized, if not fully eugenic, approach.[16] In recent years, as conceptions of "inclusion" and "diversity" have conformed educational and hiring policies, the existence of differences in ascribed intellectual endowment, or "potential," has also been cast as a matter for pluralistic celebration.[17] It is this recent form taken by merit—as driver of, explanation for, and *commendation* of social stratification—that a close look at the sociomaterialities of contemporary K–12 science education can articulate for us.

As Ferguson writes, after World War II, *yes* finally became "a word attached to minority difference" in America. The activism and legal provisions of the civil rights era redirected educational resources toward historically disadvantaged communities and eventually eroded the acceptability of explicit race-based discrimination in many settings; reformist projects along lines of identities based on gender, ethnicity, disability, and sexuality followed. In education, precepts of inclusion, and by the 1990s, so-named diversity initiatives, elevated a notion of identity-blind pedagogy in which the new stance of welcome would be accompanied by selectivity based on "excellence." Affirmative action and other compensatory approaches declined in the face of this broad neoliberal project to "maintain excellence" in places of US learning and employment. Science, technology, engineering, and mathematics education and work were now rearticulated as the "STEM" sector, a vital source of national prosperity and international competitiveness in the "globalizing" world, and one in which no rigor need be sacrificed to the aim of diversity and inclusion.[18] Yet, these efforts installed what Ferguson has called "a political economy that deploys minority affirmation to rebuttress institutional power."[19] The turn at the end of the century toward pluralism as an ostensible support for a more just and democratic polity embodied majority impulses to preserve structural inequities.

The three AFMs, as fabricated by educators and embedded in US science curricula in the early twenty-first century, embody this history. Science education—tracked and stratified—enacts excellence in opposition to whatever is not excellent. This necessarily involves a determination of *whomever* is not excellent; the three instruments themselves detect and specify human differences of these kinds, facilitating the passage of some students from rudimentary to advanced educational standing. Following the historical ownership of knowledge among individuals and groups of actors (such as youngsters encountering staged scientific experiences) can support our efforts to historicize participation in American science not as individuals' experience of knowing the world, but as the individual coming to be seen (by others, and by the self) as a knower of the world.[20]

In this way, we follow the demarcation of "excellent" scientific learners from others as deriving from the priorities of majority society (including those priorities supporting capitalist labor and production), while obscuring that derivation. The possession of knowledge is not a matter of acquisition alone, but of ascribed potential for acquisition; a central point of this chapter is that these are inseparable attributions. In particular, we can emphasize how understanding knowledge as constituting ownership resonates with the framing of whiteness (or other majority identifications such as masculinity, heterosexuality, cis-identified, or abled in body or mind) as property and resource; any instance of "belonging [to]" predicates both the thing that belongs and the owner to whom it belongs. Accounts of the historical investment in whiteness as a value proposition have helped us grasp the interested and material (rather than just the attitudinal) features of white advantage.[21]

Foundationally, for the three AFMs to differentiate among individuals as learners of various capacities, or detect them as nonknowers, academic capability and achievement must be seen to reside in the individual student. Merit makes of intellect something expressed as talent or capability, but also a quality imaginable as separate from all other factors in one's life, whether a factor is thought to be personal or societal in nature. It is significant that in the post–civil rights–era US, the meritocratic disposition has been, for some of those concerned with racial, gender, and other forms of education and employment inequity, notoriously subject to violation. Advocates of inclusive education and hiring policies meant to correct "minority underrepresentation" or encourage "STEM diversity" point to, for example, the role of stereotype bias in depriving minoritized people of resources or recognition.[22]

But while those exclusionary practices do occur, we misunderstand them as first causes of minoritization, or of racial and gender essentialization in, say, places of schooling and work. In fact, when analyzed strictly as acts of exclusion, such discriminatory operations—however pernicious they may be—disguise the social function of merit: to render individual intellects as such and provide possible classifications for intellects. In conferring or denying ownership of knowledge, and as the term *ownership* itself implies, attributions of merit distribute material and social benefits. Defined and assessed as a trait of individuals, merit produces individuated actors, each with their own calibrated potential and differential deserved life circumstances, and thereby renders unreasonable the economic redistribution or reparative initiatives associated with social-structural change. That is, belief in merit reinstates the stratified character of learning and working under US capitalism, naturalizing that system's political and economic inequities.

Hacking's conceptualizations of "making up people" suggest that such taxonomic projects comprise the production of spaces of possible action. He tells us that social change brings about new categories into which people may be sorted, but also, as in the case of a census, that "counting is no mere report of developments." That is, Hacking discourages our customary sense of empirical inquiry as an operation distinct from social action; to seek and/or find human attributes in individuals or groups, he might suggest, is to make real, or at least, actionable, differences among those human subjects. In a parallel formulation, we might say that in science education, educators' recognition of meritorious students is no mere revelation of talent. Studying the sociabilities of learning, scholars have begun to conceptualize knowledge "as emerging—simultaneously with identities, policies, practices and environment—in webs of interconnections between heterogeneous things, human and nonhuman."[23] The point, in Fenwick's words, is that "attention to the sociomaterial can help reveal the dynamics that are actually constituting what comprises everyday life, including learning," and that the objects that comprise experiences of learning and work

> might be taken by a casual observer as natural and given—things comprising a "context." But a more careful analysis notes that these objects including objects of knowledge, are very messy, slippery, and indeterminate.[24]

Allowing for this indeterminacy lets us see that one's commendable use of the scientific instrument, the child's approach to the banana as object of detection rather than snack, enacts ownership of knowledge about the banana. This is an example of Barad's "agential cut," whereby one possibility, and not another, is brought into being: what is cut in the elementary, high school, or college science classroom is each knower-and-known-about-thing.[25]

Given the huge body of critical literature on effective and equitable science education as a guarantor of positive futures for minoritized young people in the US, it's perhaps worth clarifying that the aim of this chapter is not to implicate the AFMs in the US production of "good learners"—that is, in the demarcation of eligible achievers—as a biased process. That description implies that standards exist by which an organization, such as US K–12 schooling, may "accurately" compare individuals' abilities, and that we might, with awareness, eliminate bias is such determinations. A more ontological lens is needed, whereby we can see how the ascription of relative technoscientific potential (i.e., merit) is neither anterior nor posterior to the identification of individuals by, for example, race or gender; rather, these characteristics are brought into being at once.[26] In an important sense, this recognition allows us to question the universalist idea of a postracial world in which racism is "a distortion of an otherwise aracial rationality," ready to be dispelled once the truly objective judgment of personal capacities is liberated from distorting forces.[27]

The focus on the ontological character of science teaching and learning—on the making of knowledge about people's talent, and people, as a single operation—also helps us disrupt the idea of educational opportunity as an empty location awaiting arrival or uptake by yet unspecified individuals. The proposition of such emptiness—purporting that any given human might arrive at any institutional or social position, depending only on their innate endowments—falsely claims an essential democratic nature for US economic systems. It is not mistaken notions regarding some racial bases of intelligence, nor gendered ideas of mental discipline, nor ableist conceptions of mind-body relations that falsify those claims, but rather the unified nature of individual intellectual endowment and identity US culture.

Put another way, in keeping with this volume's interrogation of the ownership of knowledge, rather than formulate the democratic ideal of science education as an "even playing field"—an image of figures of diverse identities given the chance to move freely against an unchanging, neutral ground (and the classic analogy for a bias-free society)—we might see that educational opportunity is instead a *location of ownership*. That is to say, opportunity, embodied in the next level of science instruction, in the eligible student's next possible encounter with knowledge of remote-sensing, is specified *with* the eligible actor. It does not vacantly await the meritorious, but instead conditions the meritorious. If the sociabilities of US learning and work—still vastly disadvantageous to minority communities in 2022—concern us, we need to see that a child's future that includes a more expensive remote-sensing apparatus or a more elaborate physics syllabus is not best seen as an experience of more knowledge but as the making of a proper person, a propertied person.

