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Expanding What Counts as Scientific Investigations in the Era of the Next Generation Science Standards

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Abstract: Science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory. We argue that this is a narrowly drawn image of investigation that leads to lost opportunities for learning and teaching science. These include opportunities to develop an investigator's skills and conceptual understandings and situate investigatory practices within a broader scientific epistemology. This study portrays examples of the day-to-day investigations involved in a non-laboratory, scientific workplace: a neighborhood coffee roastery. Through microethnographic analyses we show that professional coffee roasters accomplish the same goals that science education reforms seek to achieve, and that these goals take different forms. We argue that coffee roasters' uses of investigatory practices toward non-laboratory, everyday ends expand our views of what counts as scientific investigations in the current era of reform.

Introduction

Science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory (National Research Council, 2012). We will argue that this is a narrowly drawn image of investigation that leads to lost opportunities for learning and teaching science. First, an emphasis of investigation (in the NRC's terms, encompassing what is conventionally called experimentation) as theory testing minimizes the role of human agency in scientific knowledge production (Gooding, 1990), implying a view that theories, not humans, motivate scientific action (Radder, 2009). Second, investigations allow for the co-development of embodied investigatory skill and conceptual development (Maslen & Hayes, 2022) which are erased by theory-testing perspectives. Lastly, researchers have paid less attention to the interdependence of investigation and related scientific practices (e.g., modeling) in the practice turn era (Ford & Forman, 2006; Manz et al., 2020). Rather than a central driver within a broader scientific epistemology, reform documents treat investigation as a process to *confirm* existing theories and demonstrate content understanding (Hodson, 2014). There is thus a need to better understand *in situ* practices of investigation and their relevance to the current era of science education reform.

Our choice of "in situ" practices requires elaboration. First, ethnographers of science have long argued that leading images of scientific activity are partial and distorted. These images "have been culled from interviews with eminent ex-scientists or from other public pronouncements about the nature of science" (Woolgar, 1988, p. 86) and advance reconstructions of science as methodical, systematic and the logical outcome of linear scientific procedures. Ethnographic field studies of science involving the *in situ* observation of scientific activity reveal less linear and logical and far more social ways of scientific knowledge production (e.g., Latour & Woolgar, 1987). Such ethnographies make visible the embodied, material, and social ways of working ("practices") which are often written out of publications (Gooding, 1990). Second, we argue that scientific practices are not limited to the actions of professional scientists (Conner, 2005; Secord, 1998; Shapin, 2012) and that a broader view of investigation from other settings can recover the rich diversity of science in our lives. To expand our imagery, we advance findings from a multisite, ongoing project that examines the people, practices, and cultures of *non-laboratory, scientific workplaces*. We argue that this approach, and similar examinations of scientific activity outside of the laboratory, can reshape our views of how and why science is conducted, and ultimately can and should impact the ways that science is taught and learned in schools. Our objective in this paper is to portray examples of the day-to-day investigations involved in a non-laboratory, scientific workplace. Our program of work begins here with the practices of investigation enacted by professional coffee roasters.

This paper's theoretical frame for investigation comes from the National Research Council's *A Framework for K-12 Science Education* (2012). The consensus report reads, "Scientists and engineers investigate and observe the world with essentially two goals: (1) to systematically describe the world and (2) to develop and test theories and explanations of how the world works" (p. 59). Ethnographies of science, on the other hand, show that scientists investigate for goals beyond these two (cf. Knorr-Cetina, 1981; Lynch, 1985; Woolgar, 1988) and some philosophers of science view theory-testing as actually hindering scientific advancements (e.g., Feyerabend, 1975). Additional goals of investigation include scientists' attempts to simply “make things work” (Knorr-Cetina, 1984) and develop their own experimental skill (Gooding, 1992). However, and because we wish to locate our work inside ongoing reform conversations, we adopt the NRC's language.

