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The Making of Engineering Technicians: Ontological Formation in Laboratory Practice

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ABSTRACT
Technicians are largely invisible in everyday life, as are their contributions to science and engineering. In this study, I address the issue of technicians' invisibility in engineering education. The laboratory plays a central and distinctive role in engineering education, but the role of laboratory technicians in educational contexts is largely absent from the research literature. Technicians are generally not considered to be instructors, even in programs that qualify technicians. I argue that the roles of laboratory technicians, with regard to the induction of students into technical engineering practice, should be reconsidered, and address the question: What do technicians in undergraduate laboratories do, and what do they know? The walking methodology approach was adapted in order to study interactions between technicians and students in undergraduate laboratories. The findings showed that laboratory technicians inducted, guided and supported students in technical practices. In particular, I identified a pedagogy of practice in which laboratory technicians demonstrated expert artisanal techniques, shared their skillful practice and practical knowledge, and made connections between practice and abstract theoretical knowledge. The study contributes an understanding of how engineering technicians, who occupy laboratory technician roles in academic engineering departments, induct student technicians into technical engineering practice.

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Engineering technicians: under-examined and underestimated

Technical work cannot easily be classified, partly because it resists traditional categories of mental and manual labor. As a result, descriptions of technicians' knowledge and practice tend to be inconsistent. In one version, technicians are equivalent to professionals and are co-constructors of knowledge at the 'empirical edge of scientific practice'.[1] In another version, technicians' occupations are constructed from the routine, manual tasks discarded by others.[2] Abbott claims that technicians lack the powerful scientific knowledge that underpins professional practice and enables professionals to claim jurisdiction over their work.[3] Consequently, technicians tend to accumulate contextual knowledge and build their technical acumen over many years.[4] Technicians' occupations are, in some accounts,

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constructed and controlled by more powerful others[5]; in other accounts, the nature of technical work enables technicians 'to attain high levels of autonomy, and exercise discretionary power over their practice'.[6]

These conflicting accounts of technical knowledge and practice suggest that both procedural and conceptual knowledge underpin technicians' practice, and that both mental and manual labor are present in technical work. Because technical practice exists within a professional division of labor, it is necessarily linked to a formal knowledge system, and it is this that separates technical work from craft,[7] and enables it to sit 'at the intersection of craft and science, combining attributes of each that are normally thought to be incompatible'.[8]

There is considerable diversity across technical occupations and fields. My focus is on engineering technicians who, in this study, are the caretakers of undergraduate engineering laboratories. They purchase, store, and maintain equipment, and set up experiments and practical exercises in consultation with the engineering faculty to whom they report. Despite the importance of undergraduate laboratories in engineering education, the role of laboratory technicians in engineering education is largely absent in the research literature.[9] When laboratory technicians are mentioned, their role is generally to follow instructions and ensure laboratory safety.[10] Laboratory technicians are not usually considered to be instructors, even in programs that qualify engineering technicians. Technicians thus 'neither set the entry and the performance standards of their occupation, nor control the educational process through which new recruits are trained'.[11]

In this study, I reassess the roles of laboratory technicians in undergraduate engineering laboratories with regard to the induction of new recruits into technical engineering practice. I address the question: What do technicians in undergraduate laboratories do, and what do they know? Technicians in undergraduate laboratories fulfill many of the same functions as laboratory technicians in other workplaces, thus the detailed study of their work, despite the particularities of the context – undergraduate laboratories in South Africa – has implications for how one understands technicians' practice and knowledge in other contexts.

The roles played by laboratory technicians in engineering education in South Africa involve dynamics that are not as evident elsewhere, given South Africa's troubled past and current status as the world's most unequal society.[12] Yet, it is precisely South Africa's distinctiveness that makes visible the dynamics of race, class, and resilience that are perhaps not so obviously at play in many other contexts. In South Africa the majority of engineering technicians are black, while the majority of professional engineers are white.[13] These racial differences exacerbate the class divide between technicians and professionals, particularly when professionals take on the role of teaching the technicians. Racial inequalities are perpetuated in pedagogical practices and are embedded in curricula.[14] Social inequalities are consequently reproduced – and the situation is made more complex when technical qualifications are under-valued by the faculty offering them. Unsurprisingly, there are shortages of technicians in South Africa, and the number of registered technicians is on the decline. There are very few women studying or practising technical engineering: only 28.5% of students enrolled in technician programs are female and only 7.6% of registered engineering technicians are women.[15] The attrition rate of women students in technical engineering studies has been attributed to their negative experiences on engineering programs in general, and gender discrimination in particular.[16]

My focus in this study is, however, not on the race and gender inequalities that continue to plague technical and professional divides in engineering, but on the practices of engineering technicians in undergraduate laboratories. Inequalities permeate all aspects of life in South Africa and should not be underestimated, inequality is thus present as the persistent context of this study. Technicians in South Africa, as elsewhere, straddle traditional divides of mental and manual labor, craft and science, they have 'blurred identities'.[17] In order to bring these blurred identities into clearer focus, I drew on the theoretical framework of 'ontological formation'.[18] For the study of undergraduate laboratory life, I adapted walking methodologies, an approach used predominantly by urban geographers to enable the kinds of embodied interactions with spaces and persons that are difficult to achieve in a more formal interview or analytical environment. Walking methodologies are particularly appropriate when the issues and persons are overlooked by more traditional research approaches.[19]

The literature on laboratory technicians

Technicians have not been subjected to the same level of scrutiny as scientists and researchers. Most laboratory studies are located in research laboratories, where the focus tends to be on the scientists rather than on the technicians. In descriptions of laboratories, technicians are often indistinguishable from the equipment – the 'materials, instruments, bench space, and help from technicians or students who may perform part of the work'.[20] While technicians are always present in laboratories, 'carrying their lunches in brown paper bags [and] … preparing assays,' the interest is usually on laboratory life from scientists' perspectives.[21]