For generations in the United States, science curricula have been elaborated in massive guideline-setting enterprises, most recently 2013's Next Generation Science Standards (NGGS), a collaboration among twenty-six states following a framework supplied by the National Research Council.[28] The NGGS are explicitly based on the premise that the acquisition of scientific knowledge by US students will democratically support personal and collective prosperity.[29] Thus, the science classroom is meant to serve as both driver of student engagements and source of reward and promotion, according to the performance of each student. In this way, science pedagogy guides students in maintaining their motivation to learn about the world "not just in school but throughout life," and to expect rewards for acting on those impulses.[30] This is a braided imaginary of available empirical knowledge, innate endowments, cognitive agency, and postschooling rewards. It requires that the figures of students are seen to move against the ground of a knowable (for some) world. Unpacking this imaginary, the remainder of this chapter follows continuities and ruptures among student experiences of the three "levels" of AFM mastery—from shoebox to LEGOs, to commercially supplied instrument—to see how a world and people who can (and cannot) know it come into being together in US places of science education.

SCHOOLED FUTURES: THE HISTORICAL MAKING OF KNOWERS AND NONKNOWERS

Hands-On Learning: Whose Hands and Whose Learning?

Two broad historical developments in recent decades have intertwined to land the banana inside the punctured shoebox: the renewed centrality of "hands-on" learning in K–12 science education and the rise of atomic-scale science and technology in projections of US economic growth. The integration of "hands-on" and lab-based experiences into US science education has been an identifiable priority for educators since the last quarter of the nineteenth century, sidelined at moments in favor of more theoretical content but never terribly widely or for very long.[31] Within areas delineated for such instruction, modeling and materials characterization have been part of US science education for generations, but students' facility with microscopic imaging and manipulation gained new importance among such experiences with the rise of so-called nanoscience and other atomic-scale applications at the end of the twentieth century. That rise produced strong pedagogical and economic arguments for "nano-related" content in K–12 curricula. It is important to avoid the formulation that classroom experiences of scanning probe microscopy represent rudimentary forms of professional laboratory conducts in any singular or direct sense. We can review the landscape of variable selves and futurities—emplacements through ownership of knowledge—that science schooling in the US has projected since the turn of the twenty-first century. Here, we focus on a set of possible moves toward cognitive and economic self-development for some individuals that constitute nanoscale science learning.

As Rudolph and others have made clear, since the origins of formal schooling in this nation, the education of US adolescents in areas of science and technology has included hands-on experiences. The term has encompassed student experiences loosely defined in opposition to "passive" listening to lectures, watching instructors or aides conduct demonstrations, or reading textbooks. In the late nineteenth century, the take-up of German research ideals in US universities prompted influential high school educators in the country to introduce laboratory work to younger learners. Through the 1910s and 1920s, as Rudolph recounts, widening public high school enrollments and teaching experts' enthusiasm for tenets of Deweyan pragmatism lent still greater value to material engagements with scientific methods.[32] Although laboratory exercises have been understood by many generations of science educators to be a particularly engaging form of pedagogy for learners, we can be very clear that they have also historically shared social instrumentalities with other bodily experiences in science learning, such as fieldwork in botany or zoology, or survey camps for engineering students. All such experiences helped inculcate students' sense of themselves as possessing particular sociabilities: masculinity, whiteness, manifest heterosexuality, ablebodiedness, and other forms of "belonging" in places of science or engineering learning.[33]

This experience of belonging maps onto hierarchical occupational and wage structures that have served US employers' needs for human capital, following lines of race, gender, ethnicity, [dis]ability, and socioeconomic status, among other categories. Science and its applications are customarily seen by educational proponents to categorically promise advances in human welfare, meaning that all science-related or science-derived labor has some purported value, but ladders of opportunity and achievement remain integral to the pedagogy. After the emergence of wide networks of trade and vocational schooling that could follow or replace high school in the 1910s and 1920s, educators formalized programs reflecting stratified technical labor with particular ambition. This pattern was repeated in the 1950s and 1960s with the advent of junior and community colleges offering sub-baccalaureate education to students after they complete high school.[34] Tellingly, "middle-ness" has been delineated in each of these episodes as a permanent condition of some work and some workers. Technicians operate at a "middle" place between lesser and more skilled personnel; in the United States the "middle skilled" represent a frequent target audience for sub-baccalaureate STEM training in the twenty-first century.[35] In this system of discrepant experiences of economic and career mobility, getting one's hands into or onto the materials involved in technoscientific labor has historically never represented one thing, pedagogically. On one level, instructors in different sorts of schools have meant different things by the term *hands-on*. For those taking courses in academic high schools, who are generally considered more likely to reach college, hands-on learning might mean work with laboratory instruments for future scientists, or experiences with testing apparatus for future engineers. For those engaged in vocational instruction, hands-on work meant and still means a sort of manual labor strongly demarcated from cognition—literally manipulating industrial materials or medical, mining, or construction technologies preparatory for paid work of that exact sort.[36] But we also find the making of a multiplicity of life outcomes underway within a single K–12 classroom where all students are engaging in the same exercise, because different hands rest on different matter, even at the same workbench. The student who, dismayingly, eats the banana in the shoebox is handling food and thus fails the exercise; the student who, appropriately, remotely maps the banana is handling a scientific specimen and passes. More subtly distinguished errors and achievements follow to delineate students and futures at subsequent grade levels, perhaps, but the linkages of knowers and the known-about persist (just as, ultimately, the factory quality-control inspector does not examine a microchip as a piece of experimental evidence, and the industrial researcher does not examine it as a piece of inventory fit or unfit for sale).[37] The purported continuity of K–12 science education—its ostensible meritocratic futurity—masks the classificatory function of elementary and secondary school instruction, meant to cull those incapable of college from the overall pool of scientifically literate future workers—that is, to produce nonknowers, or, we might say, nonowners of the particular knowledge associated with particular futures.

Functioning in a promissory mode, scientific literacy appears as an immersion in knowledge that is imagined to be continuous over time and not susceptible to interruption. The planners of the NGGS described their priorities thus:

> The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields.[38]

The scientific knowledge accumulated by meritorious students during this passage of time is seen to be particularly durable and mobile, cast as a combination of "content," and "practices" that carry "core ideas" from location to location. Both "content" and "practices" are to be "intertwined in designing learning experiences in K–12 science education":[39]

> Student performance expectations have to include a student's ability to apply a practice to content knowledge. Performance expectations thereby focus on understanding and application as opposed to memorization of facts devoid of context.[40]

As was the case a century ago, those students in the US seen to have the most far-reaching potential for performing technical labor are seen today to require something beyond facts. As in past decades, arguments today about the economic utility of schooling and requirements of national security require that a cutting-edge of research practice be delineated and become the basis of teaching in both public and private schooling.[41] Since the mid-1990s, so-called grade-banded techniques have sought with particular focus to instill facility with techniques of detection, imaging, and modeling, and in this way, microscopy has become a central area of student learning for livelihood.

Educating for a Nanoworld

Microscopy and telescopy, and indeed, a great many science techniques including most involved in chemistry and physics, depend on detecting the so-called unseen through instrumentation. Despite this genealogy, aspects of scanning probe microscopy entered K–12 science curricula after 1995 or so as features of what had come to be understood as "next-generation science and engineering practices," seemingly novel in both form and economic import for the nation. This was the point at which practical atomic-scale science and engineering received considerable attention from the National Science Foundation (NSF), which lent its imprimatur to scientific research and enterprise loosely defined by the terms *nanoscience* and *nanotechnology*.[42] The terms referred very broadly to atomic- and subatomic-scale operations emerging in biotech, medical, materials, electronic, energy, and other sectors, and with this governmental recognition of research and development at unprecedentedly small scales came tremendous enthusiasm for projected discoveries and applications, including the creation of mass manufacturing operations claimed to bring wide employment.[43]

The enthusiasm for all things nano- went hand in hand with a view that equated new scientific knowledge with economic expansion. The founding of the National Nanotechnology Initiative (NNI) in 2000, for instance, indicated "focused investment" by multiple federal agencies supporting dozens of individual programs around the country, including both pertinent scientific research and research on science education.[44] The novel character of nanoscale science was established in conjoined technical and political terms; the notion of vast human benefits in health, environmental sustainability, and other arenas to be wrought by the "revolutionary" nature of nanoscience and nanotechnology made sense of a new vision of "nanolabor." This vision of a new prosperity for workers under capitalism was said by proponents to promise millions of new jobs in the "nanosector" within a decade or two.[45] Related allocations of NSF funds for curricular initiatives meant to prepare the nation's future workforce carried outward a general sense of urgency around the current, ostensible nonpreparedness of US students for emergent economic conditions and program development in many schools systems, at all levels. Students in elementary, middle school, and high school soon began to receive instruction on "real-world" applications of nanoscale knowledge, including regarding composites, ceramics, concrete, biosensors, electronics, polymers, pharmaceuticals, and other topics. Educational encounters via nano-focused lab kits, student-grade instrumentation, video and animated materials, board games, and other formats proliferated to prepare students for promised employment opportunities in nanoscale science and engineering fields.[46]

The rapid uptake of nanoscience and nanotechnology as bases for K–12 and postsecondary curricula in the US expressed many sorts of futurity for their proponents, often tied to regional economic concerns but inseparable from beliefs about national security and global economic competitiveness, as in the NSF funding strategies. That relatively few jobs in "nanomanufacturing" currently exist in the United States suggests that the scale of NNI-funded initiatives may have been based on extravagant projections.[47] Moreover, the positive role projected for nanotechnology sectors in the lives of students conflates persuasive pictures of economic growth and of oneself moving upward to accrete skills and knowledge. But as we discuss below, meritocratic concepts of science-based competence are nothing if not adaptable to less fortunate, and even unfortunate futures for some students.