In the following sections we will view coffee roasters' practices through a lens of Planning and Carrying Out Investigations, the third of eight Science and Engineering Practices offered by the *Framework* (NGSS Lead States, 2013). All K-12 learners, according to the *Framework*, should be able to do these seven things as part of investigations by graduation: (1) formulate questions (2) and theory-based hypotheses, decide on (3) tools, the (4) type of data, and (5) amount of data, and plan a procedure that (6) identifies variables and (7) controls (NRC, 2012, p. 60).

There are strong competing images of *what* science *is*, and we do not seek to add fuel to those ongoing debates. As such, in this paper, we do not argue that coffee roasting *is* science. Rather, we argue that *all* of the NRC's goals of investigation are involved in coffee roasting. The former is an intractable philosophical debate that distracts from the broader aims of our project: to expand our scientific imagery toward re-imaginations of science education. The latter is not a question of philosophy primarily, but one of empirical evidence.

In this paper we empirically demonstrate one roaster’s application of the goals as he develops a new coffee product. Through our analyses we will show that the science *in* coffee roasting has implications which extend beyond new perspectives of investigatory practices. For example, the scientific practices in roasting demonstrate the real-world value of scientific knowledge and know-how—answering questions teachers routinely get and often dread, such as, “When will I ever need to know this?” More broadly, presenting cases of scientific knowledge and practices of *non-laboratory work* connects with the *Framework’s* "goals [that] are for all students, not just those who pursue careers in science, engineering, or technology or those who continue on to higher education" (p. 9). The practices involved in coffee roasting thus speak to a vision of science education for *all* learners, and especially those roughly 90% of American K-12 students (NSF, 2022) who do not pursue normatively recognized science careers.

Methods: Research Context

The principal roastery in this paper is in a small Midwestern college town. Sam and Mimi operate an 800-square-foot roastery as a “community-oriented coffee company.” This sentiment is reflected in the roastery’s neighborhood location and literal opened doors, through which customers often visit to fill their reusable coffee bean containers, or to join weekend “sensory evaluation” education experiences. Sam contrasts this community feeling with prior employment as a “production roaster” at large-scale, “soulless,” industrial coffee roastery. Sam roasts 180 pounds of coffee three days a week (MWF) and Mimi handles the business’ logistics to serve its coffee houses, numerous wholesale accounts, and online orders. On the weekends they attend farmers’ markets to interact with the public and teach various beginning-to-advanced coffee tasting and roasting courses. On Tuesdays and Thursdays, Sam and Mimi travel to establish new accounts and experiment with new coffee products and services, such as the day's sample roasting of a new coffee from Peru.