A few studies have placed laboratory technicians' practices at the center, such as the work done by Sims on technicians in a pulsed-power facility, Wylie's fossil preparators, and Doing's synchrotron operators.[22] These studies pay attention to what technicians are doing and how they acquire and share their knowledge. Many studies show that technicians learn 'on the job,' developing problem-solving abilities and accumulating contextual knowledge to acquire impressive skills. Many technicians, including laboratory technicians, have formal qualifications that provide them with a range of 'practical engineering skills – such as the ability to mill, turn, drill, solder and wire'.[23]

Laboratory technicians perform a range of specialized roles, such as calibrating and repairing instruments, and 'fixing problems in order to avoid the failure of experiments and accidents'.[24] Problem-solving is the hallmark of technical practice, but technicians' work can also be creative, and even aesthetic.[25] In research laboratories, technicians are assistants, and sometimes partners, to scientists 'who extend themselves through non-authorial technicians, research assistants, and other helpers'.[26] Laboratory technicians are also caretakers of laboratory animals and other living organisms, and of the laboratory itself, its technical devices and equipment that must be cleaned, maintained, and properly stored.

Technicians shape laboratories, but laboratories also shape technicians. Laboratory spaces and equipment determine how technicians:

> … comport themselves, how they inhabit specially constructed lab spaces, how they interact with instruments and artifacts, how they shape and move their bodies to be perceived and disciplined by the gaze of others, and how their bodily experiences (their illnesses and exertions) are insinuated into their craft.[27]

Technicians' occupations include service and support work that imposes a social boundary 'between the scientist that thinks and produces original ideas and the technical workers that manipulate instruments and remain in the background'.[28] While technicians' superior practical skills are highly regarded, their scientific knowledge tends to be underestimated and their contribution to experiments and innovation is largely invisible.[29] Whalley and Barley suggest that technicians are 'obscured' rather than 'invisible' because they 'stand between technology and … a society not quite ready to leave behind the categories of industrialism, its distribution of power, and its presumed distribution of knowledge'.[30] By studying technicians' practices and knowledge, it was my intention to make visible their contribution to the education of novice engineering technicians.

The context: laboratory technicians as instructors

The laboratories in this study are undergraduate engineering laboratories intended for the training of engineering technicians. The technicians trained in these laboratories will find work as computer technicians, operators in manufacturing plants, or undertake the repair and maintenance of electrical infrastructure. Some will become building inspectors on construction sites, and some will end up in engineering laboratories, doing bench work, maintaining equipment and assisting with experiments. Like Barley and Orr's technicians, they will hover between craft and science, always working with complex technologies, building reservoirs of practical knowledge, drawing on scientific concepts, and developing their expertise over time.[31] Skills learned in the laboratory, such as experimenting, testing, creating, inventing, and innovating, are fundamental to technical work. Through their growing familiarity with laboratory practices, student technicians will acquire not only the skills, but the values underpinning technical work. The laboratory is the prime site for the socialization of novice technicians. The socio-technical practices that are enabled or constrained in laboratories will be central to novices' emerging sense of themselves as technicians.

The Engineering Council of South Africa recognizes three types of engineers, namely professional engineers, engineering technologists and engineering technicians. Professional engineers hold a four-year Bachelor of Engineering Science degree, engineering technologists hold a four-year Bachelor of Technology degree, and engineering technicians hold a three-year Engineering Diploma. In developing countries, there are shortages across all engineering professions, but in South Africa, there is a greater need for engineering technicians, due to the fact that the country is largely a user and adaptor of advanced technology rather than a technology innovator. There is consequently a need for technicians to implement, use, and modify source technologies.[32] Engineering technicians are usually trained in universities of technology. To be appointed as a lecturer in a South African university of technology requires the minimum qualification of a Master's degree. As not many engineering technicians have Master's degrees they are disqualified as faculty members, and students enrolled in technical engineering programs are therefore taught by professional engineers and scientists. The only place where students will encounter engineering technicians is in the laboratory. The social distance between the laboratory technicians and engineering faculty is exacerbated in the South African context by the fault lines of race and class and, in university laboratories, by educational qualifications.

A theoretical framework for ontological formation

Taking laboratory technicians' work in undergraduate laboratories seriously was central to my study. I wanted to understand their practices – how they used and maintained equipment, how they were positioned in the laboratory space, and most importantly, I wanted to understand how laboratory technicians inducted students into their worlds. Students who have no prior knowledge of technical engineering through family membership or schooling will need to be guided in the logic and routines of laboratory work. Understanding the role that engineering technicians might play in students' entry into, and development within, laboratories required an approach that was attuned both to the centrality of complex technologies in technical work and to trajectories of being and becoming.

Identity theory is commonly drawn on to explain trajectories within engineering.[33] James, however, argues that ontological formation provides 'a much more systematic but less reductive' way of defining different dominant modes of being.[34] Ontological formations describe the temporal, spatial, material, performative and discursive relations that underpin dominant formations. Although an ontological approach connects to identity frameworks, it goes beyond those frameworks to address, not only multiple and layered identities, but the kinds of alterity that 'the worlds that science and technology bring into being'.[35] Studying the trajectories of novices across the complexities and contradictions of technical engineering drew me to the work of Barad, Pickering, and James on 'ontological formation'.[36]

Ontological formation addresses human development across time, space, materiality, performance, and discourse. Thus, becoming an engineering technician involves trajectories of change over these fundamental categories of being. The concept of an ontological trajectory implies that novices and experts occupy different temporal, spatial, and material contexts, and that they differ in performance and in how they communicate. Ontological formations can be prospective and aspirational, thus novices can be inspired, through gaining new knowledge and acquiring new practices, to imagine different ways of being in the world.[37] Ontological formations are therefore understood to be layered and intersecting rather than singular and distinct.[38]

It is possible to translate the philosophical concept of ontological formation into practical understandings of how laboratory technicians might be re-imagined as instructors within undergraduate laboratories. James argues that identities are 'always full of tensions and contradictions' that can be 'destructive,' but that can also be 'creative and positive'.[39] In a laboratory, novice and highly competent technicians will encounter one another. Accommodating encounters between students and practitioners is not a strong feature of engineering education, although studies that foreground practice in science education are emerging.[40]

Ontological formation provided useful tools for understanding trajectories of change in the induction of student technicians into technical engineering practices, and explained these trajectories through the dimensions of time, space, materiality, performance and discourse.