The vision of an economy requiring particular scientific and technological competencies was invoked to support educational reform efforts after 2000 that enlisted empiricism in the service of capital yet again, now through coordinated projects of quantified assessment aimed at individual teachers and classrooms, schools, and the local- or state-level administrative entities that oversee schools. Through national testing initiatives, the gauged effectiveness of K–12 education allowed authorities to compare individual instructors, schools, and districts, just as classroom testing had long allowed comparison among students. Scholars have shown that multiple forms of funding depended on districts' commendable test performance, rather than on evidenced need for greater resources. This pattern strongly suggests that the further marginalization of disadvantaged communities was an acceptable outcome of the national testing initiatives, if not an acknowledged goal.[48] As Antonia Darder describes:

> Just as educational reform efforts of the civil rights era began to reap some promising outcomes in the late 1970s and early 80s, with improvement in educational outcomes for the most impoverished communities and an increase in college and university attendance by historically underrepresented student populations, the conservative antics of the Right revived their bitter campaign to discredit progressive educational efforts, advance the privatization movement, and usher in some of the most Draconian accountability measures in the history of US education. This, in turn, led to the most expansive national high-stakes testing campaign ever, aggressively solidified by the federal passage of *No Child Left Behind* by the Bush administration in 2001 and its transmutation to *Race to the Top* (RTTT) by the Obama administration in 2009.[49]

The perceived reasonableness of a national education system that relegates some communities to much less occupational preparation than others meshes in the US with centuries-old majority understandings that race and other ascribed identifications rightly determine life circumstances.[50] More apposite perhaps is that through these neoliberal formulations, an economy of profoundly stratified wage and mobility structures was firmly associated with responsible, evidenced-based oversight of national educational provisions, and that both were predicated on avowals of accountability. Examining particular moments in which talent and opportunity, as organizing epistemics of twenty-first-century STEM education in the US, have been cospecified in science classrooms can help us see these structural conditions in which knowledge finds its owners.

Claimed Epistemic Continuities, from Skewer to Electron

The three scanning devices considered in this chapter evidently engage with natural phenomena on three different physical scales. A wooden or metal barbeque skewer and a laser pen, moved over the surface of objects under scrutiny, will not reveal characteristics of the same size, and neither of these tools operates at the revelatory scale of the scanning electron probe embedded in the atomic force microscope. But educators claim considerable epistemic continuities for these three instruments, and such continuities are elemental to the promise of personal development made to many students. The near destination of a completed classroom exercise and the far horizon of college, graduate school, and professional employment in the sciences both mean that all cognitive engagements can be cast as learning or its absence—that is, as resulting in the student's acquisition of knowledge, or not. Naturalizing the image of a self moving from having not much demonstrable understanding of the world to having greater such understanding when faced with the possibility of acquiring knowledge, these claims make up the social instrumentality of "mastery" on which staged education in the US is predicated.

This enactment of mastery rests, first, on the assumption that knowledge of the world consists of knowing the world as data. All three scanning devices involve the proposition that scientific knowledge of the world is continuous and thereby subject to accretion, making reasonable the idea of expanding understanding in individuals. The very construction of scientific instruments as yielding "no," "some," or "more" information unites them as objects operating in relation to a singular cosmos, as directly representational in the unmediated sense that historians of science and science studies scholars problematize.[51] Instruments are seen to produce demarcated but not separable bodies of data because the universe they address is, according to the norms of Western science, not a disunified one; what the eleven-year-old finds out about the world is not incompatible with what the PhD molecular scientist finds out—merely, it is maintained in scientific settings, somehow lesser in amount. The stepwise character ascribed to the scientific method, in which observation and testing yield knowledge of that universe, works cognitively for the competent inquiring mind, however calibrated the tool one holds might be. Measurement and other uses of instruments produce one set of "convergent claims of decontextualized truth," as Patel paraphrases Spivak's characterization of Western epistemologies.[52]

In "Exploring the Nanoworld with LEGO® Bricks," a set of K–12 teaching materials on scanning probe microscopy (SPM) technologies produced by the University of Wisconsin in 2012, teachers are told that "by mapping [surface forces of materials on the atomic scale] much can be learned about the surfaces of materials, where many interesting and complex phenomena occur."[53] SPM includes atomic force microscopy, magnetic force microscopy, and lateral force microscopy, all "variations on the same basic principle": "Forces between the surface and a cantilever tip cause the tip to deflect up and down." The play of tip over surface (or substrate) is the meaningful interaction here. Not unlike those moving into high school from middle school, we can likely grasp the significance of such deflection by recalling the calibrated skewer playing over the surfaces of the hidden banana. Here, however, deflections are not transferred from banana to skewer to child operator's hand and eye, but from LEGO substrate to LEGO cantilever to laser-pointer beam, and movements of the beam are then recorded by a photodiode array. The resulting data is then studied by adolescent operators. As with the shoebox apparatus, good students are presumed to grasp, or to be able to learn to grasp, what about the model will carry forward in time as they move onward from their status as learners to workers, and what will remain behind. Instructions clarify that "*as in a real AFM* [my italics], the cantilever is held in place and the surface is moved back and forth underneath the probe." By contrast, neither LEGO bricks nor other elements of the apparatus ("Here, the *refrigerator magnet* at the end of the cantilever interacts with a *refrigerator magnet* taped to the LEGO® surface to alternately attract and repel the cantilever" [my italics]) have any place in the postpedagogical science world. The nature of pedagogy, the aim of personal cognitive growth, and indeed the value of accepting mock-ups and models as stand-ins for more legitimate things are parts of the lesson.[54]

For the authors of "Exploring the Nanoworld," the modularity of LEGO bricks—the possibility that one can build any shape from the pieces—seems to add to the toys' appropriateness for teaching nano-related science. Like atoms, LEGOs may be used to represent any and all imaginable things: "A set of bricks can be used to model structures of matter and the techniques used to study them."[55] Commensurable with atomic models, LEGO bricks imply a unified character to all objects of study; the intended object of representation can present no impediment to the bricks' use as representational medium. But if the standardized, modular features of LEGO bricks reflect a constitutional commonality among all scientific objects of study, what distinctions among these objects are to be revealed, to be attended to, by the modeler? What constitutes the successful use of LEGO bricks as scientific activity?

We will return below to the formulation of bad knowledge about bananas and LEGO bricks and world, but it is important to be clear that once they take the form of a classroom AFM apparatus, LEGO bricks are both autonomous and well protected from any mistaken association with frivolity. The bricks have a complex instructional credibility: they are very mobile actors, at home not only in a toy store or playroom, but also in a STEM classroom, education research program, NSF grant proposal, and many other locations in which US science education initiatives take form and achieve credibility. The LEGO-brand AFM is in fact part of an immense global initiative of corporate engagement with STEM literacy, operating in direct service to industry. Integral to a broad public/private partnership centered on "21st century readiness for every student," LEGO personnel and other corporate educational leaders advocate for federal and state K–12 STEM initiatives closely tied to projected workforce needs.[56] That workforce is of course not one of equally capacitated, or rewarded, workers, and so those who learn with LEGO bricks will somehow be differentiated from one another even as they remain enlisted in forward motion, in learning.

