Integrating ethicists and social scientists into cutting edge research and technological development

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Abstract

Ethics is an integral part of scientific and technological thinking, whether the practitioners recognize it or not. The kind of expertise the scientist gains about ethics and the ethicist about science can be labeled interactional. An interactional expert learns the language of a community with sufficient depth to communicate on matters like research strategy. The concept of trading zone is employed to understand how people from different perspectives and agencies can work together to define a common goal in a way that would be acceptable to their core communities. These concepts will be honed by applying them to case-studies of social scientists and humanists who integrated themselves into science and engineering laboratories. This paper will particularly focus on the value of complementing interactional expertise with the acquisition of somatic tacit knowledge.

Concern with the ethical and social implications of research should be an integral part of scientific and technological thinking (M. Gorman, Werhane, & Swami, 2009). There are codes and guidelines for the ethical conduct of research: for example, plagiarism and fraud are both unethical and illegal, there are norms for assigning authorship, for mentoring graduate students[1], for protecting research subjects and strict rules regarding laboratory safety and in vivo research. Scientists and engineers must not only be in compliance with these guidelines, they must play a role in shaping them, and in thinking about situations not covered in any current

[1] The National Academy of Sciences book on the Responsible Conduct of Science is an extremely useful resource on these topics (http://www.nap.edu/openbook.php?record_id=4917)

guidelines—the kinds of challenges and opportunities that are created on the research frontier, where discoveries and innovations change what is possible.

Scientists are also urged by the National Science Foundation to address the broader impacts of their work.[2] Broader impact criteria make "critical reflection on the relation of scientific discovery to societal priorities" part of "the scientific research process itself." (Frodeman and Parker: 2009, p. 304). Scientists and engineers are not trained to do this, so here they could use assistance from those better trained to think about societal and ethical implications.

One method to achieve this objective, and to integrate broader impacts and intellectual merit, is to follow Davis Baird's advice, provided in testimony before the Senate Committee on Commerce, Science and Transportation, May 1, 2003:

> Ethicists need to go into the lab to understand what's possible. Scientists and engineers need to engage with humanists to start thinking about this aspect of their work. Only thus, working together in dialog, will we make genuine progress on the societal and ethical issues that nanotechnology poses.

Indeed, the 21st Century Nanotechnology Research and Development Act of 2003 calls for the investigation of the societal impacts of publicly funded nanotechnology R&D. The Act explicitly identifies the objective of "integrating research on societal, ethical, and environmental concerns with nanotechnology research and development" (US Congress, 2003, Public Law no. 108-153). Moreover, the 2011 National Nanotechnology Initiative strategic plan includes engagement with multiple stakeholders:

> Build collaborations among the relevant communities (e.g., consumers, engineers, ethicists, manufacturers, nongovernmental organizations, regulators, and scientists—including social and behavioral scientists) to enable prompt consideration of the potential risks and benefits of research breakthroughs and to provide perspectives on new research directions (NNI 2011, objective 4.3.2).

This chapter and the one by Fisher and Schuurbiers investigate one way of bringing this expertise into the laboratory: by integrating humanists and social scientists into laboratories and research teams. This chapter will focus on the capabilities required to do this sort of integration and compare them with three engagement experiences, one upstream and two midstream. The end result will be suggestions for further research that would provide valuable lessons for others who want to try engagement as a strategy for integrating the ethical and the social into the lab—and for integrating the latest and best expertise on science and engineering into STS.

Modulation projects as trading zones

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[2] See http://www.nsf.gov/nsb/publications/2011/nsb1141.pdf for the latest recommendations by the National Science Board.

How can communication and collaboration occur across C.P. Snow's two cultures, when even participants in different approaches to a single discipline may have perspectives and practices so different from each other that they appear incommensurable? Consider, for example, the ongoing argument in anthropology over whether the field ought to be a science or not (Wade, 2010). The scientific and non-scientific approaches to anthropology are apparently incommensurable, in part because some of those uncomfortable with calling anthropology a science regard science as a hegemonic, colonial enterprise. Similar debates between Science, Technology and Society (STS) scholars and scientists were labeled the 'science wars'; some scientists argued that STS scholars did not have the expertise to study science , and STS scholars counter-argued that they wanted to study science like any other culture, without privileging the scientific world-view from the outset. Again, these positions appear incommensurable, but more recent work has showed a way to solve this problem, involving two key concepts: trading zones and interactional expertise.