Temporality – Technicians' trajectories are measured in 'increments of technical expertise and challenge'.[41] When technicians require information, they turn to more experienced colleagues in the network, rather than scientists or research engineers.[42] Thus the typical trajectory is one of novice technicians becoming more proficient at their practice by learning from other technicians and developing a supportive network.

Spatial affordances – Laboratories are the background against which novice technicians learn their practice, while the socio-technical affordances of laboratory spaces enable and constrain particular ways of being, doing, and belonging.

Materiality – Novice technicians encounter an abundance of tools, artifacts, and devices in laboratories, and engage in 'forming relationships both with people and with the technological artifacts they design and build'.[43]

Performance – Laboratories form and shape technicians' practice, delimiting the social as well as the technical dimensions of practice. Social interactions are important in practice, and expectations around laboratory practices exert an influence over who is considered to be competent as an engineering technician.

Discourse – Discourse, in ontological formation, refers to how members of social groups structure, produce and use spoken and oral texts. Gee distinguishes between discourse (with a lower case d), which refers to general communication, and Discourse (with a capital D), which he defines as 'ways of behaving, interacting, valuing, thinking, believing, speaking, and often reading and writing, that are accepted as instantiations of particular identities (or "types of people") by specific groups … [T]hey are socially situated identities'.[44] Discursive practices thus involve both the tacit and explicit communication of information, understandings, and values.

A walking methodology for researching ontological formation in laboratories

The study required research methods that could access ontological formation. I therefore drew on 'walking methodologies,' an overtly political methodology, intended to address issues and persons that are often overlooked by more traditional research methods.[45] Walking methods have predominantly been used in urban geography to enable more embodied encounters with landscapes, materiality, histories and memories. Walking as a research method implies a craft of walking, practicing an openness to encounters, learning how to forge collaborations and challenge embedded dichotomies between mind and body, reason and emotion.[46]

Although walking methodologies derive from urban geography studies, and encounters with the Anthropocene in particular, the principle of the walking methodology is the immersion of the researcher in the socio-materiality of particular spaces. There is a synergy between walking methodologies and the discovery of how to witness 'the spatial and temporal "environments" of laboratory activities, since many recognizably spatial and temporal references [are] initially opaque, undecidable, ambiguous, and strange'.[47] Walking methods are mobile research practices through which places and their occupants are encountered, and they provide new perspectives for analyzing the socio-political positions of those who work in these environments. As such, walking methods have relevance to built environments, as well as natural ones.

Part of developing the craft of walking involved learning to read the syntax of the laboratory.[48] Reading the syntax of laboratory spaces involved identifying and understanding the specific characteristics of laboratories as built work environments, as well as the larger social forces that positioned technicians, their work, and their expected relationships to their workplace and its materiality. Thus, where a laboratory technician's office was placed indicated something of the technician's status, and where a lab coat was hung could indicate the availability of a technician for consultation. Reading the syntax of laboratories involved examining the degree to which arrangements of equipment and devices re-shaped their functions and the social relationships that developed around their use. Walking was a way of thinking about, and describing, a spatial environment from the inside, that is, from the point of view of those who already understood it, interacted with it, and moved through it. The approach helped me to pay attention to the laboratory spaces and what the technicians were doing within them, and from this position of openness, to engage in practice-based theorizing.

Thus laboratories were walked, that is, they were visited frequently over a one-year period. Initially, my interest was in how students learned in laboratories, but over time the laboratory walks inspired a focus on how laboratory technicians taught. Observing the technicians, and engaging them on the details of their practice, helped me to understand what they did in undergraduate laboratories. Listening to technicians explaining concepts and procedures to students became a proxy for rendering visible their knowledge. My understanding of what technicians do and what they know is grounded in walking the undergraduate engineering laboratories.

My gender (female), race (white), class (middle) and institutional position (not an engineering technician) undoubtedly impacted what was made visible on my laboratory walks, as well as what was obscured. The engineering technicians and I have history, a recent example of which, in my previous life as an academic developer, was championing the inclusion of laboratory technicians in a national curriculum development project to revise and re-develop diploma-level engineering technician programs.[49] I think the technicians regarded me as a nuisance in their laboratories, but as someone who was basically on their side, so they tolerated me and answered my questions patiently.

While I walked the laboratories, I observed, photographed and video-recorded interactions between students and technicians. I also conducted interviews with the technicians, which often started as conversations. I audio-recorded these interviews and used short video-clips or photographic images of interactions between technicians and students as prompts to elicit information, when necessary.

The research sites for this study comprised thirteen engineering laboratories in two universities of technology in South Africa, one with a current disadvantaged status, the other slightly better resourced. Laboratories in the disadvantaged university lacked equipment and were overcrowded. Workstations intended for one or two students were more often shared by a cluster of five or six students. The technicians in charge of the laboratories were, however, resourceful, often building their own equipment and figuring out ways to ensure that all students were able to participate in experiments and practicals. Fifteen laboratory technicians across a range of engineering fields (Table 1) participated in the study.

Ethics clearance was obtained from the lead university, and informed consent to observe and video-record laboratory interactions between students and laboratory technicians, and to interview laboratory technicians, was obtained from the participants. I used the temporal, spatial, material, performative and discursive dimensions of ontological formation to provide some structure to the findings. In the observations and interviews these categories were woven together and often difficult to separate.

Table 1. Research Sites and Participants.