As educators enact this system of teaching and learning for mastery, the conception of knowledge as data correlates with a specific understanding of *what there is to be learned* in the world. The revelatory functions of the shoebox- and LEGO-based AFMs, like that of the $40,000 AFM, orient the capable operator of each toward useful/factual understandings; matter is willing to reveal itself to the right human partner. The three detecting instruments are all premised on some specific shared elements of observation undertaken in the scientific manner—that is, of attention to the world undertaken in support of inferential learning. As Warren et al. point out, experimentation is taught to children as a process of logical inference rather than as one that is open-ended, or geared toward constructing meanings for emerging variables.[57] All three AFMs deploy incremental, systematic description of the unseen in order render the unseen visible. The good student is drawn into an act of temporary faith (an orientation of "stick with it and knowledge will be had") and a willingness to sustain attention. The weak student drifts from the task or otherwise comes to infer nothing and, possessing no recognized knowledge, goes nowhere—or possibly goes somewhere, but not in the direction of science mastery.

The nature of optimized science pedagogy in the United States institutionalizes these binary dispositions of learning and not learning, as in what the NGGS define as "basic understandings about the nature of science," expressed on a matrix of grade-appropriate language for students in grades K–2 (roughly ages 6 to 8), grades 3–5 (ages 9 to 11), middle school (ages 12 to 13), and high school (ages 14 to 18). These "basic understandings" include such directives as "Science Is a Way of Knowing" that demarcate science from other activities and separate knowing from other ways of sense-making (such as pleasure, pain, yearning, art, or love, for example).[58] Another basic understanding, "Scientific Knowledge Assumes an Order and Consistency in Natural Systems," is expressed on the NGGS matrix of grade-appropriate formulations as follows:

> [K–2] Science assumes natural events happen today as they happened in the past. . . . Many events are repeated.
> [3–5] Basic laws of nature are the same everywhere in the universe.
> [Middle school] Objects and events in natural systems occur in consistent patterns that are understandable though measurement and observation.
> [High school] Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. . . . The universe is a vast single system in which basic laws are consistent.[59]

Two points bear emphasis, as I read this rubric. First, we can note that there is no possibility in the above descriptions to consider that the ways in which such "basic laws" are formulated are themselves historical, changing with our changing understand of nature. Second, the similarity among the statements for six- through eighteen-year-olds here is striking. It suggests that science mastery is both staged and additive (where it indeed occurs); no knowledge is subject to being taken away from the individual who possesses it, even as shoeboxes and LEGO bricks are replaced by laboratory-grade apparatus. The rhetoric of this pedagogy often takes the consistency of knowledge across time and across different levels of learning to be fundamentally grounded in the assumed consistency of the very objects it studies; as one teacher's manual puts it, students shall learn "what a nanometer *is* [my italics]."[60] For the meritorious learner, the world's spatial and temporal continuities assure that a sustained disposition of inquiry cannot result in anything but more knowledge.

Many ontological functions are achieved by this projection of a world waiting to be known. Historians of education and human capital, some following Foucault, have identified the moral and mental disciplining on which modern schooling depends, and historians of science enrich our understanding of research as a further disciplining experience.[61] Nanoscale science pedagogy in no way departs from these regimes of student self-control. Inquisitive individuals not only will take up a focused position regarding inquiry but also remain comfortable with the existence of temporary unknowns; "good science pedagogy" produces not only questions that are not easily answered, but also some that are unanswerable.[62] Observation in places of science should be unimpeded by impatience or other inappropriate impulses that may supersede the intention to learn (such as, say, fatigue, hunger, or rage), and it should be norm-based in all possible respects; there are right and wrong ways to hold the body, the eye, the mind in proximity to the object of study. Only certain "kinds" of people hold the potential to assume these relationships with matter.[63]

With our close study of classroom instruments as expressions of staged mastery we can follow specific techniques for the production of differences supposedly inhering in individuals. In the K–12 science classroom, instructional experiences are organized so that students hear the message over and over: "Here are the necessary actions for a person of your stage in order to become eligible for the subsequent stage. . . . Can you take these up?"[64] Since the system requires incapacity in some individuals, teachers and learners understand that an answer of "no" to that question is always a possibility and exclusion always a possible outcome of effort. At the same time, the filter is meant to let some through; the high schooler is not faced with a research-grade AFM but rather a construction of LEGO bricks that, intentionally, "does not intimidate or frustrate" the competent student unnecessarily.[65] Those who pass through to become college undergraduates are taught via staged presentations of the concepts behind and operational features of research-grade AFMs, with the sensation of challenge again carefully titrated. In other words, science education posits that knowledge cannot circulate apart from its possession by humans, some of whom are incapable, and others of whom are capable, of knowing. No student, no person, evades placement on that totalizing scale of capability. Overall, the purported learnability of scientific techniques and findings establishes individuals deserving of more educational opportunities (those seen to learn in a classroom) and those who manifest disqualifying deficits (those seen not to learn).[66]

The Not-to-Be-Knower and the Not-to-Be-Known

That sorting simply could not happen if only learners were being made in places of science schooling. The to-be-learned must also come into being. Experimentation in school, as in settings of professional science, derives from that possibility of restricted material essences: Students need "the ability to conduct an investigation where they keep everything constant while changing a single variable."[67] The "variable" is of course merely one that is subject to swapping for certain alternatives, not one that varies in its essence. Laboratory enactments included in the process of schooling tell us about individuals directly, signaling their presence in the classroom, their willingness to grow, and their intellectual ability as ingredients of scientific merit. But they thus also tell us about the solidity and predictability of the cosmos to be known by the meritorious.

As critical scholarship on enlightenment ideologies and coloniality have shown, those features of the world are necessary if Western scientific learning is to be posited as independent of culture and maintain its self-confirming political functions.[68] We might now add to such power relations that such behavioral constancy on the part of the world is necessary if students are to be understood as more or less *able* (and with fitting levels of education, *enabled*) to detect the world—that is, if performance metrics for efficacious citizens are to seem reasonable (building on Ashley Taylor's powerful framing of "knowledge citizens"[69]). Biesta, reflecting on Dewey, gives us a basis for seeing this relational character of education as it currently restricts our view of students as empowered subjects of "action and responsibility." For Dewey, student experience and, accordingly, an immediacy or flexibility to all pedagogy supersede in importance student acquisition of particular pieces of knowledge. To this image of dynamic learning, Biesta adds:

> Whereas many would argue that the prime function of schools is to create a common outlook so that future collective action becomes possible, Dewey suggests that schools should instead focus on the creation of opportunities for participation for such a shared outlook to emerge. . . . [Yet the] creation of a shared outlook will not result from simple coexistence or from forms of pseudo-participation in which the activity is set and controlled by others.[70]

Thus, solidifying both knower and known-about in the science classroom involves exclusions of unauthorized subject (i.e., student) activity, of illegitimate knowing.

The science student, swathed in a positivist epistemology, is drawn into the existence of both cognitive possibilities and impossibilities; only that which is deemed potentially seeable, revealable, can possibly exist. As Mukharji makes clear, the rise of modern "oculocentric science" dependent on visualizing and visualization helped displace any knowledge that involved occulted powers and forces—a historical development reflecting the "privileged ontology of the west."[71] This privileged ontology populates the NGGS grid that tabulates the "nature of science" for learners at all levels. In that grid, we find graded expressions of the proposition that "Science Addresses Questions about the Natural and Material World," as follows:

> [K–2] Scientists study the natural and material world.
>
> [3–5] Science findings are limited to what can be answered with empirical evidence.
>
> [Middle school] Science limits its explanations to systems that lend themselves to observation and empirical evidence.
>
> [High school] Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decision about use of knowledges.[72]

Uncertainty plays a profoundly political role here. In particular presentations, uncertainty signals the "not yet known," a safe object of attention, and in others, uncertainty indicates that attention is being paid to the problematic, to "not knowable" or impossible worlds. It might be helpful to bring such a notion of "multi-natures," as Viveiros de Castro terms it, to the study of minority marginalization in US technoscientific places.[73] As a very small step in that destabilizing project, it is worth thinking about how nano-focused K–12 education articulates the two distinct versions of uncertainty.

