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Ethnographic Invention: Probing the Capacity of Laboratory Decisions

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Abstract In an attempt to shape the development of nanotechnologies, ethics policy programs promote engagement in the hope of broadening the scope of considerations that scientists and engineers take into account. While enhancing the reflexivity of scientists theoretically implies changes in technoscientific practice, few empirical studies demonstrate such effects. To investigate the real-time effects on engineering research practices, a laboratory engagement study was undertaken to specify the interplay of technical and social considerations during the normal course of research. The study employed an ethnographic invention in the form of a decision model to structure reflection on ongoing social processes. A short series of interactions with one engineering researcher illustrates the deployment of the model in the form of an interview protocol. The cultural embedment of the protocol allowed it to function as a feedback mechanism, creating a more self-critical environment for knowledge production, and perturbing the system in research-tolerable ways.

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Introduction

In an effort to shape the development of nanotechnologies, national policies, engagement programs, and calls for ethical reflection seek to stimulate greater awareness of the social dimensions of nanoscale science and engineering research, at both institutional and individual levels. Given the early stages of much nanotechnology research, and the uncertainty and complexity that characterizes it, modulating emerging research and development paths may require more than standardizing new ethical codes of conduct or restructuring scientific research priorities. Accordingly, 'ethics policies'[1] suggest that scientists and engineers have a role to play in making choices differently than they otherwise would, for example by broadening the scope of what they take into account through more reflexive decision making. While grounded in decades of social and historical research, however, it remains unclear what the real-time effects of engagement activities may be on scientific practices and decision making. To investigate such effects, an empirical study was undertaken to monitor and assess the capacity of academic

[1] A term coined in conversation with Carl Mitcham.

laboratory researchers to respond to reflection on the social dynamics of their own work. Rather than introduce specific ethical principles, issues, or claims, the study sought to render ongoing decision processes more visible to the researchers who performed them. It employed an ethnographic invention to specify the interplay of technical and social considerations during the normal course of engineering research. The invention functioned as socio-technical integration architecture, in that it structured space for reflection that could in turn stimulate alternative courses of action (Rabinow 2007, personal communication).[2]

Ethics Policies

Around the world, science policies are aimed at shaping the development paths of nanotechnologies by mandating the integration of social and scientific considerations. In a move that resonates with constructivist perspectives, policies directly and indirectly pertaining to nanotechnology in at least four countries – the United States (USA), United Kingdom (UK), The Netherlands, and Belgium – imply that technological development is the product of socially contingent processes and thus can be influenced by more reflexive choices on the part of scientists and engineers.

In 2003, US federal legislation required "integrating research on societal, ethical, and environmental concerns with nanotechnology research and development" [1] to influence "the direction of ongoing nanotechnology research and development" [2]. Accordingly, in 2005, the National Science Foundation awarded approximately $6 million for the development of real-time technology assessment (RTTA), which seeks "to build into the R&D enterprise itself a reflexive capacity that...allows modulation of innovation paths and outcomes in response to ongoing analysis and discourse" [3]. RTTA explicitly intends to stimulate laboratory researchers to "think about different research questions or strategies" so as to "make different research or application choices" [3].

In the UK various policy statements since 2000, including a 2004 Royal Society report on nanotechnologies [4], reveal an interest in 'upstream' engagement activities that are meant to "shape the trajectory of technological development" [5] through "improved social intelligence and better decision-making" [6]. While upstream engagement is focused on the role citizens and lay publics can play in influencing research, it is also meant to build "more reflective capacity into the *practice* of science" [5], thus raising "many unresolved questions for...science itself" [7].

The Dutch national nanotechnology program established in 2005 tasks constructive technology assessment (CTA) to interact with the other program "flagships" [8] so as to "broaden the scope of strategic choices" [9]. Since the 1980s, CTA has sought to influence design and technical change [10] by broadening the scope of issues that influence assessment and technological decisions [11, 12]. Central to the design and evaluation of CTA activities is the concept of reflexivity, which entails acting on the premise that "technology design and social design" comprise "one integrated process" [13].

Finally, the regional nanotechnology program in Flanders, Belgium mandates "increasing awareness about the societal impact of engineering decisions" [14]. Indeed, "the primary aim of the project is to stimulate the *reflexivity of scientists* themselves" [15].