Methods: Data Collection and Analysis

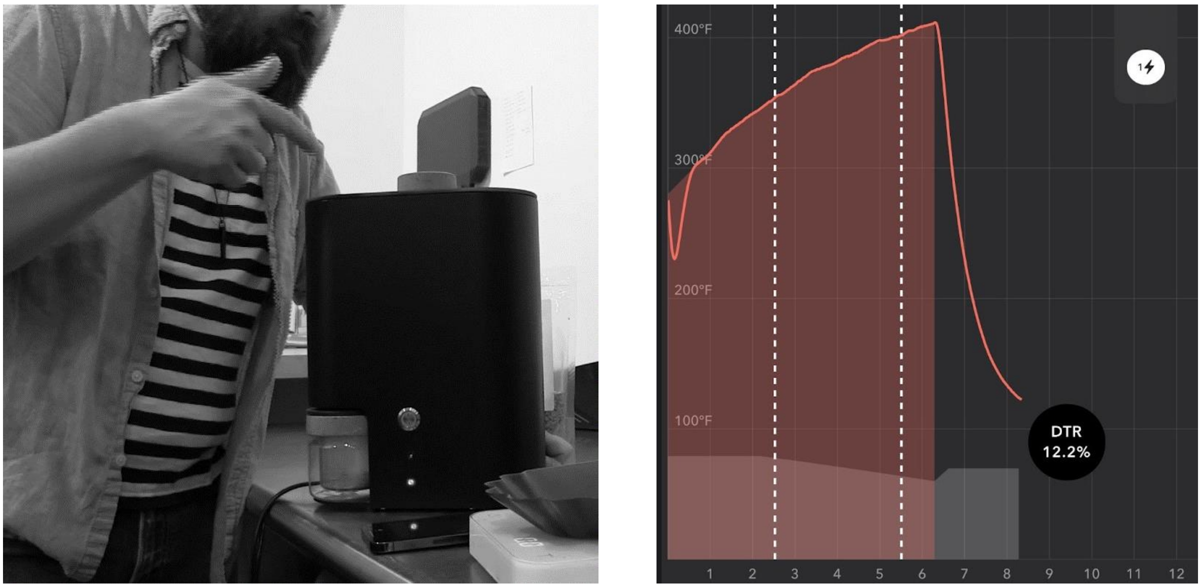
We began participant observation (Becker & Geer, 1957) with Sam and Mimi in May, 2022. We have since participated alongside and observed Sam and Mimi during roasting sessions, sensory evaluations, barista trainings, and coffee classes. This paper draws from a broader data corpus that consists of audiovisual data (Erickson, 2006), semi-structured and photo-/video-elicitation interviews (Harper, 2002), as well as field notes, jottings, memos, and annotated photographs (Emerson et al., 2011). In combination with participant observations at additional roasteries, these sources represent roughly 200 hours and 250 pages of data. In this paper we present microethnographic analyses (Streeck & Mehus, 2005; Stevens & Hall, 1998; Hall & Stevens, 2015) of Sam’s investigatory practices recorded on video over the course of an afternoon. What was captured during this afternoon is representative of what we see in the broader data corpus. These analyses include Sam’s non-verbal actions, verbal explanations of his actions, and our interpretations of how these actions allow for the completion of his work. Lastly, Sam reviewed our findings and incorporated his insights when possible.

Findings: Sample Roasting

The investigation we explore is a sample roasting session, and a brief introduction is needed. Sam’s raw, green coffee ranges from $4 to $7 per pound and he buys beans in thousand-pound shipments. The unknown quality and characteristics of the raw coffee makes each purchase something of a gamble. To minimize risks, Sam sources 300-gram samples from coffee importers, develops various "roasting profiles," performs sensory evaluations by smelling and tasting the coffee, and ultimately decides to purchase it in bulk or not. Sam invited us to observe sample roasting so that we could understand the entire scope of his workflow: from sample roasting and purchasing, to fine-tuning “retail roasts,” educating the company’s baristas, and selling the coffee. The data below are drawn from a sample roasting session which Sam described as “literally the very first step” in his process. The machine that Sam uses in his daily operations is a 26-pound capacity IR-12 Diedrich and is thus too large for sample roasting. Instead, Sam uses a 50-gram PRO50 Ikawa sample roaster (Figure 1, left). Sam’s down-scaling of tools resembles microscale investigations in laboratories:

> Which is why it's nice using the Ikawa. You can try multiple things and you're using only 50 grams per batch. Where if I wanted to have that experimentation on the Diedrich I'd have to use 60 pounds for three different sample roasts. And that's expensive for me, and importers, and farmers.

Figure 1
Sam’s Ikawa Roasting Machine (left) and “Roasting Profile” (right).