The first version might be titled, "The Bag Remains Closed!" This version of uncertainty concerns the "not-yet-known" and those eligible for reaching knowledge; it projects a valorous disposition towards the accumulation of knowledge. Consider an exercise meant to prepare grade schoolers for their encounter with the punctured shoebox AFM, as described by Jones, Falvo, Taylor, and Broadwell in their "nanoscale science activities for grades 6–12." The instructor is to conceal an object unknown to the students (a model configured of LEGO bricks is recommended) in a sealed, fully opaque plastic garbage bag. Student teams are asked to use as many nondestructive methods as they can to try to determine features of the hidden object; this might include feeling through the bag, or using magnets "to glean material information." The student teams are equipped with a second set of LEGO bricks, outside of the bag, that they can use to make a known model of the (temporarily) unknown. Since "discussion and consensus building" are significant parts of the project, in the next stage of the exercise multiple student teams hold "conferences" to compare and reconcile their findings.

The exercise is meant to imitate the ways in which scientists can come to know the world, and in which they shall contribute to their own or others' well-being through extremely specific sorts of efforts. In a "Helpful Hint" for teachers piecing together the hidden models, the authors note that "it is best to err on the side of making [models] more complicated rather than less. The more challenging the modeling of the unknown, the more effective the exercise." Making the unknowns so complex that students will be "unlikely . . . to reproduce them exactly" is said to produce a still "richer and more interesting exercise, as well as being a better analogy for real scientific work." Here again, patience and fortitude are invoked as valuable characteristics for science learners. But even more interesting, perhaps, is that this educational exercise ends with "The Last Lesson: The Bag Remains Closed!" because "scientists don't get to 'open the bag.'" That is, "We never have complete knowledge of a system under investigation," yet the pursuit of such completion is reasonable and commendable:

> The nanoscale of molecules, viruses, and DNA is a reality of which we have increasingly refined view using the latest technology but there are large gaps in our knowledge. Much remains within the bag. Much remains to discover![74]

The future belongs to explorers: those who not only seek to learn what is in the black bag, and believe its contents to be knowable, but also feel no urge to attack it with a scissors or find some other path of lesser resistance into the future. Keeping the bag closed represents the appropriate, credible condition of investigation in this instance. Surely innovation in science involves "breaking rules" at times, but in each setting of scientific learning or investigation, some standard of rigor (whether centered on objectivity, precision, replicability, or other normative expectation) must operate for activity to be recognized as science (and not, say, fraud, or fantasy), with attendant social effects.

The second version of uncertainty (and thereby what shall constitute scientific certainty), by contrast, points to a less valorous orientation towards the unseen or unexplained. Were our nano-educators to describe this form of nonknowing, it might be headed: "Leaving aside the Black Bag." For example, Jones, Falvo, Taylor, and Broadwell also provide true/false questions on nanoscale science findings to guide students away from any temptations of fantasy or empirical overreach while maintaining their forward-facing stance toward learning: "Gold nano-sized balls can be injected into the body to destroy cancer cells . . . *True*; . . . Scientists have created a nano-sized car that has four doors, tires, and tiny seats and can move around freely . . . *False*."[75] We can put aside for the moment the somewhat fantastic tone that the false statement lends to the true one (awe and wonder are perhaps not as easily controlled as the authors presume). More to the point of the arguments being made here is that the entire dichotomy of real and unreal science marginalizes what Mukharji frames as “potentialities [that] could never be fully or exhaustively witnessed,” conditions or experiences that are “unavailable to naturalistic interrogations.”[76] The social consequences of this marginalization are multiple. The nature of knowability is narrowed in order to exclude particular people.

Many scholars of indigenous epistemics and cognitive diversity have made this prejudicial function of intellectual credibility abundantly clear; the notion of epistemic rigor itself depends on defining the membership of a given epistemic community, as my own research on the whiteness of US engineering has tried to show.[77] But the exclusion of potentialities has additional worldly effects. The true/false binary, deployed by educators in support of naturalistic interpolation, also rejects the possibility that the surface of a material might be characterized, say, genealogically or politically. The surface of the nanoengineering device, developed for mass production, cannot reasonably be detected in the nano-classroom as involving “concern” and “regret,” such that risks to the health of the nano-factory workforce or to those living downstream of the factory become evident. The barbeque skewer cannot find the conditions in which the banana was grown, the pollution caused by pesticides, or the low wages of farmworkers to be “facts” of the banana.[78] Science might provide other devices for such investigative purposes, but for the learner presented with the “necessary tool for the research,” the tool determines the research to be done.

This rather simplistic set of examples at least helps us see why, as I said earlier, the idea of expanding STEM participation for minority communities is a problematic goal if what we actually seek is a more just society with fewer differentials in life circumstances. Critical literature on the inequities of US STEM education makes clear that marginality historically has not been incidental or in any helpful sense prior to schooling, but systematically produced by schooling.[79] The study of the three remote-sensing devices helps us see the mechanics by which faith in the possibility of possessing knowledge is in no sense equivalent to eligibility for the possession of knowledge, let alone to possession itself. The idea of “kn/own/ables” grounding this volume captures well how the particular imaginable ways of knowing in a given historical setting preset the possibility of possessing knowledge, which also entails dispossession. The description of learning as incremental, celebrated by Dewey, may in fact hide the role of that incremental nature in demarcating those without merit. That is to say, US schooling and work comprise a system in which facility itself constitutes a technology of oppression, something that is apportioned in ways that naturalize different life attainments. As Patel has written,

> Democracy is often conflated to actualizing equity, with assumptions that democratic processes can only result in more equity. This frame thereby situates ruptures of equity and injustice as problems within a society rather than as architecture within the tenets of the society itself.[80]

The production of science knowers and things-known-about that constitutes K–12 education in the US surely represents such architecture.

CONCLUSIONS

A central point of this chapter is that the lack of dependence among learner encounters with the $4, $40, and $40,000 AFMs in US science classrooms in 2022—the foreshortening of this sequence, in many instances—is not well explained by any accounting of missing opportunities for minoritized students, missing people of color in the places of science education, or not-yet-mastered knowledge among certain groups of aspirants. That comforting imaginary of potential learning awaiting actualization is captured in well-worn tropes of the “leaky pipeline” in science and technology education, which depict eligible young learners dropping out of occupational contention due to local issues of underresourcing or discrimination. This picture of STEM fields conveniently elides the ways in which science literacy enacts and necessitates marginalization.[81] Instead, the proposition of existing, possessable knowledge about a singular world, a possession to be obtained in part through science education as we know it, is historically an adjudicating system, an ontological production of scientific minds, but also of “valueless understandings” and thus “nonknowers,” or, we might say, nonowners of knowledge.[82]

Perspectives drawn from science and technology studies concerned with the relational nature of technoscientific knowledge, such as we find in Law and Lien, may be helpful here.[83] Specifically, they can help us to recognize insistent indeterminacies regarding human difference with which onto-epistemological projects grapple in the science classroom. We see how US science education is predicated on the making up of people with set and identifiable inclinations, conducts, and prospective bodies of knowledge regarding a fixed and knowable world.[84] This is the premise on which notoriously unjust deficit-based models of student difference are founded, as Freire articulated. It has also lately produced possibly well-meaning, inclusive STEM diversity interventions that for the most part neither interrupt the violence enacted by meritocracies nor address structural conditions generally.[85] But so, too, do notions of knowable individuals as disrupted by queer studies, and ideas of measurable human capacities problematized by disabilities studies, remind us that education and resultant instances of knowledge ownership express much wider cultural commitments in the US to ordering individuals' prospects in service to current distributions of capital, legal security, political influence, and other advantages of the nonminoritized.

With those commitments in mind, we might come to see the relationality that historicizing educational opportunity brings to the surface, yet without falling back on the duality of classified people/apparatuses of classification that I think configures Hacking's outlook on the "making up people."[86] For example, the idea that in a racialist, ableist, sexist, heterosexist, xenophobic society, it is *identity* that constrains *opportunity* badly mistakes the nature of both. Instead, we can grasp that opportunity is not separable from either "potential" or "achievement." Those latter terms exist *in order to* valuate people in light of particular societal aims—again, to cast society as a collection of figures moving against a single, unchanging ground to greater and lesser effect depending on each figure's capacities. In the case of science learning, students are in actuality constructed as figures against the ground of a world that is knowable by some and not others. Identifications such as race, gender, sexuality, and (dis)ability operate throughout, not as a priori determinants of opportunity or post hoc ascriptions following from individuals' perceived relative attainments.