Engagement programs thus target as a key intervention point the decisions of nanoscale research practitioners. Similarly, calls for what some have termed "nanoethics" [16] seek to go beyond "conventional rule-based, prescriptive engineering codes and guidelines" [17] and to encourage "nanotechnology researchers to engage – in a thoughtful and critical manner – with [ethical and social] issues as an integral part of their research endeavors" [18]. Yet despite the hefty body of literature on the social dimensions of technoscience, there is a lack of policy precedents [19] and social research [7] for designing and assessing engagement strategies, and of empirical research to demonstrate the effects of such interactions (for exceptions, see [20] and [21]).

Influencing Socio-Technological Change

Social constructivist [22] and evolutionary [23] frameworks provide an intellectual basis for the social shaping of technology. Rather than determined by

[2] The idea of creating architecture to house human and material practices can be compared to Paul Rabinow and Gaymon Bennett's notion of 'contemporary equipment.'

internal logic, technological developments are held to be co-constructed or coevolved by social and technological actors and dynamics. Engagement activities thereby seek to influence knowledge production and socio-technical outcomes by augmenting social contexts during malleable stages of nanotechnology development. Influencing technological trajectories is thought to be more possible at early periods "where research trajectories are still open and undetermined" [24], since they take place before "closure" [25] and reification of interpretations and agendas has transpired. Over time, individual selections give rise to larger dynamics of "emerging irreversibilities" [9] or technological "lock-in" [26].

While early stages of innovation are thought to afford greater degrees of freedom, they are also characterized by deep uncertainty. Only during later stages of development, when investments have been made and interpretations stabilized, do socio-technical outcomes begin to become more clearly identifiable. The "control dilemma" [27] thus implies that anticipatory [21] and other "midstream" [28] approaches may be viable alternatives to traditional command and control attempts to direct technology from the outset or to regulate it after the fact. This has occasioned renewed interest in early socio-technical integration sites such as laboratories. While the role of the micro-level is limited, laboratories set many of the initial conditions for knowledge production, diffusion, and transformation. They help codify material practices and, to some extent, thereby inform the behavior of meso- and macro-level institutions populated by technological actors.

Laboratory Studies

Since the 1970s, laboratory ethnographies have approached scientists as "alien tribes" [29], documenting the social processes that run throughout scientific [30] and engineering [31] work. Insofar as laboratory studies revealed that experimental results are underdetermined and subject to further interpretation, they seemed to imply that "almost everything is negotiable" [32]. But while the knowledge generation practices in laboratories were discovered to be "amenable to empirical analysis" [32], the inference that they can be effectively engaged by social actors familiar with this work remains largely unexplored.

Laboratory ethnographies that employ decision-related methodologies suggest that supplementing cultural analysis in this way can shed light on the direction and control of research [33]. As units of analysis, decisions allow fluid social processes to be subdivided into logically discrete components for the sake of assessment, as seen in policy studies [34, 35]. Decision process frameworks represent an opportunity to map the "real-time" [3, 32, 36] complexities and contingencies of laboratory activities in various states of completion and revision, and in cases of distributed agency and responsibility. Given the emphasis placed on decisions by nanotechnology engagement programs, the empirical study of laboratory decision processes is an apt approach to investigate the capacity of research scientists to more reflexively attend to the integration of technical and social considerations.

A Laboratory Engagement Study

From the fall of 2003 through the spring of 2006, I was a member of the Mechanical Engineering department's Thermal and Nanotechnology Laboratory (TNL) at the University of Colorado, Boulder. During this time, I performed a series of studies with the researchers of the TNL and involving several projects it sponsored to ascertain the feasibility of modulating engineering research decisions. In addition to archival research, empirical data were collected through participant-observation and unstructured and semi-structured interviews. Responses were recorded in field notebooks and, in several cases, recorded and transcribed. Observations and findings were periodically presented to the TNL group and to individual researchers. The resulting dialogues formed the basis of an ethnographic invention – a decision model, developed collaboratively over several months with the participation of over a dozen TNL researchers, designed to specify the interactions of social and technical considerations during research activities.