Trading Zones

Peter Galison's (1997) solution to the problem of incommensurability is the development of trading zones (see also Gorman, 2010). Different cultures who do not understand each others' perspectives and practices can still trade; all they need is to establish what each wants and negotiate an exchange that satisfies both sides. From simple trades like this, more complex exchanges may develop that require a shared language; pidgins, for example, develop to facilitiate exchanges in places like ports where multiple cultures mingle. Out of a pidgin may emerge a creole that becomes a language of its own. Most of our modern languages began as creoles.

Trading zones can permit scientists and engineers to work across apparently incommensurable barriers of language, culture and practice. Here the exchanges are often in pursuit of a common goal. For example, Galison shows how the development of radar required scientists, engineers, military experts and others to work together to develop a system that was critical to the survival of Britain in World War II. Patrick McCray has described the kinds of trading zones that go into the development of giant telescopes (2004). [3]

The academic analogy is the kind of exchanges of knowledge, time and

[3] A system like radar involved work on the boundaries of several disciplines; therefore, different expertises represented the emerging system and sub-systems in unique ways characteristic of what Leigh Starr called a boundary object (Bowker & Star, 2010).
Boundary objects and systems can facilitate coordination in trading zones, especially ones that involve creating systems, where working prototypes and detailed plans can serve a role similar to an emerging creole.

resources that led to the establishment of new fields like science and technology studies, born out of a shared interest in studying science among a few sociologists, anthropologists, historians and psychologists who found they needed additional expertise and so started slowly to develop a creole in order to found a new society, journals and discipline.

Therefore, the apparent incommensurability between scientists and STS scholars requires development of trading zones where these disciplines can exchange knowledge and work together on projects. Good examples are provided by the two Centers for Nanotechnology in Society at ASU (www.cns.asu.edu) and University of California Santa Barbara (www.cns.ucsb.edu) where STS work on nanotechnology includes engagement—and sometimes collaboration—with scientists.

But what about the expertise problem posed in the science wars: how can someone without deep background in a scientific domain understand enough to study and/or work with the members of that expertise community?[4]

Interactional expertise

An interactional expert learns to communicate with members of another discipline or culture by immersing her/himself in the community and learning both the explicit and tacit aspects of the language. Collins (2004) did this with the gravitational wave physics community; after a long immersion period, he could converse fluently with experts and even pass as one on a kind of Turing test in which a gravitational wave physicist had to determine which of two individuals was a member of his community and which not. Collins passed the test by being chosen as the gravitational wave physicist (Collins and Evans, 2007). Interactional expertise is therefore a solution to the central concern of scientists' in the science wars: Collins demonstrated it was possible to learn enough to interact intelligently and deeply with members of a specialized community without having to learn all the laboratory and mathematical skills necessary to do the research. [5]
It might therefore be possible for humanist or social scientist to gain sufficient interactional expertise to follow Baird's advice and 'go into the laboratory' to engage with the work. But if this engagement includes participation, there will also be trades involved; the laboratory members must see a benefit for making their time available to this newcomer who has little or no expertise in their area of science and engineering.

What follows are several case studies that illustrate the potential for, and

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[4] Galison has a PhD in physics as well as in history of science, which facilitates his study of trading zones—but even in his case, he does not have expertise across all the elements of the trading zones.

[5] Collins and Evans have developed a program of research using the imitation game, a kind of Turing test for interactional expertise, but that important work is beyond the scope of this paper (Collins & Evans, 2007).

limitations of, this kind of engagement, using trading zones and interactional expertises as a framework.

A micro nanotechnology trading zone

Gorman (psychologist) shared a graduate student with Groves (material scientist).[6] Gorman had advised Masters and PhD students in Systems Engineering students on topics like innovative environmental design where ethical and social issues are explicit components of the degree (M. E. Gorman, Groves, & Catalano, 2004). This project with Groves was different because the student wanted to get a Materials Science degree and Gorman and Groves were equal co-advisors. Since Gorman was not an expert in the research domain, he played the role of an embedded social scientist, asking lots of questions and discussing options as the work progressed.

Groves suggested the student make a chart of global problems and see which ones could be mapped onto nanotechnologies that corresponded to the capabilities of this small team and the constraints of a Masters thesis—an apparently impossible set of constraints, until Groves suggested development of a metaphoric language, based on the fact that all three of us liked to hike. He said the global problems were like distant mountains. The student's project corresponded to a bridge across a stream on a route that could lead to the mountain. This meant the student did not have to think about solving a major health or environmental issue; she could simply focus on a bridge that might be built in the course of a Masters thesis.