Writing about the interpretive possibilities of actor-network theory (ANT) for a newly critical understanding of learning, Fenwick commends ANT for tracing networks as they produce "force and other effects: knowledge, identities, rules, routines, behaviors, new technologies and instruments, regulatory regimes, reforms, illnesses and so forth." She welcomes ANT's premise that "nothing is given in the order of things, but performs itself into existence" and its constant questioning of any network about "what is holding its system together."[87] I would suggest that in the case of the twenty-first-century United States, the project of emplacement/ownership we have seen in the teaching and learning of remote-sensing is one answer to that question. Generations-old patterns of stratified education and employment would of course be a sturdy enough foundation for any such distributive efforts in 2022, any such difference-making among people. But the location of scientific merit in individuals has recently achieved a new efficacy. Following a period of civil rights reforms that legally prohibited segregation, as the nation turns to the comprehensive criminalization of people of color and the foreign-born, the sorting of individuals—the classificatory projects of racism and related dispositions—continue through these more conciliatory means.

The alternative to the three AFMs as we have met them might be envisioned as a liberatory pedagogy of knowers-who-are-not-knowable, of "caring yet vulnerable and risky relations" between teachers and learners, or employers and employees. This stance might involve crediting all sorts of presently illegible knowledges of the world, such as schoolchildren's everyday knowledge, or presuming competence in order to demolish "archaic distinctions between people with or without learning difficulties."[88] Decentering the humanist achievements ascribed to education in a self-consoling democratic polity also recommends itself; this is required if self-determination is to be honored as an alternative to self-efficacy, to the "grit" of the dedicated STEM learner.[89] Whatever our critical approach, if we are determined not to reproduce the oppressions that the notion of alterity enacts, we can recognize the inescapably ontological character of science learning and knowing—its making of people and what it is they know and can know, all in one operation. The conditions of learning and work, and the world to be learned and worked with, this way stay together in the analytic frame. But the power of the assemblage is no longer denied.

Notes

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2. NGSS Lead States, "Executive Summary," in *Next Generation Science Standards: For States, by States*, June 2013, https://www.nextgenscience.org/resources/ngss-introduction-and-overview; Susan Loucks-Horsley et al., *Elementary School Science for the 1990s* (Andover, MA: NSTA Press, 1990), ix; National Research Council, *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (Washington, DC: National Academies Press, 2012); David Kaiser, "Introduction Moving Pedagogy from the Periphery to the Center," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005).

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4. Christina V. Schwartz, Cynthia Passmore, and Brian J. Reiser, *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices* (Arlington, VA: NSTA Press, 2017); Dean Campbell et al., "Exploring the Nanoworld with LEGO® Bricks," Bradley University, 2012, section 2–1, 17–19, accessed September 4, 2022, https://chem.beloit.edu/edetc/LEGO/PDFfiles/nanobook.PDF. On the history of scanning probe microscopy, see Cyrus C. M. Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (Cambridge, MA: MIT Press, 2011). On historiographies of science pedagogy, see Kathryn M. Olsesko, "Science Pedagogy as a Category of Historical Analysis, Past, Present, and Future," in "Textbooks in the Scientific Periphery," ed. Antonio Garcia-Belmar et al., special issue, *Science & Education* 15, no. 7/8 (2006): 863–880, On the "staged mastery" of pedagogy as a modern project, see John Carson, *The Measure of Merit: Talents, Intelligence, and Inequality in the French and American Republics, 1750–1940* (Princeton, NJ: Princeton University Press, 2007), and Kaiser, *Pedagogy and the Practice of Science*.

5. Michael R. Welton, ed., *In Defense of the Lifeworld: Critical Perspectives on Adult Learning* (Albany: State University of New York Press, 1995). I take as exemplary here Simon Schaffer, "Accurate

Measurement Is an English Science," in *Values of Precision*, ed. M. Norton Wise (Princeton, NJ: Princeton University Press, 1995), 135–171.

6. Kristin L. Gunckel and Sara Tolbert, "The Imperative to Move toward a Dimension of Care in Engineering Education," in "A Critical Examination of the Next Generation Science Standards," ed. Troy D. Sadler and David E. Brown, special issue, *Journal of Research in Science Teaching* 55, no. 7 (2018): 938–961; Michael Lachney, "Building the LEGO Classroom," in *Lego Studies: Examining the Building Blocks of a Transmedial Phenomenon*, ed. Mark J. P. Wolf (New York: Routledge, 2014), 174.

7. For example, William C. Symonds, Robert Schwartz, and Ronald F. Ferguson, *Pathways to Prosperity: Meeting the Challenge of Preparing Young Americans for the 21st Century* (Cambridge, MA: Harvard University Graduate School of Education, 2011); National Academy of Sciences, National Academy of Engineering, and National Institute of Medicine of the National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (Washington, DC: National Academies Press, 2007); "Benchmarks for Science Literacy," American Association for the Advancement of Science/Project 2061, accessed August 5, 2018, http://www.project2061.org/publications/bsl/online/index.php.

8. For an overview of the historical function of education as actualizing potential, see Steven Bowles and Herbert Gintis, *Schooling in Capitalist America: Educational Reform and the Contradictions of Economic Life* (Chicago: Haymarket Books, 1976), 4–20; Christopher J. Phillips, *The New Math: A Political History* (Chicago: University of Chicago Press, 2015). Recent work has addressed how instructors and others in authority bring into being scientific interest and attainment in individuals concurrently with racial, gender, or other biological identifications; see Michael S. Dumas, "Against the Dark: Antiblackness in Education Policy and Discourse," *Theory into Practice* 55 (2016): 11–19; Kathryn L. Kirchgasler, "Dangers of 'Making Diversity Visible': Historicizing Metrics of Science Achievement in U.S. Education Policy," in *Handbook of Education Policy Studies*, ed. G. Fan and T. S. Popkewitz (Singapore: Springer, 2020); and Will Letts and Steve Fifield, eds., *STEM of Desire: Queer Theories and Science Education* (Leiden: Brill, 2019).

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11. Paolo Freire, "The Banking Concept of Education," in *Thinking about Schools: A Foundations of Education Reader*, ed. Eleanor Blair Hilty (Boulder, CO: Westview Press, 2011).

12. Andrew Pickering, "New Ontologies," in *The Mangle in Practice*, ed. Andrew Pickering and Keith Guzik (Durham, NC: Duke University Press, 2007), 4.

13. Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC: Duke University Press, 2007), 18–19. Science education is of course

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16. Slaton, *Race, Rigor and Selectivity*; Carson, *Measure of Merit*; Stephen Jay Gould, *The Mismeasure of Man* (New York: Norton, 1986).

17. See Carnegie Corporation of New York and Institute for Advanced Study, *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy*, Commission on Mathematics and Science Education, Carnegie Corporation of New York and Institute for Advanced Study, June 2009, https://production-carnegie.s3.amazonaws.com/filer_public/80/c8/80c8a7bc-c7ab-4f49-847d-1e2966f4dd97/ccny_report_2009_opportunityequation.pdf; Symonds, Schwartz, and Ferguson, *Pathways to Prosperity*; David E. Drew, *STEM the Tide: Reforming Science, Technology, Engineering and Math Education in America* (Baltimore: Johns Hopkins University Press, 2012); Kevin O'Connor, Frederick A. Peck, and Julie Cafarella, "Struggling for Legitimacy: Trajectories of Membership and Naturalization in the Sorting Out of Engineering Students," *Mind, Culture, and Activity* 22, no. 2 (2015): 168–183; Heidi B. Carlone, Julie Haun-Frank, and Sue C. Kimmel, "Tempered Radicals: Elementary Teachers' Narratives of Teaching Science within and against Prevailing Meanings of Schooling," *Cultural Studies of Science Education* 5, no. 4 (2010): 941–964; and Secules et al., "Zooming Out," 56–86.