In the form of a semi-structured interview protocol, the model framed differentiated levels of interaction between myself and three graduate researchers for a 12-week quasi-experimental study. This study correlated an increase in reflexive awareness to the deployment of the protocol and documented specific modulations of research practice [37]. The present paper describes a short series of decisions surrounding one such modulation. It reveals the interplay of decision components over time to demonstrate the effects of the protocol during the emergence of an unplanned research project.

The Decision Model

The in-house protocol was intended to describe in generic terms any given research decision.[3] In keeping with observations and researchers' critiques, the model consisted of four conceptually distinct but, in practice, highly iterative components – opportunity, considerations, alternatives, and outcome – defined here as follows:

Opportunity A perceived state of affairs characterizing the imminence of a decision. An opportunity could take the form of a problem requiring a solution, an occasion to take advantage of, or any situation eliciting a response.

Considerations Internal (cognitive) or external (social or physical) selection criteria that may operate as enablers or constraints, and that potentially influence or determine the response to the opportunity. Examples of cognitive and social considerations might include stated or implicit goals, values, and expectations (whether personal or institutional). Examples of physical considerations might include resources – equipment, time, funding; material properties and behaviors; and research data and experimental results.

Alternatives Perceived options or courses of action available for selection in response to the opportunity.

Outcome The decision, understood as a particular response to the opportunity, through selecting one or more alternatives, in light of one or more considerations. The outcome may be an initial, revised, or final response. Outcomes occasion new opportunities.

The model was meant to simulate research decision components quickly and intuitively during the course of laboratory work. It explicitly aimed to minimize intrusiveness by not adding to the cognitive overload reported by several TNL members. Its primary function was to render ongoing decision processes more transparent – to the author and to researchers themselves – to facilitate reflection on the interplay of social and technical considerations. It was not meant to alter research, but to create a structure that would characterize decision flexibility in light of such interplay. While intended to be descriptive rather than prescriptive, the act of rendering decisions more transparent to those who made them was necessarily a form of intervention. For researchers were often found to be unaware that they made decisions in the first place. It was applied retrospectively, prospectively, and in real-time.[4]

In the following account, the protocol frames a short series of interactions between myself and a TNL doctoral student ('K'). During the study, K and I met up to four times a week. My presence in the TNL and its associated Nanotechnology Characterization Facility varied from two and a half to 5 h per week, primarily in conversation with K and others, but also attending to separate research tasks, and participating in weekly TNL research group meetings.

K's doctoral research involved synthesizing carbon nanotubes (CNTs) for a thermal interface material (TIM) within a device as a part of an energy efficient combustion engine. The process for synthesizing or 'growing' the nanotubes was chemical vapor deposition (CVD). CVD took place within a reactor at extremely high temperatures, in which a catalyst, for example Ferrocene, was deposited on a substrate, such as silicon, after which hydrocarbon gasses were released. Unstable carbon particles then reacted with the catalyst to form into CNTs – rolled sheets of graphite with "surprising" thermal, electrical, and mechanical properties.

[3] A decision is here defined as a 'commitment to a course of action.'

[4] The analytical limitations of this particular invention from the standpoint of social science represented a concession to the collaborative enterprise. For instance, the conceptual overlap of opportunities and considerations meant that the same component could register in either of these categories. Additionally, it compressed a wealth of anthropological data into the considerations component, which could become overloaded with social networks, organizational structures, imaginaries, infrastructure, etc.

An Initial Idea

While reading about CNT synthesis for his primary project, K conceived the idea of generating CNTs within a cylinder. It appeared to him that, although at least one research group had published the results of CNT growth “on top of a cylinder...no one has attempted to grow them inside a cylinder.” K presented this idea, which the lab director came to refer as “tubes within tubes”, at a weekly TNL meeting during a talk he gave on his plans for proceeding with the TIM project, almost as a side note. It was decided at the meeting that a copper cylinder filled with CNTs could be useful for various heat transfer applications. As a preliminary step, K tested the idea on a quartz tube with an inner diameter of three millimeters.

Playing a New Game

K’s ‘tubes’ idea was deemed successful since the quartz tube contained visible CNT growth. Accordingly, the TNL director “got excited” and shared this information with a respected colleague who ran another laboratory. During their exchange, the question emerged of whether it was possible to grow nanotubes within an optical silica fiber. The TNL director accepted the challenge and formulated a new research objective to ascertain whether it was possible to synthesize CNTs within a 10 μm silica fiber, which the colleague had supplied for this purpose. The colleague “may have had some applications in mind” but, as far as K was concerned, the director did not (Table 1).