Site	Participant	Gender	Home language	Engineering field	Type of laboratory	Video-recorded topic
A	'Andile'*	M	isiZulu	Chemical	Materials	Alloys
A	'Bomikazi'	F	isiZulu	Chemical	Chemical Eng.	Distillation
A	'Chuma'	M	isiZulu	Civil	Concrete	Asphalt test
A	'Dlamini'	M	isiZulu	Civil	Concrete	Slump test
A	'Eesha'	F	Hindi	Computer	Electronics	Oscilloscope
A	'Fundile'	M	isiZulu	Electrical	Electrical	Circuits
A	'Gabi'	F	Russian	Mechanical	Automotive	Torsion
B	'Anna'	F	Afrikaans	Chemical	Process	Hydrolysis valves
B	'Bongani'	M	isiXhosa	Civil	Hydraulics	Water flow
B	'Charl'	M	Afrikaans	Civil	Structures	Compression
B	'Dumo'	M	isiXhosa	Electrical	Power	Resistors
B	'Eddie'	M	Afrikaans	Industrial	CAD	Ergonomics
B	'Fezile'	M	isiXhosa	Mechanical	Workshop	Lathe
B	'Gary'	M	English	Mechanical	Workshop	Lathe
B	'Henri'	M	Afrikaans	Communication Technology	Communication Technology	Radio transponders

*All names are pseudonyms.

Findings: what laboratory technicians do and what they know

Prior to walking the laboratories, I knew that many students had enrolled for technical engineering programs because they had not obtained the necessary school-leaving grades to undertake professional studies, and that many struggled with the demands of the technical courses. It was not uncommon for students to repeat subjects, and the programs had high failure and attrition rates. In my previous life as an academic developer, I had sat in on many engineering lectures in which students seemed bored or unable to follow the lecturer. I had been told that the students were considerably more engaged in practical laboratory work, and this was what I wanted to observe. Thus, at the start of a new academic year, I found my way through a maze of undergraduate laboratories in the electrical engineering building at Site A, to meet with Fundile, the electrical engineering technician in charge of the digital electronics laboratory, and to wait for the first laboratory practical to begin.

Trajectories of identification and recognition

I expected the students to be more engaged in laboratory work, but I had not expected the enthusiasm with which the students and Fundile greeted one another. I knew that Fundile was going to introduce the experiment as I had seen him preparing the workstations, but I had not anticipated that he would actually teach digital circuit concepts to the students. Fundile gathered the group around a whiteboard. The students stood or perched on benches. Fundile then delivered a lecture on digital circuits, drawing diagrams on the whiteboard to explain microcontrollers, flip-flops, and gates. His lecture included jokes and instances of code-switching between English and isiZulu. Switching between African languages and English is common in South Africa's multilingual classrooms and laboratories. Engaging in code-switching is a resource often used amongst student groups for negotiating their understanding new concepts; it thus has both 'pedagogic and social functions'.[50] Code-switching does not imply limited linguistic ability; it is a complex process that requires skill in both languages, and is increasingly recognized as a way in which black South Africans claim a hybrid identity.[51]

Fundile drew on his code-switching abilities to introduce the experiment that he had set up, and allocated students to workstations, all the while engaging them in banter. The students worked in teams, and called for Fundile when they needed help. Fundile moved among the groups, explaining and demonstrating, and sometimes sending a more proficient student off to help a team that seemed to be in trouble. This was a very different kind of teaching to the formal engineering lectures that I had observed.

In debriefing after the above laboratory practical, Fundile told me that the students, who had mainly seemed confident and capable to me, had all failed the Digital Electronics Circuits course, some of them more than once: 'What I'm doing is building up their confidence. There's a lot of relationship building in the first semester, community building, and building a network that can support them.' Watching the video recording later, I could see that Fundile's code-switching, joking, and banter were intended to build rapport with the students. He recognized them as novice technicians; he did not misrecognize them as failed engineers. Fundile described the group of students as his 'family for the year'. Most of the students were in residence and physically separated from their own families; as first-in-family students at university they were also socially and intellectually separating from their families. Fundile believed that he offered them a sense of belonging that included identification with technical engineering.

The technicians were deeply involved in the students' trajectories – from their orientation and induction into laboratory work, to assisting them with final year capstone projects. The technicians were extremely busy when student groups arrived – they circulated between workstations, correcting errors, demonstrating tasks, and offering encouragement. A part of the laboratory practical was always devoted to teaching abstract concepts. For example, I watched Bomikazi, a chemical engineering technician, teaching the concept of separation, drawing diagrams on the whiteboard, demonstrating a distillation process, and then engaging students in practical tasks, often referring back to the concept drawings on the whiteboard. Bongani, a civil engineering technician, taught students the mathematics underpinning the concepts of hydraulics and fluid flow. It seemed to me that the laboratory technicians facilitated students' acquisition of engineering knowledge as much as they trained them in laboratory skills.

Technicians were a constant presence in the laboratory, and thus always available to the students. Discussing a photograph of himself in his laboratory, Dumo, an electrical engineering technician at Site B, pointed to his orange lab coat draped on the back of a chair (Figure 1). He explained that when the students saw his lab coat, they knew he was in the lab and was available to assist them.

Bomikazi's chemical engineering laboratory was one of my favorite places to visit. There were always groups of students chatting and collaborating on projects. Bomikazi was at the center of all the activity, sometimes leaping onto a chair and ululating to call everyone to order when the noise levels rose too much. Like Fundile, she understood how a network that included both novices and adepts could help to develop the novices' technical expertise. She created such a network by partnering novices with senior students:

> Peer learning was something that helped me as an undergraduate. Different students – first years, final years – we would work on different parts of the project. We would work together in groups outside of class time. We would teach each other in ways that we understood.

Figure 1. 'We are always here … they can always come to the lab.' (Dumo, electrical engineering technician)

Describing how different members of the team worked on different parts of a project and taught one another in ways that made sense in their context approximates to a description of situated learning.[52]

Several of the technicians had experienced similar challenges to the students, as Fundile expressed it: 'we all had our own struggles that we had to go through'. Thus, the fact that a group of students might have failed a subject was not an undue concern. Students were expected to develop proficiency over time, and this is what the laboratory technicians instilled in the students. When technicians require help, they tend to turn to colleagues in the network, not scientists or research engineers.[53] The laboratory technicians had recreated these work practices in their educational practices. The technicians showed the students how to develop their own supportive networks and demonstrated how sharing knowledge through the network-enabled practice. Students regarded the laboratory technicians as repositories of engineering knowledge, and considerably more approachable than faculty. The student technicians were therefore learning to trust the network.