The sample roasting session (hereafter “investigation”) is motivated by Sam’s concern that his existing “lineup is really small compared to most roasters.” The roastery’s four coffees don’t meet consumers’ wide-ranging expectations. To fix this, Sam wants to create a rotating blend. “My goal is...a roaster's blend...like a rotating blend that we just come up with here. We probably won't even put the origin on the bag...So people always know it's a rotating blend.” Expectations has two meanings here. The first is what a roastery is expected to offer in terms of coffee varieties; the second is an alignment between consumers’ and roasters’ sensory expectations. The latter informs many of Sam’s practices:

> This is a coffee, that, if I do like it, I'll probably buy it to create a new blend for [current company]. It'll be a mixture of this Peru and a, hopefully, Burundi. I'm starting with a Peru and a Burundi, something that I did with [previous company] back in the day. I was just spitballing, and I was bored, and I blended these two coffees together and it was just ((gestures with hands)) delightful. It was so good. You know. You get the nuttiness and caramels of a Peru, and you get those higher acids, little bit of a tea and herbal thing from the Burundi. It was so nice. I called it Perundi ((laughter)). Yeah, it worked out pretty well.

With a *question* to guide his work (SEP3 goal 1), “What’s the best way to roast this Peru?”, Sam plans a *procedure* (SEP3 goals 6 and 7). A procedure in coffee roasting takes the form of a “roasting profile” (Figure 1, right). Profiles are sets of time and temperature values that roasters design for each individual coffee. As another roaster in our study has said, “Each coffee demands something different. It’s like they have their own personality.” For Sam, roasting profiles are graphical representations of these time and temperature values (Figure 1) and he annotates these graphs with crucial decisions made while roasting. Sam’s annotations allow for an iterative process with the ideal procedure becoming the final “standard profile” (see Gloess et al., 2014 for laboratory investigations of roasting profiles). Sam begins by selecting a procedure from Ikawa's online repository. To refine his search, Sam looks for a profile for Peruvian coffees, "I know we've had a Peru before. I'll do a couple roasts of this. The first one I'll do [is] a standard, 'oh if you don't know anything about this coffee, this is a good starting point.'" Sam is unable to find a profile for Peruvian coffees in Ikawa's database. Instead, he selects one from a trusted source, coffee consultant Rob Hoos, who has uploaded his procedures to Ikawa. "The point of this roast, according to Rob, is...to emulate...a real time roast that would have all your sets of drying, browning, and development."

Sam has chosen his *tools* for this initial investigation (SEP3 goal 3). Moreover, we view his decisions to use the smaller-scale Ikawa and a roasting profile from coffee consultant Rob Hoos as framing a *theory-based hypothesis* (SEP3 goal 2) in ways that move beyond the NRC's goals. Sam does not simply think about what kind and how much data to collect. Rather, his first strategy, selecting a profile and roasting a coffee based on its origin, requires discipline-specific knowledge of coffees that originate from the same country. This is what historians and philosophers of science term *theoretical presuppositions*: "Such commitments cannot *all* be optional, nor can they be treated as if they were distorting 'biases.' Rather they are the sine qua non of beginning an experiment—as well as ending it" (emphasis in original, Galison, 1987, p. 4). Sam's second strategy, selecting a profile based on someone else's expertise, indicates trust in the broader organization of shared disciplinary knowledge—a phenomenon some ethnographers of science call "epistemic cultures" (Knorr-Cetina, 1999). Both decisions display a continuum of knowledge and trust of competence that pervade the discipline of coffee roasting. Sam's reliance on prior knowledge and a community of practitioners as entry points into his investigation underscore reasons for investigation beyond theory testing (Radder, 2009). For instance, Sam's work highlights the role of human agency in experimentation (Gooding, 1992) as a way to "make things work" (Knorr-Cetina, 1984). To summarize Sam's investigation so far: he is driven to re-create the Peru's "nuttiness and caramels"; has chosen appropriate materials (the Ikawa rather than the Diedrich; SEP3 goal 3); and decided on a procedure (Rob Hoos' roasting profile). Sam's choice of profile reveals the relevant types of data (SEP3 goal 4) he requires in this investigation, such as quantitative time and temperature data, as well as qualitative data of the Peru's "drying, browning, and development" (Folmer et al., 2017).