Although unclear what – if anything – might emerge from this decision, from a policy studies perspective it constituted the setting of a research priority. While “too early” to assign much status to the project, TNL projects and papers could suddenly become formalized only after gradual progress. Thus, early conditions that set the stage for trajectories-in-the-making may frame future decisions, interactions between actors, and events. The prescription authorized *what* research to perform and established an agenda, albeit open-ended.

The playfulness with which the agenda was undertaken indicates that at this point it was tentative. It could have been abandoned at any time, was not prescribed by an external agency, and involved no obligations, for instance to the colleague who supplied the fiber. Since no publications on synthesizing CNTs within “cylindrical geometries” were known to exist, its uniqueness impregnated it with the potential to turn into “serious” research if the results were deemed successful. As K reflected later, “with the fibers, we didn’t know if it had any potential applications. We thought, why not try it and see? Let’s play a new game. Just for fun. Now it’s actually turning out to be something.”

Table 1 Playing a new game

Components	
Opportunity:	“Can we grow tubes in a fiber?”
Considerations:	“No one had done it, so we wanted to do it.” Also, it would be “fun.”
Alternatives:	“Why not try it and see?”
Outcome:	Authorization of an experiment on the silica fiber.

Just Going to Do it

While the agenda was suggested by the colleague and determined by the director, the task of implementing it fell to the graduate researcher. K must independently answer questions of *how* to conduct the research, namely, by determining the experimental procedure for synthesizing CNTs within a 10 μm silica fiber. The challenge involved several uncertainties, arising from the small diameter of the fiber. It was unclear whether the fiber would withstand the temperatures of the reactor, and whether the gasses would enter its minute diameter. The main challenge K perceived was “coating” the inside of the fiber with an alumina slurry, thought necessary as a barrier between the silica substrate and the Ferrocene catalyst particles. K had experienced problems in attempting to uniformly coat the inside of the quartz tube with the slurry. Now, he speculated that the alumina particles might clog the fiber, keeping the Ferrocene or gasses from entering the fiber, and prohibiting CNT growth within the target area.

Coincidentally, upon inspecting the quartz tube sample, K suspected that he had seen carbon growth on a section of the tube that has not been coated with alumina. This led him to hypothesize that CNT growth might in fact be possible without a barrier layer between catalyst and substrate. He applied this reasoning to the fiber: if the alumina could be dispensed with, there would be an increased chance for CNT synthesis within the fiber's hollow core. Still, the experiment would be difficult (Table 2).

As evident, when we arrived at the alternatives prompt, K thought about catalysts and identified the one most readily available to him – Ferrocene (without alumina). The question of which catalyst to use, however, constituted a different opportunity than the one originally framing the exchange. Still, I probed K about other choices. He replied, "I can only think of Ferrocene" and fell silent for a moment. He then suggested possibly dipping the fiber into ferrofluid, a solution containing nanoscale iron particles. K speculated that the particles might deposit on the fiber's inside surface and catalyze the desired CNTs. However, to acquire ferrofluid, either he would have to travel several miles to another facility in hopes of acquiring a sample, or wait for someone to bring it to the TNL. Either case would result in a frustrating delay. Besides, K admitted that there would be no loss if running the experiment with Ferrocene did not work.

In reflecting on the available alternatives, K had reframed the opportunity and, soon after, had also expanded the set of alternatives. Moreover, identifying the alternative catalyst revealed new considerations: K thought there were potential environmental and health considerations involved in selecting ferrofluid over Ferrocene. He stated that Ferrocene was "messy"; generated unnecessary residue; and posed potential problems for measurement, inspection, equipment performance, disposal, and "contamination of the atmosphere." K's offhand comment that he "wouldn't have to use Ferrocene" was thus prompted by – and intensified – a number of previously undisclosed concerns.

Table 2 Just going to do it

Components	
Opportunity:	"Coating the inside of a fiber."
Considerations:	Prohibitive size of fiber, related material uncertainties.
Alternatives:	"I can only think of Ferrocene." "Maybe dip the fiber in ferrofluid and hope that the particles deposit within the fiber." "Then we wouldn't need to use Ferrocene."
Outcome:	"Just going to do it" using Ferrocene. "Everything is available here" and then K doesn't "have to run around."