Spatial affordances for technical work

During my laboratory walks, I tried to identify the practices that were enabled and constrained by the spatial affordances of the laboratories. The laboratories at both sites were large, often two stories high. Areas were demarcated for specific purposes within the larger spaces – in a chemical engineering laboratory someone had painted yellow lines on the concrete floor to separate the different areas, but in most of the laboratories different functions were implied by the equipment or furnishing. Equipment clusters were often labeled: 'Wetted Wall', 'Rice's Method Apparatus', 'Worms and Wheel', 'Hydroclone'. There were safety notices and danger warnings. Scientific equipment: flasks, pipes, tubes, and chemical storage vats, were interspersed with everyday objects: a spray bottle, a wheelbarrow, a plastic chair. The laboratories were always neat and well-organized.

Laboratory technicians' official role was to introduce students to the physical spaces of the laboratory, guide them in experimental procedures and ensure that they followed safe practices. Eesha, a computer engineering technician, took pains to guide her students in computer laboratory practices, explaining that it was important that the students 'fit in' with required behaviors:

> Many of the students didn't have laboratories at school and also many didn't have computers so for them working in a computer laboratory is something new. I have to go back to the beginning and explain what a computer lab is – the rules to follow [and] safety. We have to talk to them about basic safety, like grounding mats, and also about the equipment they'll be using [and] how to look after it properly, how you must behave in the lab, why it's important to be serious about your studies [and] behave like a computer engineer when you are in here.

Technicians were clearly in charge of 'their' laboratories and they asserted their ownership of the laboratory space by various means. Anna was in charge of a large processing laboratory and managed a team of technicians. She asserted her authority by moving her desk out of her office (which was tucked away in a corner that literally 'side-lined' her from the main laboratory area) and into the main three stories high space of the laboratory. On some days, if there was nothing particularly important happening in the laboratory, she even parked her car there.

The spaces in Anna's large laboratory were designed to accommodate the large apparatuses needed for process engineering. Workstations were clustered around large pieces of equipment, while the spaces between the machines directed the flow of human traffic through the laboratory. Time spent in the laboratory, Anna explained, was expensive (costing the university more than double the time spent in classrooms), consequently the students needed to move in and out of the space efficiently. Anna managed the flow of students through her laboratory like a process engineering technician. Her space expressed the logic of flow processes, rather than a (traditional) pedagogical logic, another way in which practice segued into instruction. Efficient use of the space was evident in labels on devices, and the instructions to students on the tasks they were required to perform and the time allocated to the tasks.

In Bomikazi's chemical engineering laboratory the equipment was older and the movement of students through her laboratory was less pressured. As in most laboratories, the equipment and apparatus took pride of place. Perhaps because the equipment was less state-of-the-art, its identification as having scientific status seemed to be particularly important. On the wall alongside each apparatus was a scientific drawing of the apparatus and how it worked; see, for example, the distillation column and its accompanying scientific drawing in Figure 2. Scientific diagrams can 'reinforce or redistribute task area boundaries,' and in this case they seemed placed to reinforce the scientific legitimacy of Bomikazi's'

Figure 2. Bomikazi's chemical engineering laboratory; an actual distillation column, alongside a scientific drawing of a distillation column.

occupational jurisdiction and authority in the laboratory.[54] Their function was therefore 'not only technical but social'.[55]

In the concrete laboratory, I observed students making asphalt slabs, which they would test for strength once hardened. After the students had left the laboratory, Chuma, a civil engineering technician examined the still-warm asphalt slabs that his students had made. He prodded the structures with his fingers (reminding me of a doctor prodding the stomach of a patient to detect abnormalities). When I asked him what he was doing, he replied: 'I'm checking [a student's] work. He didn't do the mix properly so this is not going to work.' Chuma walked to a cabinet that I hadn't noticed. The cabinet contained specimens of aggregate and asphalt mixtures in folders with notes and graphs. The asphalt samples were in different states of compaction and degradation. Chuma looked through the folders for a particular sample. When he found it, he held it up: 'This is what is going to happen – too many voids in the aggregate. This is the reason why we have so many potholes in this country … ' Without compactors or other laboratory equipment, Chuma was able to identify, by prodding the setting asphalt mixture, which of the students' structures would degrade and fail. It seemed as if he was reading the state of the asphalt mix with his fingers, but clearly he was determining the relationship between aggregate, asphalt and void. The specimen cabinet represented Chuma's knowledge of asphalt, accumulated over many years and developed through the experiments and calculations that he had undertaken and codified into notes and graphs. In the cabinet was the knowledge he had accumulated to develop his 'lab hands' (Figure 3).

Figure 3. The concrete laboratory: students' asphalt experiments, ordinary things (wheelbarrow, spade, dustbins), and Chuma's specimen cabinet (far left).

Technical work, artifacts, and tools

The laboratories contained many specialized tools and 'signature artifacts,'[56] intended to enable particular kinds of work. The technicians were experts in the use of these tools, and shared their expertise with students, as Bomikazi explained:

> I follow the practice of those technicians who taught me. They taught me in a way that I could relate to things physically. They would explain concepts to me with physical activities – chemical reactions – I've never forgotten till today. They brought it to life – I could relate – I will never forget. So all of those little things influence what I do with the students.

Bomikazi told me a story about her mentor, a chemical engineering technician (since retired) who had taken up a position at the university after working many years on the mines in Johannesburg. He was able to identify the constituents of an alloy by the sound it made when he tapped it with a hammer. Bomikazi's mentor had trained her in what Nersessian calls 'person-to-artifact cognitive partnering,'[57] and she similarly imparted an understanding of laboratory tools as representing familiar and trusted processes to her students:

> My philosophy is based on trying to make students create their own knowledge in a particular way. You put the equipment out there for them, introduce them to it, try to give answers to the questions they have and then fill it in. So filling the gaps about the things you think they need to know and the concepts and the terminology and all of those. That way it goes through. So I also do a lot of group activities in the lab. I will put them into groups and give them a particular

> task to do with the equipment and I say 'you do this, this and this' and I will ask them to come present and over the years I've realized how smart our students really are if you put them to work.