18. Slaton, *Race, Rigor, and Selectivity*, 171–204.

19. Roderick A. Ferguson, *The Reorder of Things: The University and Its Pedagogies of Minority Difference* (Minneapolis, MN: University of Minnesota Press, 2012), 179; see also Damani J. Partridge and Matthew Chin, "Interrogating the Histories and Futures of 'Diversity': Transnational Perspectives," *Public Culture* 31, no. 2 (2019): 197–214; Sara Ahmed, *On Being Included: Racism and Diversity in Institutional Life* (Durham, NC: Duke University Press, 2012).

20. See Kirchgasler, "Dangers of 'Making Diversity Visible'"; and O'Connor, Peck, and Cafarella, "Struggling for Legitimacy." Critical studies of intellectual disability are immensely helpful here. See, e.g., Ashley Taylor, "Knowledge Citizens? Intellectual Disability and the Production of Social Meanings within Educational Research," *Harvard Educational Review* 88, no. 1 (2018): 1–25.

21. See Daniel Martinez HoSang, Oneka LaBennett, and Laura Pulido, eds., *Racial Formation in the Twenty-First Century* (Berkeley: University of California Press, 2012).

22. See National Academies, "Executive Summary," in *Rising Above the Gathering Storm*. Very helpfully, Kirchgasler historicizes such claims of a one-way causal relationship between stereotype bias and resource distribution; see "Dangers of 'Making Diversity Visible,'" esp. 338–342. Adding further complexity to all such historical accounts are vigorous claims from the right about the fragility of meritocratic systems following the civil rights era—for example, David O. Sacks and Peter A. Thiel, *The Diversity Myth: "Multiculturalism" and the Politics of Intolerance at Stanford* (Oakland, CA: Independent Institute, 1995).

23. Ian Hacking, "Making Up People," in *Reconstructing Individualism: Autonomy, Individuality, and the Self in Western Thought*, ed. Thomas C. Heller, Morton Sosna, and David E. Wellbery (Stanford, CA: Stanford University Press, 1986), 223; Clara O'Shea, "Learning How Kinds Matter: A Posthuman Rethinking Ian Hacking's Concepts of Kinds, Dynamic Nominalism, and the Looping Effect," in *Proceedings of the 11th International Conference on Networked Learning 2018*, ed. Milan Bajic et al. (Zagreb: Zagreb University of Applied Science, 2018), 203; Fenwick, "Re-thinking the 'Thing,'" 104.

24. Fenwick, "Re-thinking the 'Thing,'" 105.

25. Barad, *Meeting the Universe Halfway*, 140.

26. See O'Connor, Peck, and Carafalla, "Struggling for Legitimacy."

27. Gary Peller, *Critical Race Consciousness* (Boulder, CO: Paradigm Publishers, 2011), 6.

28. NGSS Lead States, "Executive Summary," 1. Phillips follows the parallel development of mathematics teaching standards through the Cold War and subsequent political periods in the US. See Christopher J. Phillips, *The New Math: A Political History* (Chicago: University of Chicago Press, 2015).

29. Darren G. Hoeg and John Lawrence Bencze, "Values Underpinning STEM Education in the USA: An Analysis of the Next Generation Science Standards," *Science Education* 101, no. 2 (2017): 278–301, 279.

30. National Research Council, *Inquiry and the National Science Education Standards*: *A Guide for Teaching and Learning* (Washington, DC: National Academy Press, 2000), xiii; and Loucks-Horsley et al., *Elementary School Science*, ix.

31. Amy E. Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930* (Baltimore: Johns Hopkins University Press, 2001), 20–61; see Kaiser, *Pedagogy and the Practice of Science*.

32. John L. Rudolph, "Epistemology for the Masses: The Origins of 'The Scientific Method' in American Schools," *History of Education Quarterly* 45, no. 3 (2005), 352–354. On technical education in particular, see Slaton, *Reinforced Concrete*, 20–61.

33. See Slaton, *Race, Rigor, and Selectivity*; Sharon Traweek, *Beamtimes and Lifetimes: The World of High Energy Physicists* (Cambridge, MA: Harvard University Press, 1988); and Jonson Miller, *Engineering Manhood: Race and the Antebellum Virginia Military Institute* (Ann Arbor, MI: Lever Press, 2020).

34. See Steven Brint and Jerome Karabel, *The Diverted Dream: Community Colleges and the Promise of Educational Opportunity in America, 1900–1985* (Oxford: Oxford University Press, 1989).

35. Mary F. E. Ebeling and Amy E. Slaton, "Promise Her Anything: Education for Work in the U.S. 'Nanoeconomy,'" (unpublished manuscript, 2018); Gunckel and Tolbert, "Imperative to Move," 945; Whalley and Barley, "Technical Work," 32–34.

36. See Mike Rose, *The Mind at Work: Valuing the Intelligence of the American Worker* (New York: Penguin, 2004); Slaton, *Race, Rigor, and Selectivity*; and Justin Carone, "Fixing Value: History, Ethnography, and Material Ontologies of Deservingness in a Philadelphia Repair Shop," *History and Technology* 33, no. 4 (2017): 367–395.

37. See Gunckel and Tolbert, "Imperative to Move"; O'Connor, Peck, and Cafarella, "Struggling for Legitimacy"; and Erin A. Cech et al., "Epistemological Dominance and Social Inequality: Experiences of Native American Science, Engineering, and Health Students," *Science, Technology & Human Values*, 42, no. 5 (2017): 743–774.

38. NGSS Lead States, "Appendix A: Conceptual Shifts," in *Next Generation Science Standards*.

39. National Research Council, *Framework for K–12 Science Education*, 10–11.

40. NGSS Lead States, "Appendix A: Conceptual Shifts."

41. See Christopher Newfield, *Ivy and Industry: Business and the Making of the American University, 1880–1980* (Durham, NC: Duke University Press, 2003); David C. Mowery et al., *Ivory Tower and Industrial Innovation: University-Industry Technology Transfer before and after the Bayh-Dole Act* (Stanford, CA: Stanford University Press, 2004); and Slaton, *Race, Rigor, and Selectivity*.

42. See Mihail C. Roco, Chad A. Mirkin, and Mark C. Hersam, *Nanotechnology Research Directions for Societal Needs in 2020*: *Retrospective and Outlook* (Berlin: Springer, 2011).

43. See Mody, *Instrumental Communities*; Mary F. E. Ebeling, "Mediating Uncertainty: Communicating the Financial Risks of Nanotechnologies," *Science Communication* 29, no. 3 (2008): 335–361; and Ebeling and Slaton, "Promise Her Anything."

44. See Ebeling, "Mediating Uncertainty"; Judith Light Feather and Miguel F. Aznar, *Nanoscience Education, Workforce Training, and K–12 Resources* (Boca Raton, FL: CRC Press, 2011), 126. Nano-related workforce anxieties took shape as part of the more general worry in the US about global economic competition. For representative arguments, see National Academies, *Rising Above the Gathering Storm*.

45. William Sims Bainbridge, ed., *Societal Implications of Nanoscience and Nanotechnology* (Boston: Kluwer Academic, 2001).

46. See Light Feather and Aznar, *Nanoscience Education*; Campbell et al., "Exploring the Nanoworld"; Turner et al., "Seeing the Unseen," 58.

47. See Ebeling and Slaton, "Promise Her Anything."

48. See Frederick M. Hess and Michael J. Petrelli, *No Child Left Behind: Primer* (New York: Peter Lang, 2006); and Tim Walker, "Despite Progress, the 'Charade' of High-Stakes Testing Persists," *NEA Today*, April 4, 2018, https://www.nea.org/advocating-for-change/new-from-nea/despite-progress-charade-high-stakes-testing-persists.

49. Antonia Darder, foreword to *Neoliberalizing Education Reform*, ed. Keith M. Sturges (Rotterdam: Sense Publishers, 2015), x–xi.

50. See Jacqueline Jones, *American Work: Four Centuries of Black and White Labor* (New York: Norton, 1998); and Nikhil Pal Singh, *Black Is a Country: Race and the Unfinished Struggle for Democracy* (Cambridge, MA: Harvard University Press, 2004).

51. Pickering, "New Ontologies," 5; see Geoffrey C. Bowker, *Science on the Run: Information Management and Industrial Geophysics at Schlumberger, 1920–1940* (Cambridge, MA: MIT Press, 1994). Of special interest for this paper are accounts that analyze identity constructions contingent on such representations, e.g., Traweek, *Beamtimes and Lifetimes*; Tiago Saraiva, *Fascist Pigs: Technoscientific Organisms and the History of Fascism* (Cambridge, MA: MIT Press, 2016); and Carone, "Fixing Value." See also Slaton, *Race, Rigor, and Selectivity*.