Sam not only *identifies relevant data* (SEP3 goal 4) but integrates these into a broader investigatory repertoire involving his senses. Roughly six minutes into the nine-minute roast, he leans into the Ikawa, places his left ear above the machine's roasting chamber, and says, "I'm gonna try to listen for first crack." As the liquid water inside the Peruvian beans begins to boil, transition into gas and expand, the beans become visibly larger and crack open like popcorn. The relationship between temperature and "first crack", as detected by Sam's sense of sound, is important to future roasts with the Peru: "You want to be able to taste all the nuance of the coffee. That will give you an idea of, [should I] take this a little darker and give it more body?" First crack is thus a reference point that Sam must establish in his aim to highlight the Peru's characteristics. Sam does not want to roast beyond first crack as that would impart smells and tastes from the roasting process, thereby masking the qualities inherent only in the beans. Once he knows the Peru's first crack temperature, he can adjust parameters to optimize different characteristics in the coffee. Discerning first crack is not easy: "I heard one little pop. That's what I call a ghost pop. I'm gonna wait until we hear a really consistent ((interrupts statement to listen in silence))." Seconds later, Sam annotates the graph with what he believes to be first crack (white lines in Figure 2), thereby producing a piece of knowledge in the multi-step process of developing a new rotating blend. The ambiguity of first crack is not a result of Sam's senses, but rather chemical reactions' stochasticity. All roasters in our study note that few roasts behave identically, even those with seemingly identical beans. In this episode Sam identifies sound as *data type relevant* to his investigation (SEP3 goal 4) and his pausing for more sounds identifies a *relevant amount of data* required in his investigation (SEP3 goal 5).

Sam's sensory discernment (Goodwin, 1994) of first crack resembles many scientific practices in the face of nature's recalcitrance (Gooding, 1992). For example, these practices are found in Goodwin's case study of geochemists (Goodwin, 1997) who use their senses to determine when a chemical reaction should be terminated. For Sam, the variability in roasts causes ambiguity in first crack and leads to abundant evidence that he is exercising his human agency: hesitation, uncertainty, finer discernment, and subsequent identification. Sam's practices so far seem to challenge images of scientific activity that advance accounts of objective, meticulous adherence to rigidly followed procedures. However, this "is another artifact of the disembodied, reconstructed character of retrospective accounts [of scientific activity]" (Gooding, 1992, p. 68).

Sam revises his procedure in light of new data. To do this, he inspects the roast's time and temperature data and analyzes what roasters call the rate of rise: the average rate of change in temperature computed over 30 second intervals. Sam notices that the rate of rise headed toward a negative value. On a previous day he said, "When we're getting close to the end ((points at computer monitor)) you don't want this number, your rate of rise, to drop below 0." A negative rate of rise, according to Sam, means that "essentially nothing is happening. There's no activity going on...there's less reactions happening because of the low energy." In this sample roast, Sam interprets the negative rate of rise to mean that the profile was probably not meant for a Peru: "That's one thing I noticed about Rob's profile is that the rate of rise dipped into the negatives there ((points at graph; Figure 2, left)). So I think that could have potentially stalled this coffee and maybe on a different coffee that rate of rise wouldn't have dipped...Maybe an Ethiopian?" Sam interprets data (time, temperature, sound, rate of rise; SEP3 goal 4) and creates new knowledge: the Peru requires a changed profile for a positive rate of rise.

Revising investigations in light of new evidence is notably missing from the NRC's seven goals. We suggested that too narrowly drawn images of investigation lead to lost opportunities for teaching and learning science. This is one such opportunity. Revising investigations based on new evidence is a hallmark of scientific practice (e.g., Gooding, 1990) and is argued to be a causal mechanism underpinning revolutions in scientific theories (Kuhn, 1970). However, Sam demonstrates that revising investigations has utility and meanings in addition to theory testing. For instance, Sam's revisions are made possible by his investigatory skill—in particular, his sense of hearing and identification of first crack. Second, Sam ties his revisions to conceptual understandings, exhibited by his analyses of the roast's rate of rise ("There's no activity going on...there's less reactions happening because of the low energy"). Related, Sam's revisions are dependent on his analyses, showcasing an interdependence of practices that is underdeveloped in the NGSS era (Manz et al., 2020).