Like Bomikazi, the other laboratory technicians drew on undergraduate students' fascination with engineering devices to train them in the skillful use of tools and techniques, and to engage them more deeply with the materiality of practice. Using engineering tools was an area in which the technicians were expert. In the extract below, Henri, a telecommunications technician, explained a video clip of himself providing feedback to students who were inserting transponders into devices that would be carried by weather balloons. The students would later release the weather balloons and track their signals:

> I gave that student a role and he was supposed to perform an action. He's getting feedback from me. I believe that feedback needs to be quick, that feedback happens right after the lab and needs to be practical, while the student has the technology in his[58] hand. That's my teaching approach and that is what I practice in the laboratory. I combine my feedback with the technology.

Henri understood the importance of 'person-to-artifact cognitive partnering;' hence the need to provide 'quick' feedback while the particular technology or equipment was in use by the student. Henri's 'quick' feedback was a form of constructive, formative feedback that was well-suited to the laboratory context.

Competence and professionalism in technical work

Competency, and competent performance, is foremost in laboratory technicians' work.[59] Becoming an engineering technician requires recognition by others that high levels of skill and competence have been attained. The laboratory technicians demonstrated their high levels of technical problem solving and practical expertise for the purpose of passing this craft knowledge on to students so that they could 'participate in the practices of the community they have entered'.[60] The students, as several interviewees pointed out, tended to be practically oriented and often frustrated that their academic programs delayed their engagement in practical engineering work. In contrast, laboratory technicians provided activities that introduced students to the world of practice. As Eddie, an industrial engineering technician, put it: 'when they get stuck into something that's when you see the best of the students'.

Fundile spoke of the 'professionalism' of technical practice in a way that echoed Barley et al.'s analysis of a professional identity among technicians. Technicians' understanding of professionalism had little to do with occupational status, and everything to with 'respect, collaboration, and expertise'.[61]

> I was going to say that this is big issue for me and I speak about it often to the students and it seems [referring to the video] that I am trying to get them so passionate about what they're doing that they become guided by their own professionalism to do excellent work rather than be driven by me. I tell them we are the ones who can solder. Engineers can't solder.

Fundile's assertion that 'engineers can't solder' captures both the distinctiveness of technical engineering work, and the technician's pride in this work. But although the craft of the technician was foregrounded in laboratory work, the technicians did not underestimate the relation between theory and practice in competent performance. As Bongani, a civil

Figure 4. 'We help the students to put things together' (Bongani, civil engineering technician).

engineering technician, stated: '[The students] have to know the theory before they come to the lab … '

The equipment in Figure 4 was built by Bongani to help first year students in the civil engineering program to understand fluid flow for application in hydraulics. The students had to mathematically predict the outflow curve from the cylinder for a given level. Using their calculation, they had to position the rods at various points on the curve of the water outflow. The idea was that the points at which they positioned the rods should match the actual water outflow. Bongani explained the effect of his apparatus:

> I want them to put their trust in the maths, not in trial-and-error, so that's why they need to do the calculation first. When the calculation and the actual water flow match it's an eye-opener for the students. It boosts their confidence when they see that they have worked out the water curve using their knowledge. When I put a group of new students on this apparatus – first they're struggling to work it out but eventually they get it. They put the markers in position then they open the valve – and *Yebo*![62] They are so excited, they are so proud of themselves.

The above quotation and the apparatus that it refers to (Figure 4) typified the way in which technicians inducted students into their technical field. Mastery of their craft was key to the technicians' practice, even to the extent of inventing an apparatus to reveal the mathematics underpinning technical practice.

In the following exchange, Fezile and Gary, both mechanical engineering technicians, discussed a video clip in which a student was arguing with Fezile. Fezile was trying to convince a student of the importance of developing hand skills on the lathe alongside her digital skills on CAD in order develop the practical competence that is the mark of the technicians' expertise:

> Fezile: [The student] is arguing with me. She had her design on CAD so she didn't want to cut by hand so I'm telling her, no, you need to develop your hand skills.
>
> Gary: It's not just about the hand skills. The hand skills are important. In some cases we need them to build their hand skills, but it's more to get the students to make the connection between the machine tools and the computer tools.
>
> Fezile: The details of the design – how is it going to work?
>
> Gary: They can't understand what they are doing if they don't actually do it.
>
> Fezile: Yes, we help them to appreciate practice and it's not just – oh the machine will do it for you.
>
> Gary: The hand skills and the CAD skills is not each in its own box. There is a connection between them.

The above exchange shows Fezile and Gary trying to make explicit their tacit knowledge and its implied value 'to appreciate practice'. The technicians modeled the expert practice of technical mechanical engineering, but they also helped students to recognize themselves as mechanical engineering technicians through an appreciation of practice.

Anna (the chemical engineering technician in charge of the large process laboratory), reflected on the connections between theory and practice in technical work. She compared the theoretical concept of a valve with the practical competence required to install an actual valve:

> Sometimes a valve can be concrete but it's also abstract because you can never just have the concrete. Your mind has to think about how would you explain it in a way that can make it explicit to a student by explicitly telling them there is levels of abstraction more explicitly so that with unintended complexity we're flicking between levels of abstraction. We move between levels by saying 'and now we are going to generalize and now we are going to be kind of specific' and this is where I actually show them how we install a water shut off valve making it more explicit and very practical to the student.

Anna described what many of the engineering technicians were trying to achieve, which was to shift between 'levels of abstraction' – technical craft skills and the underpinning theoretical knowledge – both of which were necessary for competent technical practice.

Technicians' talking and writing in the laboratory

Orr found story-telling to be the central means by which technicians constructed and exchanged their knowledge of machines,[63] but in my laboratory walks I did not find one dominant discursive mode. The technicians frequently switched between joking and bantering (a form of storytelling) and more technical discourses, using scientific terms for materials and devices. This could be because the technicians were communicating with students, rather than colleagues, and therefore were at pains to ensure that students acquired technical discourses. For example, the technicians often assisted students with the written laboratory reports that would be assessed by engineering faculty. Andile explained that the students tended to ask him 'for help when it comes to writing their lab reports'. Laboratory technicians also mediated the feedback that students received from faculty. Several students brought their marked assignments to Fundile because they did not understand the lecturer's comments, so he 'usually also add[ed] to the feedback'.