The expansion of both alternatives and considerations did not affect the immediate outcome. Eager for results, K ran the experiment with Ferrocene, but it proved unsuccessful. Later, however, K successfully tested and then adopted ferrofluid as the catalyst of choice. Thus, the fiber project eventually would undergo a shift in catalyst from Ferrocene to ferrofluid. This proved to have consequences for the life of the project. For K came to hail ferrofluid as "the way to go" for synthesizing CNTs within silica fibers. In fact, as K admitted afterwards, if ferrofluid had not occurred to him in that moment, the fiber project may have been "dropped for good." Moreover, the change in practice coincided with his desire to bring the project into closer alignment with a series of considerations – environmental, health, measurement, inspection – that had not, up until now, operated at the levels of discourse and decision making.

Why was K using Ferrocene in the first place? Previously, the first TNL researcher to successfully synthesize CNTs had employed Ferrocene, after abandoning several different approaches. This success had established Ferrocene as a precedent. Although other catalysts were available, Ferrocene now served as a TNL baseline and K had selected it for continued use. Path dependencies such as this were not uncommon in the TNL; they aided the progression of trial and error research, more rapidly extending research developments by refining and giving rise to new research capacity and new potential applications. This example suggests that the momentum generated by closing down options, however, can be balanced by productive and timely refection on what is otherwise taken for granted.

Saving the Project

As stated, the fiber run had been unsuccessful: K could not visually identify anything that looked like CNT growth inside or around the edges of the fiber. As a result of this "failed fiber experiment," K stated there was now a "new focus." This, the director had christened the "how low can we go" idea. It involved determining the limiting internal diameter of a tube in which CNT synthesis could be achieved, regardless of the substrate material (silica, quartz, copper, etc.). Yet, during the group meeting at which the new focus was discussed, K had received mixed messages from the director and another faculty researcher as to which project to focus his energies on: the TIM or the one just hatched. In either case, none of the faculty members made any mention of silica fibers. Still, K didn't want to give up on the fiber idea, and mentioned in passing that perhaps he would "try once more on the fiber."

The next day, K conducted an experiment on a number of material samples that allowed him to move forward with three separate projects. Significantly, K had obtained ferrofluid (as it turns out, from the faculty researcher just mentioned) for the sake of achieving more uniform CNT growth for the TIM project. K, however, now tested it on a copper wafer for the TIM project, a copper tube for the "how low can we go" project, and a second silica fiber for the (now formally in limbo) fiber endeavor. K's response to the mixed messages he had received and the complex demands under which he labored was creative. He simultaneously implemented the two separate directives he had been given, tested the performance of ferrofluid with respect to two different applications, and tried once more to synthesize CNTs within a small silica fiber. The following week, K disclosed to me that his second fiber attempt had been positive. This success helped trigger the resurrection of the fiber project agenda during the next day's group meeting. The silica fiber project had thus been authorized, terminated, and then reauthorized, largely due to independent decisions made by K during research agenda implementation.

Moving Fast

At the meeting, K presented a scanning electron microscope image of a silica fiber nearly bursting with nanotubes. This was interpreted as a "proof of concept" that CNT synthesis could occur within silica fibers. K also reported the "bad news" that he had discovered in a new literature search that two other research groups had grown CNTs within cylinders – robbing the research of its original claim to novelty. He offered some "good news," however: no group had yet demonstrated this effect on silica fibers. K then made a pitch for the project in terms of potential technological applications – the search for which had prompted his return to the literature. After some discussion of viable applications, the director crisply stated "let's move fast, get a paper out."

In fact, for the last 2 or 3 days, K had been considering placing an order for more silica fibers, in order to redouble his efforts on the fiber project. But he had demurred, feeling more comfortable presenting the results and application ideas to the group first. Now, directly after the meeting, he spent nearly seven hours searching for company suppliers, his enthusiasm carrying him until nearly midnight. Next morning, he began making phone calls. He finally settled on a package of silica fiber samples and requested that the fibers be sent overnight, uncharacteristically incurring additional costs. If they arrived in time, as he hoped, he might be able to conduct experiments over the weekend, perform the necessary microscopy, and present the results to the director Monday morning. The director, he reasoned, could then approach potential collaborators whose expertise would be needed to pursue the envisioned applications (Table 3).