Sam's "Maybe an Ethiopian?" displays the tacit knowledge he has developed from years of roasting. This knowledge "is as much an art of doing as it is an art of knowing" and has long "remained unspecifiable at the very heart of science" (Polanyi, 1962, p. 56). While not a goal of SEP3, Sam's sensory discernment between "ghost pops" and "consistent" first cracks, analysis of rate of rise, and ability to integrate these toward revisions to his procedures underscore the role of knowledge and skill in investigations. One wonders how the disembodied goals of SEP3 (asking questions, identifying data and variables, and so on) are differentially achieved by an investigator's ability *and* desire to answer those questions and identify those data. More broadly, Sam's investigatory practices cause us to re-ask the question of how human skill impacts the quality and quantity of data that can be collected, and how human skill impacts subsequent revisions to investigations. Further, these data and revisions are made possible by Sam's skills *and* interest and promote conceptual development that are core outcomes of school science investigations (Hodson, 2014).

We observed interdependence between Sam's investigatory skills and his conceptual understandings. During his post-roast analyses Sam pauses and says, "...honestly, before I started doing this I should have…tested the density of this coffee and the moisture content…I'll do that on another day. I'll test everything first and really hone in on what I think will be a good profile for it [the Peru]." These data (SEP3 goal 3), according to Sam's theory of roasting, impact a roast's "charge temperature" (SEP3 goal 6: identification of variables). Sam says that "the more dense something is, the higher temperature it can withstand." Thus, if this Peru is more dense than the coffee Rob Hoos developed his profile for, then Sam has to adjust the initial temperature of the roast: "If this was a tiny little peaberry [a type of coffee bean], that's super tightly densely packed, it's gonna need more heat, more energy, to penetrate the bean. So, yeah. It will tell me the starting point of the coffee." Laboratory studies confirm Sam's comments about density and moisture content affecting a roast's heat distribution, and likewise recommend changes to charge temperatures to maintain consistency (Ogunjirin et al., 2020). Sam did not measure the density or moisture content of this Peruvian coffee, despite articulating that he should have and will in the future. This once again highlights the methodological necessity to observe scientific activity as it unfolds and restore what is often written out of narrative reconstructions (Gooding, 1990) and other influential images of science.