The small team expanded by adding a bio-medical engineer who was studying blood flow in the hopes of making an eventual contribution to an understanding of artheriosclerosis. Groves made artheriosclerosis a foothill that lay between the bridge and the distant mountain representing a significant reduction in heart disease. The student looked at creating a nano platform that would hold a blood cell in place long enough for its deformation during flow to be modeled. This kind of a nano platform was far too complicated for a Masters thesis, so the student ended up working on what nano materials might be used for such a platform and conducting experiments on one of the best options.[7]

At one point late in the project, Groves rushed into Gorman's office and spent a half-hour explaining why the consideration of these societal dimensions made the science better. Groves said he would not have stuck with such a difficult problem for so long; the societal goal motivated persistence down a line of research that eventually led to a patent application. The science was better because the team tackled a more ambitious problem and stayed with it until they made a small discovery about the way two metal oxides could be deposited on a surface.

The Gorman/Groves project involved starting a new line of research, and

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[6] Societal dimensions of nanotechnology (SES 0210452)

[7] For more details on this project and its outcomes, see (M. E. Gorman, Groves, & Shrager, 2004).

therefore constitutes an example of upstream modulation. Mahajan (engineer) encouraged Fisher (humanist) to embed in his laboratory, interacting with researchers in ongoing projects. Therefore, Fisher was engaged in midstream modulation. Downstream modulation would occur in the late stages of a research project, when the insertion of a humanist or social scientist would be least likely to affect the course of that particular line of research, though modulation could certainly affect dissemination and application of the research, as well as recommendations for regulation of the research products, where necessary.

Fisher also found evidence that modulation could improve the science. His questions about decision-making processes in the lab stimulated one researcher to reflect on alternative possibilities. This resulted in a decision to replace a key compound in the synthesis with a related, but as yet un-thought of and untried, compound. The replacement turned out to be successful in increasing yield with a cleaner process that reduced the fouling of the instruments involved in synthesizing the compound (Fisher & Mahajan, 2010). This example illustrates the role of the embedded humanist in encouraging the researcher to reflect—which can open up new possibilities that improve the science.

Interactional expertise

To ask thoughtful questions about research strategy, Gorman had to learn enough about the relevant concepts to interact intelligently with Groves and the Materials Science student . Gorman was not able to do any of the research proposed by the student, but he had to understand it well enough to have input on what experiments the student ought to do, and why.

This kind of expertise is called interactional. The canonical example is how sociologist of science Harry Collins gained fluency in the language of gravitational wave physicists sufficient to participate in deep conversations about the domain with members of the community and even understand their jokes (H. Collins, 2004). But Collins could not actually conduct a gravitational wave experiment or do the mathematics.

Similarily, Gorman gained his interactional expertise by asking questions when meeting with his collaborators and then trying to make suggestions based on what he had learned. He also visited the laboratory and learned a bit about the processes involved in conducting the research, but could not conduct any experiments himself. Like Collins, Gorman had spent his career studying how scientists thought and worked, which facilitated his ability to grasp the methodological issues.

Collins and Evans developed a kind of Turing test for interactional expertise and Collins passed it. In the test, a gravitational wave physicist asked a series of brief questions designed to discover which of two respondents was a gravitational wave physicist (H. Collins, Evans, Rieiro, & Hall, 2006). The exchange was done on-line, and Collins was identified slightly more often as the physicist than the actual scientist.

To determine whether Gorman had actually achieved interactional expertise, he could have been put through a similar test in the domain he and Groves and the student worked in. Such a test would have been difficult to set up because Gorman's interactional expertise was research focused, not discipline focused. But Gorman's level of interactional expertise was almost certainly well below Collins'—the latter spent years with the gravitational wave community, and the former only spent parts of two years working with Groves and the student.
An embedded humanist or social scientist is going to need to gain a certain amount of interactional expertise similar to what Gorman acquired—otherwise he or she will not be able to ask intelligent, provocative questions about research strategy. In the rest of this paper, we will consider the value added by the acquisition of what Collins calls somatic tacit knowledge (H. M. Collins, 2010), or the kind of embodied knowledge that seems to reside in the eyes and hands and is virtually impossible to describe linguistically. Erik Fisher's Socio-Technical Integration Research (STIR) project (NSF #0849101) involved midstream modulation studies across 13 countries (see chapter by Fisher and Schuurbiers). Calleja-Lopez and Conley were part of this project, and their experiences included both the acquisition of interactional expertise and somatic tacit knowledge.