K's reluctance to give up on the fiber idea had paid off. He had creatively aligned multiple objectives – the director's, another senior researcher's, and his own – within a single experiment. Despite taking these initiatives, he was careful not to overstep his bounds. Although he had achieved experimental success, the consent of the group and the director became the overriding consideration in his mind regarding an expenditure of funds – despite the necessary delay. Nevertheless, K had produced and gathered sufficient intelligence and had effectively promoted it to the group. The shift from the earlier

Table 3 Moving fast

Components	
Opportunity:	Proof of concept had been established for CNT growth within silica fibers.
Considerations:	"Now it's turning out to be something"; "move fast"; "get a paper out."
Alternatives:	Order fibers on K's own initiative or "run by the group first."
Outcome:	Order the fibers, but only after the group and the director had concurred.

playful mood of the project to one of urgency was palpable.

Over time, K. performed numerous successful experiments on silica fibers, spawning several different ideas for research applications and new fiber-related projects. These results were achieved using ferrofluid, which for K became the more desirable catalyst not only because of its perceived experimental effectiveness, but because of its perceived environmentally benign characteristics.

Discussion

As the episode suggests, a 'bench scientist' such as K can play a significant role in the emergence and evolution of research paths. Although the director made the decisions that determined the formal status of the fiber project agenda, K's resourcefulness, coupled with his tenacity, allowed the project to resurface as a viable agenda and also contributed to its framing and experimental design. The role K played is perhaps easily lost on more formal policy conceptions of the laboratory, for his decisions occurred after the project was initially authorized yet before it stabilized as a TNL focus. Thus, the account demonstrates the co-production of research agenda setting and research conduct. It also suggests that K was able to reflect on his role in the overall distributed decision process recounted above. For instance, he was able to observe the changed mood of the project from playful to urgent, give voice to his own concerns in using Ferrocene, align multiple competing agendas, and negotiate the limits of his power and authority within the group. Finally, it suggests that K's reflections entailed a responsive capacity to inform his own research and even modulate its outcomes. K's concerns regarding Ferrocene might have never come to light had he not engaged, during a crucial moment, in an extended series of associations occasioned by the protocol. Additionally, if K had not connected ferrofluid with the fiber project, thereby expanding his perception of available catalysts, he likely would not have attempted the second fiber experiment and the project may have been "dropped for good."

While theoretically everything may be negotiable at some level, the laboratory decisions mapped above reveal that they were enabled and constrained by numerous social and material considerations. The colleague's challenge, the director's mandate, the prior use of Ferrocene, the publications of another group – these spurred K to action and at the same time limited his flexibility. Such de facto modulators thus influenced K's decisions, and his decisions in turn influenced the social context from which they emerged. In light of this reflexivity, the model's application above suggests that decision flexibility – and hence negotiations – can arise in any of the components: the *opportunity* for initiating a decision process (what to respond to, how to frame it); the *considerations* that influence the choice (which and whose selection criteria are to be invoked, to what degree and on what grounds); the *alternative* selected (which possible courses are to be transformed into action); and the *outcome* itself (will it be revised, and at what point).

Accordingly, the three decisions listed above exhibit – and operationalize – varying degrees of negotiability. The decisions to experiment with a new medium (Table 1) and to order a batch of silica fibers for further experimentation (Table 3) were driven predominantly by the TNL value of gaining recognition through achieving and publishing novel research. Similarly, the perceived alternatives did not leave much room for negotiation – other than whether or not to incur a delay in ordering new fibers. On the other hand, each of the components of the middle decision (Table 2) underwent changes: the opportunity shifted from how to coat the fiber, to whether to coat it, and finally to which catalyst to select. The considerations fluctuated from material, to environmental, to timing concerns; and the alternatives expanded to include an additional catalyst. Even the outcome was revisited when K later made a second experimental run, this time choosing a new catalyst.[5]

The catalyst decision in particular reveals an informative interplay between considerations and alternatives, for the expansion of alternatives occasioned the expansion of considerations, rather than other way around. Thus, K's offhand comment the he "wouldn't have to use Ferrocene" reflected his discomfort with Ferrocene and his latent desire to cease using it – although he had not up until then

[5] The tables represent K's more or less sequential responses to the various components during interviews; thus, they do not convey all the content discussed in my analysis here.

been animated enough by this desire to seek an alternative. Only when a second alternative (ferrofluid) occurred to him did his discomfort with the default alternative (Ferrocene) emerge and begin to intensify. Only then did the perceived considerations expand to include not only research-normal concerns about the equipment and measurement, but also environmental and health concerns about disposal and contamination.