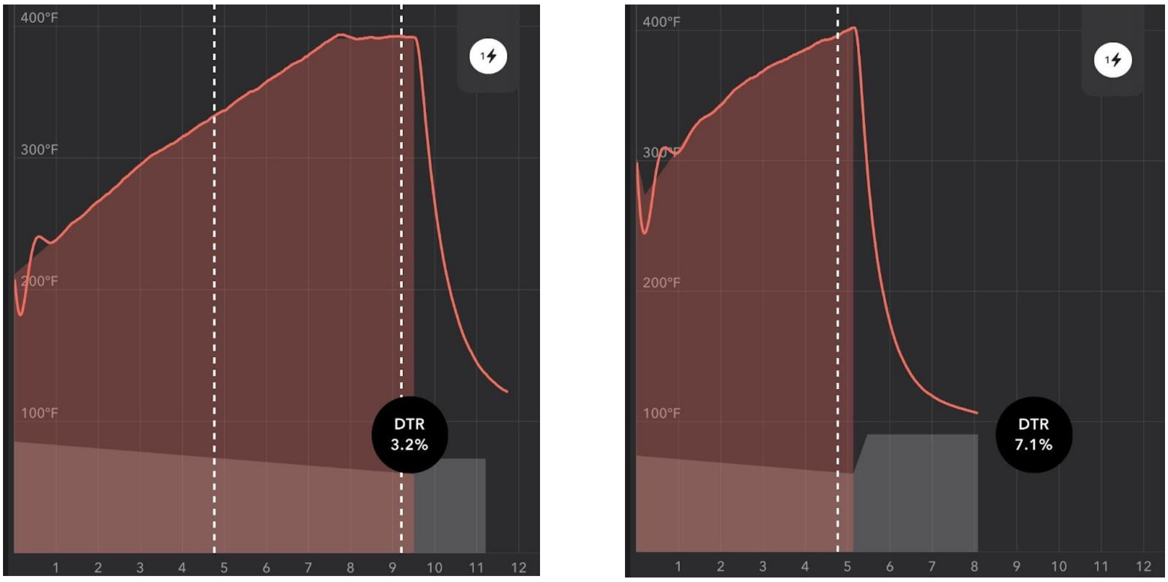
Sam produced new knowledge about how to roast Peruvian coffees, learned from his post-roast analysis, and revised his procedure in response. "My goal is to add more temp on there" to "get a nice rolling crack for this coffee." Sam's revisions allow him to compare roast #1 with roast #2 (SEP3 goal 5) and experience all of the Peru's nuance in a tasting session that will follow (SEP3 goal 4). To add more temperature to the roast, Sam literally clicks and drags the end point of the time-temperature graph in the Ikawa app (Figure 2). A higher temperature means that oils and related organic molecules in the beans will undergo additional chemical reactions and produce a wider range of flavors, and that already-ongoing reactions will occur at a greater rate and over a longer period of time (for an overview of the organic chemistry of roasting see Folmer et al., 2017). Sam makes his new knowledge and revisions explicit:

> So what I want to do with that info is…I want...a profile now that goes a little bit deeper into the roast. Shorter, but higher end temp. The end temp on this one was only 394[°F]. So, I don't think it really had enough energy to really get a nice first crack going…I think it will still give me a good idea of the potential that this coffee has. So, I'm gonna go edit ((clicks edit)) and I can adjust the curve here ((drags curve on Ikawa app)). My goal is to add more temp on there.

> So I'm just gonna [drag it up]. There we go...And now we're gonna try this one out ((laughs)) and see.

Figure 2

Sam's first profile from Rob Hoos (left) and the revised profile (right). Sam shortened the roast time from 9:31 to 5:08, increased the charge temperature from 210℉ to 302℉, and raised the target end temperature from 392℉ to 403℉. The revisions resulted in greater development time ratio (DTR) by 3.9% (from 3.2 to 7.1).



Sam's revisions provide a snapshot of investigation in a longer arc of work, revealing interdependencies between practices of investigation and interpretation (Manz et al., 2020). Here, he analyzes data from roast #1 to make sense of roast #2: "...we started getting ghost pops on that last round around 392[°F]. Right now we're at 391. ((leans in and listens)). And we have a lot more energy right now than we had in the last roast." Sam demonstrates this arc as the Ikawa reaches its target end temperature and begins to cool down: "There we go. So it was subtle, but it was definitely ((gestures with hands)), I could hear a little bit more activity going on. It [rate of rise] definitely didn't go negative, so, I'm expecting more vibrancy out of this roast." Sam's next steps involve the integration of sensory data with time and temperature data. These analyzes will allow Sam to confirm his claim that the second roast will be more "vibrant" than the first. Sam will do this by smelling and tasting the coffee: "I'm saving the remainder of the green for after cupping [tasting] these so I can make some adjustments as needed." With the information from a sensory evaluation, Sam will carry out more sample roasts and ultimately decide if this Peru fits his vision for the roastery's first rotating blend.