Doing a PCR

Conley did her first modulation project in a genetics laboratory in Vancouver, that was exploring novel prenatal diagnosis techniques and genetic causes of premature infertility focusing on chromosomal abnormalities, epigenetic changes, and disorders that are linked to the placenta. The laboratory included a female PI, two PhD students, one post doc, one lab manager, one lab tech, one masters student, an undergrad, and a research coordinator. Conley had no prior knowledge of genetics and met with initial hesitance and distrust from the lab. Laboratory members expressed fears that Conley was on a mission to "dig up" dirt on the laboratory. Laboratory members initially viewed Conley (a political scientist) as an "ethics expert" and feared that she would tell them how to be more ethical scientists. In addition to having to navigate the doubts and distrust of the individual laboratory members, she experienced an immediate language gap and her queries about jargon could not be answered by searching on Google. She needed either to develop a creole across the laboratory, or gain interactional expertise herself. Either could facilitate development of a micro trading zone, in which laboratory members exchanged their time and knowledge with her because both understood the value added by the sharing.

Conley decided her best strategy was to "go native" and learn how to act and function like a member of this community. She felt she needed to probe for diverse ways of engagement/understanding, beyond observation and interviews. So when laboratory members urged her to learn how to do a poymerase chain reaction (PCR)

in order to copy a DNA sequence (see Rabinow, 1996 for the story of the discovery of this technique) she jumped at the opportunity. She worked closely with a postdocand also benefited from a one page form known in the laboratory as a "PCR sheet" that scaffolded the activities involved in doing a PCR. The rows of the table corresponded to different samples and the columns reminded the researcher to keep track of concentrations of chemicals.Doing a PCR was like cooking: practicing with a recipe and taking notes on improvements.
Conley's postdoctoral mentor felt that her PCR was so good it he photographed it as an exemplar for others. She was able to transfer the PCR skill to a doctoral student in another laboratory who was unable to do a good PCR. She also engaged in other material practices, such as making gels to be used in experiments.
Collins' interactional expert learns to understand the tacit knowledge associated with the language. Conley learned aspects of the discourse of the laboratory and also gained somatic tacit knowledge. This ability to do the procedural work made her more of a member of the laboratory: she was willing to master one of the core activities and could even transfer it to another laboratory.
Engagement is two-way. Conley's credibility in the laboratory helped her train the post doc in basic sociology, ethnography and "Science and Technology Studies 101." The post doc was not only sensitized to the social context of his laboratory, he gained awareness of the ways in which the lab could be perceived "from the outside" and became actively involved in shaping those same perceptions among the rest of the research staff. This re-description resulted in observable changes in his own professional behavior, including, notably, reaching out to Conley for her assistance in finding speakers for a workshop on genetics and society and to draft a paper about the lab and its situatedness in its community.

Following a casual bench-side conversation on the meaning of "responsible innovation" in different contexts, the post doc encouraged Conley (with the approval of the laboratory director) to lead a laboratory meeting on the topic. Conley was scheduled to lead the lab meeting towards the end of her three-month project. Rather than lecture the laboratory members on responsible innovation, Conley instead utilized the meeting time as a venue for open dialogue and brainstorming with the scientists. In order to stimulate the researchers' own thoughts on responsible innovation, Conley fed insights from individual interviews over the past three months back into the larger group. Conley highlighted concerns of one of the PhD students, who in an initial interview, had expressed concerns regarding patient engagement and outreach efforts, and that to keep patients abreast of laboratory research through workshops and other outreach efforts would be one way of engaging in "responsible innovation." The laboratory director responded that workshops might not be the best way to engage patients, as the samples that the laboratory collected were sensitive in nature (placenta samples from failed, aborted, and successful pregnancies), but a newsletter with updates on laboratory projects might be more appropriate. At a subsequent laboratory meeting, the laboratory director instructed the researchers to each write a "lay" account of their research, so the laboratory could send out a newsletter to patients about ongoing research.