While the protocol rendered elements of K's decision making more visible to the author, it also made them more visible to K. His reflexive capacity to identify and align 'social' considerations with 'technical' alternatives in order to solve a complex problem – as seen in his project-saving response to the mixed messages in the form of the ferrofluid substitution – was conditioned by a reformulation of the social in terms of the technical.

In the language of the protocol, decision capacity may be defined as the ability to identify and select an alternative that is aligned with one or more hypothetically desirable considerations in such a way as to influence the outcome. Engaging this capacity is taken to be the goal of the nanotechnology engagement programs mentioned at the outset. As the case above reveals, decision capacity can be engaged by the expansion of decision alternatives and/or by the expansion or operationalizing of decision considerations. In simple terms, the engagement of laboratory decision capacity consists here of cognitively linking (societal) considerations with (technical) alternatives. An important conceptual dynamic and engagement-oriented research agenda thus emerges: the alignment of non-research-normal decision components with research-normal components.

The design and inhabitation of structured spaces for socio-technical integration can thus, by increasing reflexive awareness, affect decision making. The particular mechanism employed represents one approach for broadening the social influences on the development of nanotechnologies. While the model – which itself comprises a cultural artifact – affords interesting opportunities for analysis, engagement, and modulation, its pragmatic effects (largely because it was developed on site) come at the cost of analytical limits, as indicated. What it lacks in nuance and robustness, however, it makes up for in utility. As K stated more than once, his research was influenced by the continuous engagement. In his words, the project "could have been a whole different thing." K also noted on several occasions that discursively analyzing his decisions as they unfolded helped clarify his own thinking, a point that was illustrated when he requested copies of the author's field notes. As K stated at one point, his thoughts were frequently "in flux," and the ritual of applying the protocol afforded him opportunities to conceptualize and work out his own approaches.

The protocol was developed from ethnographically informed research in an attempt to interface with local practice. As such, it can be thought of as an ethnographic intervention [38] – or better, an ethnographic invention, in that it arose from the cultural context that it studied. Further, its cultural embedment allowed it to function as a feedback mechanism, creating a more self-critical environment for knowledge production and the potential to engage decision capacity. Its collaborative development rendered it a boundary object, and the participation of research subjects in its creation and vetting likely increased its acceptance in the form of an interview protocol. The continual feedback generated by the embedded protocol was effective not only for analyzing the social system but for perturbing it in research-tolerable ways.

The progressive expansion of perceived and, to some extent, operative considerations in the catalyst substitution was instrumentally triggered not by the interjection of mandates or prescriptions, but by K's own cognitive work of reflection, association, and invention. Rather than introduce social or ethical considerations, the protocol instead allowed K's latent concerns to surface. As an intervention, this engagement of research capacity was productive because of the work of the subject – the engagement may have influenced practice, but to do so it required the practitioner's desire to remedy a perceived deficiency. K's recognition was, in turn, enabled by my ongoing attentiveness to his unfolding account of social processes and material properties. Such continual observation is perhaps associated more readily with ethnographic work and collaboration, than with engagement and intervention, perhaps indicating one reason why ethnographers and collaborators have traditionally been able to gain access to laboratories. Of course, in choosing to offer ethnographic feedback to K – which I felt bound to do insofar as I was viewed as a collaborator – my role fluctuated between observation and participation. Perhaps the point of the story is that while one can only discover reflexivity oneself, this does not mean one only discovers it *for* oneself.

Depending on the policy goals that inform them, engagement programs may well require supplementing the approach outlined here either with more numerous perspectives or by advocating specific social and ethical norms. To be effective, this paper suggests, supplementation of this sort may do well not to lose sight of the context-specific factors in which is bound up the capacity of research practitioners. For, without reconfiguring its architecture, which starts with experience of the existing configurations, research decision space may not be capacious enough to accommodate the range of societal dimensions that oscillate on the outskirts of laboratory life.

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