We next demonstrate how Sam *uses controls* in his investigations (SEP3 goal 7). Roughly 30 minutes after the episode above, Sam and the first author carried out a sensory evaluation by tasting coffees. During that tasting, the first author asked Sam, "How does cupping impact your roasting practices?" He responded:

> So, I think, you know, especially with this Guatemala [a coffee Sam has been experimenting with for two months], I think it's a great example. You know, I would say, only changing one thing at a time. Having controls. And, you know, not changing too much. I really want to make this ((points at graph)) basically the exact same except for bringing up my energy here ((moves finger to right)). So that's the one change I'm making, just so I can ensure that change is accurate. You know. I don't want to make too many changes and say, 'Well, what was the real cause for this?' So, just having those controls there. Yeah, I think that's the big thing.

Table 1

Summary of Sam's Demonstration of the Seven SEP3 Goals

SEP3 Goal	Selected Evidence
1: Questions	"What's the best way to roast this Peru?"

2: Hypotheses	“Oh if you don't know anything about this coffee, this is a good starting point.”
3: Tools	“Which is why it's nice using the Ikawa. You can try multiple things and you're using only 50 grams per batch. Where if I wanted to have that experimentation on the Diedrich I'd have to use 60 pounds for three different sample roasts.”
4: Data Types	“I should have…tested the density of this coffee and the moisture content”
5: Data Amounts	“I'm saving the remainder of the green for after cupping these so I can make some adjustments as needed.”
6: Variables	“If this was a tiny little peaberry, that's super tightly densely packed, it's gonna need more heat, more energy, to penetrate the bean. So, yeah. It will tell me the starting point of the coffee.”
7: Controls	“You know, I would say, only changing one thing at a time. Having controls.”

Discussion

Our objective in this paper has been to portray examples of the day-to-day investigations involved in a *non-laboratory, scientific workplace*. We began with the practices of investigation enacted by Sam, a professional coffee roaster. We have been careful to avoid the pitfalls of discussing whether Sam’s work *is* science or not, an unhelpful, unanswerable ontological question or an effectively political one. Asking the “what science really is” question distracts us from our broader purpose: to *expand* our imagery of scientific practices toward re-imaginations of science education. Toward this end, we showed how Sam’s practices met all seven of the NRC’s goals for investigation.

We have shown Sam’s practices for two reasons. First, science education reforms advance an epistemology of investigation as hypothesis-driven tests of theory. We argue, and Sam demonstrates, that investigations have utility and meanings beyond the testing of theories. These include opportunities to develop an investigator’s skills, conceptual understandings, and situate investigatory practices within a broader repertoire of scientific practices. Second, we argue that scientific practices are not limited to the actions of professional scientists and that images narrowly drawn *only* from these sources fail to capture the rich diversity of science in our lives. Sam demonstrates the importance of investigatory practices in his work.

Our demonstration of Sam’s use of scientific practices toward real-world, everyday ends is perhaps our most significant contribution. The *Framework’s* “overarching goal…for K-12 science education is to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science” (p. 1). A central argument in the *Framework* is that K-12 science education fails to achieve this outcome, because it is not organized systematically across the grades, focuses on breadth over depth, and does not provide opportunities to “experience how science is actually done” (p. 1). To this list we add that K-12 science education fails to recognize the beauty and wonder of science that exists outside of the laboratory, and that this failure represents tragic, lost opportunities to connect with the roughly 90% of K-12 students (NSF, 2022) who do not pursue normatively recognized science careers.

Continued conversations about how science is conducted are needed, as these will influence how we teach and learn science (NRC, 2012), will influence what images of scientific practice are elevated, effaced, and ignored. Our study, the first of many planned investigations of *everyday scientific practice*, leverages the practice turn (Ford & Forman, 2006; Knorr Cetina et al., 2001) to step outside of the lab into the wider world of scientific work. Sam’s diverse forms of investigatory practice, as inextricably tied up with personal and commercial concerns, are suggestive for new directions in understanding how and where science happens, and why science can be meaningful and relevant in the pursuit of *non-laboratory, everyday concerns*. We are inspired by Sam’s work to imagine potential transformations of science education in the era where the practice turn guides us to continuously renew and expand our images of science (Davey & Stevens, 2023; Stevens et al., in preparation).

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