A 'trajectory of identification' can be identified in ways in which students gain proficiency in oral and written technical communication practices.[64] Fundile offered such a trajectory of identification by sharing his 'own struggles':

> A lot of the students – you don't know what they're going through while they're studying. When I get to know the students better and they start learning a little bit more about me and they also realize that I didn't just get here. We all had our own struggles that we had to go through.

War stories are generally told 'down the hierarchy,' in this case to student technicians, thereby enacting the social order that enables 'a community of workers [to] define themselves as distinct from other communities'.[65] Fundile's war stories built a connection with the students and helped them to understand their difficulties as part of becoming an engineering technician.

Technicians straddle the scientific and the everyday worlds of practice, thus they were aware that the students needed to master a range of registers and to understand when it was appropriate to use more formal, scientific terms and when effective communication required informal registers and local languages. In the following extract, Gabi, a mechanical engineering technician, explained the different communication genres that the students needed to acquire:

> It was more getting the students to be responsive. Who are you actually communicating this to? When should you use the more scientific terms and when is it okay to use the more everyday language? And also isiZulu. My idea is that lab has got walls that you can write on and things like that. So I put up notices: this word for the mechanic, this word for the client, this word for the engineer. Communication is a big issue in preparing students for industry.

Chuma and Dlamini, civil engineering technicians, watching a video clip of students conducting a slump test, explained that the civil engineering students were required to conduct such tests and then build a structure to specifications with the correct concrete strength. Later the students would test the strength of their structures, comparing the actual strength of the structures to their slump test calculations. In the following brief exchange, the focus was on communicating concrete strength:

> Chuma: When they do the slump test we make sure that we use the proper names, technical terms, for everything.
>
> Dlamini: But we need to prepare them for the building site too.
>
> Chuma: As technicians we must be able to communicate with engineers and other professionals.
>
> Dlamini: Students must know how to explain concrete in a technical way, but they also go on site to communicate with the foreman, so then they must know the terms that the builders use – then they have to communicate in the vernacular.

The practice of code-switching between the technical and the vernacular is relevant to the world in which most technicians practice. Their expert craft skills are obvious and are valued, but their skilled practice is underpinned by knowledges that are both scientific and contextual, both codified and tacit. Orr's description of technicians' narratives as exemplifying 'thoughtfulness, attention to detail, freedom from panic, and resourcefulness' captures their teaching style.[66] The technician's unflustered and patient ways of explaining reminded me of a YouTube technician, calmly explaining how to troubleshoot my garden irrigation system. Undoubtedly, this calm, collegial communication style impacted the students' sense of belonging. In particular, the students enjoyed the technicians' narratives of prior experiences, especially disasters. As Bomikazi put it 'they love to hear about all the things that went wrong in the lab'. Orr points out that technicians' disaster stories are predominantly educational, although 'some of the war stories are clearly intended more to amuse than enlighten'.[67] The disaster narratives 'promote collaboration, a sense of belonging, and the value of continuous learning for all lab members,' while also demonstrating that technical engineering studies do not suffer from a 'lack of real-world application, and lack of meaning'.[68]

Conclusion: reassessing laboratory technicians as instructors

Reflecting on what laboratory technicians did and what they knew through the lens of ontological formation, it was clear that they were deeply engaged in shaping students' identities as engineering technicians. The students were inducted into the network, they became 'family,' and they were supported in achieving competence in technical work. Like Orr's technicians, the laboratory technicians in this study through 'relating machine lore and talking through the problems of the day,'[69] modeled a technician's version of reflective practice.

The affordance of undergraduate laboratories is for engaged practice, for discovery and meaning-making. The laboratories were lively social spaces – with laboratory technicians at their center and asserting their ownership of 'their' laboratory. The aspiring technicians were disciplined into particular practices, how to dress, how to flow efficiently through laboratory spaces, how to interact with tools and devices, and how to acquire practical knowledge. Knorr Cetina explains that in the laboratory the 'main and rightful knowledge-creating unit' is not an individual, but many actors 'linked with other agents and epistemic objects'.[70] This is what the laboratory technicians practiced and understood. They understood how the spatial infrastructure accommodated systems, other structures, technologies and social arrangements. They shared this knowledge, 'an embodied kind of know-how irreducible to symbolic terms,'[71] with the students. Technicians were a constant presence of the laboratories, they were always available. The technicians saw themselves in the students; over time, the students saw the technicians in themselves.

To a far greater extent than is generally acknowledged, laboratory technicians enabled students' transition from the lecture hall and theoretical forms of knowledge, to a world in which knowledge creation, application, and verification took material shape. The laboratory technicians were engaged in important interactions with students to ensure that they worked precisely, to spark their interest and curiosity, to inculcate the practice of continuously improving and honing skills, to provoke critical thinking – and always to explain carefully, to show and demonstrate. The technicians rendered abstract, theoretical forms of knowledge visible through the laboratory practices of experimentation, observation, and measurement. From producing scientific drawings on whiteboards and writing technical and vernacular terms on laboratory walls, to building machines for learning, the laboratory technicians were instrumental in imparting the knowledge and underpinning values of technical engineering to the next generation of practitioners.