Engagement Agents and Mobile Trading Zones

While traditional ethnographic sensibilities warn against "going native," Conley's time as an embedded researcher in the Canadian laboratory entailed a significant amount of boundary blurring, as she moved between the roles of observing social scientist to novice natural scientist in training. Conley's engagement strategy, which evolved organically from her interactions in the laboratory, entailed stepping into the shoes of those she was observing. During the three month period, Conley shifted from impartial observer, to benchside interlocutor, to donning a white laboratory coat and engaging in material practices alongside the other laboratory members. While progressively shifting into (and out of) these roles enabled increasingly rich and dynamic dialogues and interactions, Conley's assumption of the different roles was not static. When she put on the lab coat, she knew that she would be taking it off at the end of the day. Conley's presence became so normalized in the laboratory that her name and picture were added to the list of laboratory members on the door of the laboratory. Laboratory members would share articles they were reading with Conley, and would leave articles at her desk space in the laboratory, with notes pointing out the science-society connections of the research. While Conley's normalization into the laboratory's culture enabled for an evolving and expanding trading zone, it also was accompanied by the risks of going native, of being unable to differentiate between the roles of observer and participant, of being unable to take off the metaphorical lab coat.

Conley's experience in the laboratory equipped her with tools that enabled her to engage "between multiple dimensions of research, innovation, and policy processes" (Conley 2011). Conley was able to apply her experiences in the laboratory to her interactions with policymakers, clinicians, and stakeholders. As an individual with no prior background or training in genetics, she gained enough interactional expertise to dialogue with a multiplicity of actors involved in the socio-technical arena, in multiple international and institutional contexts. For example, Conley was able to dialogue with top British scientists about pre-implantation genetic diagnosis of embryos in relation to genetic conditions that exist on a gradient (such as autism). Conley was able to dialogue with the scientists because in her British laboratory engagement she had worked directly with a scientist researching autism. Such individuals can be thought of as "engagement agents" (see te Kulve and Rip 2011; Conley 2011), actors who operate almost as "mobile" trading zones, with the necessary interactional expertise and "on the ground experience" to interface across multiple domains of a particular socio-technical system.

Making an STM tip

Antonio Calleja-Lopez is a philosophy student who had only high school chemistry and physics courses as background when he embedded in a laboratory at ASU working on nanotechnology applications to solar cells. He attended laboratory

meetings involving three/five senior scholars and about a half-dozen PhD students, of whom two or three would speak at a given meeting. He became particularly interested in a sub-group working on electrical measurements of conductance at the nanoscale, a critical component in using nanoarrays to develop solar panels. Two female PhD students and the lab director, Stuart Lindsay, made up this sub-group. Calleja-Lopez noted that making Scanning Tunneling Microscope (STM) tips was a basic laboratory activity, because without these tips, laboratory members could not visualize the nanoscale surfaces they were working on.
The tips have to be made with great precision and care. Calleja-Lopez thought if he worked on making these tips, it would be a form of payback, fostering a trading zone. Laboratory participants thought it would help him understand the work, to get in their shoes, feel what benchwork is like—its details, time consuming and sometime reiterative tasks, etc. Calleja-Lopez had no prior laboratory experience.

Acquisition of somatic tacit knowledge

Conley had learned how to create a PCR partly from a written guide that provided scaffolding for her learning process. Calleja-Lopez, in contrast, had to learn purely through apprenticeship—he was not provided with a written guide. One of the female PhD students taught him via apprenticeship. The first day, she showed him how she made an STM tip. Basically, he had to carve a cone out of a gold string using electrical current. The string was dipped into a 1” plate that contained an acidic solution. Electrons moving through a copper ring supplied the current, which Calleja-Lopez had to modulate carefully so the cone would be properly shaped.
The graduate student taught Calleja-Lopez how to use the sound of the current to guide his modulation of the current itself. She also looked at the color of the solution, and smelled it to judge the quality of the product. She could only judge the product a posteriori, during the manufacturing process: the colors, sounds and smells generated by the process told her things the instruments did not.
Calleja-Lopez was gaining somatic tacit knowledge (Collins, 2010).
After the cone was formed, Antionio had to take the gold string out of the holder, bring the tip to microscope, adjust the light and refocus the lenses to fit his vision. so he could look carefully at the shape of the tip. Was it round? Or deformed? Or a cone?
The PhD student initially made the decisions, using experience-based judgment. In some cases a flawed tip could not be fixed, but in other cases, one could put it back into the solution and shape it again using the current. Calleja-Lopez gradually gained somatic tacit knowledge of how to make a tip and the ability to judge a good one. He felt the main by-product of his tips was his integration with the team, so it was not just a trade in a strict sense: the team did not need him to make tips in exchange for their time, although once he became proficient, they did take advantage of his skill .
Tip-making, like doing a PCR, is a sign that the embedded humanist or social scientists is willing not only to talk like a member of the culture, but learn to do an important activity.
In his second lab study,