52. See Rudolph, "Epistemology for the Masses"; Leigh Patel, "Reaching beyond Democracy in Educational Policy Analysis," *Education Policy* 30, no. 1 (2016), 117.

53. Campbell et al., "Exploring the Nanoworld," 17.

54. Campbell et al., 17–18.

55. Campbell et al., 6.

56. Partnership for 21st Century Learning, "Framework for 21st Century Learning," Battelle for Kids, 2019, http://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf; Lachney, "Building the Lego Classroom," 174.

57. Beth Warren et al., "Rethinking Diversity in Learning Science: The Logic of Everyday Sense-making," *Journal of Research in Science Teaching* 38, no. 5 (2001), 539.

58. On the arbitrary nature of these demarcations, see essays in Letts and Fifield, *STEM of Desire*.

59. NGSS Lead States, "Appendix H: The Nature of Science," in *Next Generation Science Standards*.

60. Jones et al., *Nanoscale Science*, 69.

61. See Barbara Townley, *Reframing Human Resource Management: Power, Ethics and the Subject at Work* (London: Sage, 1994); David A. Hollinger, "Inquiry and Uplift: Late Nineteenth-Century American Academics and the Moral Efficacy of Scientific Practice," in *The Authority of Experts: Studies in History and Theory*, ed. Thomas L. Haskell (Bloomington: University of Indiana Press, 1984), 142–156; and many of the essays in Kaiser's *Pedagogy and the Practice of Science*, which delve deeply into the contingent and morally freighted character of scientific replication and certainty. The most helpful history of science literature from the perspective of structural discrimination has picked up science's emphasis on the identities, broadly conceived, of "good" research actors

at the level of experimenter, technician, or witness, as in Schaffer, "Accurate Measurement," and Steven Shapin, "The Invisible Technician," *American Scientist* 77, no. 6 (1989): 554–563.

62. Jeff Nordine and Ruben Torres, "Enhancing Science Kits with the Driving Question Board," *Science and Children* 50, no. 8 (2013): 57–61.

63. Michel Foucault, *Discipline and Punish*, trans. Alan Sheridan (New York: Vintage Books, 1977), 136; Amy E. Slaton, Erin A. Cech, and Donna M. Riley, "Yearning, Learning, Earning: The Gritty Ontologies of American Engineering Education," in Letts and Fifield, *STEM of Desire*, 319–340; Slaton, *Reinforced Concrete*; and Slaton, *Race, Rigor, and Selectivity*. Recent work on intellectual disability is central here; see note 20.

64. O'Connor, Peck, and Cafarella, "Struggling for Legitimacy," 177; Hoeg and Bencze, "Values Underpinning STEM Education."

65. Campbell et al., "Exploring the Nanoworld," 5.

66. Taylor, "Knowledge Citizens," 2.

67. National Research Council, *Inquiry*, xiii; Loucks-Horsley et al., *Elementary School Science*, 18.

68. Examples include Warwick Anderson, "Introduction: Postcolonial Technoscience," *Social Studies of Science* 32, no. 5 (2002): 643–658; and Ann Laura Stoler, ed., *Haunted by Empire* (Durham, NC: Duke University Press, 2006).

69. See Taylor, "Knowledge Citizens."

70. Gert Biesta, *The Beautiful Risk of Education* (Boulder, CO: Paradigm Press, 2014), 1, 34.

71. Projit Bihari Mukharji, "Occulted Materialities," in "Thinking with the World: Histories of Science and Technology from the 'Out There,'" edited by Gabriela Soto Laveaga and Pablo F. Gómez, special issue, *History and Technology* 34, no. 1 (2018), 33–34.

72. NGSS Lead States, "Appendix H: The Nature of Science."

73. See Eduardo Viveiros de Castro, "Perspectival Anthropology and the Method of Controlled Equivocation," *Tipiti: Journal of the Society for the Anthropology of Lowland South America* 2, no. 1 (2004): 3–22.

74. Jones et al., *Nanoscale Science*, 42–43.

75. Jones et al., 42–43.

76. Mukharji, "Occulted Materialities," 35–36.

77. See Taylor, "Knowledge Citizens"; Cech et al., "Epistemological Dominance"; and Slaton, *Race, Rigor, and Selectivity*.

78. Megan Bang and Douglas Medin, "Cultural Processes in Science Education: Supporting the Navigation of Multiple Epistemologies," *Science Education* 94, no. 6 (2010): 1008–1026.

79. Secules et al., "Zooming Out," 60; see Cech et al., "Epistemological Dominance."

80. Patel, "Reaching beyond Democracy," 117.

81. In critiquing the pipeline model, Carone problematizes economic disadvantage as arbitrary exclusion (see "Fixing Value"); O'Connor, Peck, and Cafarella articulate, following Leigh Star, how those deemed peripheral actors secure the centrality of those in authority ("Struggling for Legitimacy," 168–169). Research literature on science education in America is vast, and in addition to unreflective projects aiming to support meritocratic visions, it includes important critical work that helps explain such unjust social instrumentalities/ For excellent overviews, see Secules et al., "Zooming Out," and Donna M. Riley et al., "Feminisms in Engineering Education: Transformative Possibilities," *NWSA Journal* 21, no. 2 (2009): 21–40. Here I want to draw in particular on ideas of epistemic imperialism and epistemic injustice to displace rhetoric of "inclusion" and "diversity" in research and historical studies of technical education that routinely hide how epistemic operations produce human difference. On epistemic imperialism, see Dan Goodley and Griet Roets, "The (Be)comings and Goings of 'Developmental Disabilities': The Cultural Politics of 'Impairment,'" *Discourse Studies in the Cultural Politics of Education* 29, no. 2 (2008): 239–255, and on epistemic injustice, see Taylor, "Knowledge Citizens."

82. Taylor, "Knowledge Citizens," 2–3; Warren et al., "Rethinking Diversity," 546; O'Connor, Peck, and Cafarella, "Struggling for Legitimacy," 181. Warwick and Kaiser problematize Kuhn's point that the learning of physics was not based in "understanding, but practice." That disarticulation of "mastery of craft skill" and "insight into meaning" is one of the stubborn framings of science pedagogy that this essay also challenges. Andrew Warwick and David Kaiser, "Conclusion: Kuhn, Foucault, and the Power of Pedagogy," in Kaiser, *Pedagogy and the Practice of Science*, 395.

83. John Law and Marianne Elisabeth Lien, "Slippery: Field Notes in Empirical Ontology," *Social Studies of Science* 43, no. 3 (2013): 363–378.

84. See in particular Goodley and Roets on "poststructuralist thinking" in disabilities scholarship ("(Be)comings and Goings," 242–243). Also, Steve Fifield and Will Letts, "[Re]considering Queer Theories and Science Education," *Cultural Studies of Science Education* 9, no. 2 (2014): 393–407.

85. See Paolo Freire, *Pedagogy of the Oppressed* (1970; London: Continuum, 2007); Amy E. Slaton, "Merit Makes the Difference" (paper presented at "Technologies in Use" Conference, Max Planck Institute for the History of Science, Berlin, April 5, 2018); and Ferguson, *Reorder of Things*, 223.

86. I am deeply indebted to Jesse Smith for his articulation of this distinction.

87. Fenwick, "Re-thinking the 'Thing,'" 110–112.

88. Warren et al., "Rethinking Diversity," 546; Susan Gabel, "Some Conceptual Problems with Critical Pedagogy," *Curriculum Inquiry* 32, no. 2 (2002), 184; Goodley and Roets, "(Be)comings and Goings," 243; David J. Connor and Jan W. Valle, "A Socio-cultural Reframing of Science and Dis/Ability in Education: Past Problems, Current Concerns, and Future Possibilities," *Cultural Studies of Science Education* 10, no. 4 (2015): 1103–1122.

89. See La paperson, *A Third University Is Possible* (Minneapolis: University of Minnesota Press, 2017); and Slaton, Cech, and Riley, "Yearning, Learning, Earning." The historicization of inventive

deficit in STEM settings as a racialized concept is very well supported by André Brock, *Distributed Blackness: African American Cybercultures* (New York: New York University Press, 2020).

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