I identified a pedagogy of practice in which laboratory technicians not only demonstrated the craft of technical engineering, helping novice students to acquire more skillful techniques, but also made connections between laboratory procedures and theoretical knowledge. The laboratory technicians thus played a key role in integrating theoretical and practical knowledge, embodying a scientific performativity that incorporated the 'material and discursive, social and scientific, human and nonhuman, natural and cultural'.[72]

The focus on technical practices within laboratories raised awareness of the laboratory technicians' role in the making of engineering technicians. Several key elements seemed pertinent to students' sense of belonging in the laboratory: Fundile's student family, and his pride in his soldering skills, Duma's orange lab coat which signaled his availability, Henri's quick feedback, Anna's flicking between levels of abstraction, Fezile and Gary's insistence on hand skills and the appreciation of practice, Bomikazi's multi-level student groups, Bongani's self-built apparatus that helped students to understand fluid flow, Chuma and Dlamini's code switching, Chuma's specimen cupboard and his 'lab hands,' and many others. These, and other, components of practice could be intentionally integrated into the technical engineering curriculum to enhance some students' sense of belonging (and possibly increase students' retention and success across engineering technician programs). Such 'a practice-oriented curriculum,' as Mody suggests, 'may offer something more durable and engaging than a largely temporary familiarization with formulas, laws, and rationally reconstructed derivations'.[73] Barley pointed out the difficulties that arose when organizations employed technicians but failed to appreciate the nature of their work[74]; the same could be said of universities that employ laboratory technicians, but fail to appreciate their roles as educators.

Notes

1. Barley and Bechky, 'In the Backrooms of Science," 92.
2. Whalley and Barley, "Technical Work in the Division of Labor," 58.
3. Abbott, *System of the Professions*, 64.
4. Barley and Orr, *Between Craft and Science*.
5. Keefe and Potosky, "Technical Dissonance," 53–4.
6. Orr, *Talking about Machines*, 81.
7. Keefe and Potosky, "Technical Dissonance," 51.
8. Barley and Orr, *Between Craft and Science*, 12.
9. Feisel and Rosa, "The Role of the Laboratory," 22.
10. Lewis and Gospel, "Technicians under the Microscope."
11. Keefe and Potosky, "Technical Dissonance," 54.
12. In 2019 the World Bank ranked South Africa as the world's most unequal country of those on which comparable data were collected.
13. In its 2019/2020 report the Engineering Council of South Africa noted for the first time more black professional engineers in the 20–29 age group than white engineers in the same age group.
14. Motala and Stewart, "Hauntings Across the Divide."
15. Engineering Council of South Africa, *Report 2019/2020*, 83.
16. Von Solms, Nel, and Meyer, "Gender Dynamics."
17. Keefe and Potosky, "Technical Dissonance," 54.
18. Barad, "Posthumanist Performativity;" Pickering, "The Ontological Turn;" James, "Despite the Terrors of Typologies."
19. Springgay and Truman, *Walking Methodologies*.
20. Knorr Cetina, *Epistemic Cultures*, 217.

21. Latour and Woolgar, *Laboratory Life*, 17.
22. Sims, “Safe Science”; Wylie, “The Artist’s Piece is already in the Stone;” Doing, “Lab Hands.”
23. Lewis and Gospel, “Technicians under the Microscope,” 428.
24. Vinck, “Maintenance and Repair Work,” 6.
25. Doing, “Lab Hands,” 207; Wylie, “The Artist’s Piece is already in the Stone,” 32.
26. Knorr Cetina, *Epistemic Cultures*, 171.
27. Mody, “The Sounds of Science,” 176.
28. Denis, Mongili, and Pontille, “Maintenance and Repair,” 6.
29. Shapin, “The Invisible Technician.”
30. Whalley and Barley, “Technical Work in the Division of Labor,” 24.
31. Barley and Orr, *Between Craft and Science*, 14.
32. Blake, “Software Engineering.”.
33. Tonso, “Student Engineers and Engineer Identity.”
34. James, “Theory and Society in the Shadow of Terror,” 378.
35. Woolgar and Lezaun, “The Wrong Bin Bag,” 323.
36. Barad, “Posthumanist Performativity;” Pickering, “The Ontological Turn;” James, “Despite the Terrors of Typologies.”
37. Pickering, “The Ontological Turn,” 136.
38. Barad, “Posthumanist Performativity,” 812.
39. James, “Despite the Terrors of Typologies,” 175.
40. E.g. Mody, “Scientific Practice and Science Education.”
41. Zabusky and Barley, “Redefining Success,” 189.
42. Barley, “Technicians in the Workplace,” 423.
43. Newstetter, Behravesh, Nersessian, and Fasse, “Design Principles,” 3559.
44. Gee, *Ideology in Discourses*, 4.
45. Springgay and Truman, *Walking Methodologies*.
46. Ernsten, Shepherd, and Visser, “The Walking Seminar.”
47. Lynch, “Laboratory Space,” 56.
48. van Nes, “Space Syntax,” 237.
49. Winberg, “Defending the Diploma.”
50. Paxton, and Tyam, “Xhosalising English?”
51. Ndimande-Hlongwa, and Ndebele, “Digging Deep into IsiZulu-English Code-switching.”
52. While I have not specifically referenced the situated learning literature, the work of John Seely Brown, Allan Collins, Paul Duguid, Edwin Hutchins, Jean Lave, Etienne Wenger, and many others, have been formative to my understanding of learning in and through practice.
53. Barley, “Technicians in the Workplace,” 423.
54. Bechky, “Workplace Artifacts,” 720.
55. Bechky, “Workplace Artifacts,” 724.
56. Nersessian, “How Do Engineering Scientists Think?,” 738.
57. Nersessian, “How Do Engineering Scientists Think?,” 741.
58. Henri’s use of the male pronoun was common, even in classes where both male and female students were present.
59. Barley, “Technicians in the Workplace,” 409.
60. Johri, “Learning to Demo,” 2.
61. Barley, Bechky, and Nelsen, “What Do Technicians Mean When They Talk about Professionalism?”
62. “Yebo!” is an isiZulu exclamation that means “Yes!”
63. Orr, *Talking about Machines*.
64. Jocuns and Stevens “Current Is the One That’s Mean.”
65. Wylie, “Socialization through Stories,” 4.
66. Orr, *Talking about Machines*, 34.
67. Orr, *Talking about Machines*, 3.
68. Wylie, “The Artist’s Piece is already in the Stone,” 827.
69. Orr, *Talking about Machines*, 55.
70. Knorr Cetina, *Epistemic Cultures*, 192.

71. Mody, "The Sounds of Science," 192.
72. Barad, "Posthumanist Performativity," 808.
73. Mody, "Scientific Practice and Science Education," 1027.
74. Barley, "Technicians in the Workplace," 404.

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