Calleja-Lopez had the opportunity to use his background knowledge to suggest new ways of visualizing and communicating aspects of the laboratory work. During his study in Madrid, a PhD student analyzing a STM image used the metaphor of fried eggs, sunny side up or down depending on the voltage, to describe the appearance of the graphene surface displayed on the computer screen. Calleja-Lopez suggested that it looked more like a honeycomb. This second metaphor may be more helpful in thinking the geometry of graphene, as it happened in conversation a few days later with another of the PhD students. The student was trying to describe to Calleja-Lopez the structure of this new material,, stressing the fact that graphene molecules have the appearance of arrays of hexagons, sharing sides and corners, what diminishes the total number of atoms and bonds—if we compare with a hypothetical series of discrete molecules. In order to both show understanding and help with the difficulties in the exposition, Calleja-Lopez suggested the image of row houses common in urban areas. Row houses share walls, which means that 20 row houses need only 21 walls—rather than 40, as would be necessary in the case of free-standing houses. The researcher agreed, and mentioned the value of the example for the purposes of exposition..

These examples show how outsiders can encourage new ways of thinking—and perhaps improve the science once they gain even more interactional expertise.

Expertise is in the interaction, not just in the individual

In an interaction of the kind stirred by the integration experience, there are outcomes that none of the individuals by themselves can claim hers or his. When a STIR student enters a lab and begins to gain interactional expertise and even, in the cases presented here, some somatic tacit knowledge, the student is not only changing her or his expertise, he/she is changing the collective expertise of the lab. Cognitive scientists use the term distributed to refer to the kind of cognition that relies on technologies like computers and smart phones that perform cognitive functions for the user, e.g., provide greatly extended memory and organize social contacts. These technologies impose their own additional constraints and loads (Norman, 1993).

Cognitive scientists use shared cognition to refer to the way in which laboratory members rely on each others expertises and memories to perform tasks. Obviously, the line between distributed and shared cognition is blurry: a smart phone may include information on who is the expert contact on a particular problem, and which member of the team has the memory or knowledge of the state of the project and its requirements. High-functioning teams have good transactive memory, which is the knowledge of who in the team knows what and who can do certain procedures (Gorman, 2002). Transactive memory is therefore an act of attributing expertise to laboratory members, based on experience—it is fluid, can evolve over time. In the highest functioning teams, individuals flow to the work, each fluidly adjusting to the others in a way that needs little discussion—the expertise here is truly shared.

The STIR student becomes part of the collective transactive memory of the laboratory, part of the shared and distributed cognition. Calleja-Lopez's lab could distribute some of the STM tip work to him. More importantly, however, the laboratory gained the ability to look at itself the way an outsider would—and this kind of reflexivity has to emerge in the interaction. One possible end result is an expansion of research and outreach possibilities.

Lessons for achieving integration, and suggestions for future research

The case studies presented here suggest that it is valuable to think of a laboratory engagement experience as a kind of micro trading zone, because this concept emphasizes that exchanges of knowledge, time and resources can occur across apparently incommensurable boundaries.
It is important for the embedded humanist to acquire interactional expertise—and for one or more members of the laboratory to reciprocate This kind of mutual interactional expertise in a micro trading zone facilitates development of a shared language, beginning with mutual understanding of a few terms and expanding if the micro trading zone lasts long enough.

Calleja-Lopez's and Conley's experiences suggest that interactional expertise can be complemented by the ability to do hands-on laboratory work. Learning laboratory procedures makes it easier for a social scientist or humanist to go from being a participant in a micro trading zone to becoming a full-fledged member of a laboratory team because it shows the social scientist or humanist is willing to leave her/his comfort zone and acquire the same skills as any other laboratory member. The 'offer of effort'' has more the character of a gift zone than a trading zone (Baird & Cohen, 1999). . These laboratory interactions are not just trades, they involve giving without exact calculation of what one receives in return. The exchange has symbolic value; it points to something deeper, a shared understanding and identity.

In Gorman's upstream engagement experience, he learned no laboratory procedures, though he visited the laboratory and observed the student in action. But Gorman was an embedded social scientist coming in as a Masters thesis advisor, in a position of authority. Gorman never became a member of a laboratory; he functioned as a member of a committee. Upstream roles will involve more of the sort of strategic planning he engaged in.

Does the acquisition of interactional and procedural expertise enhance ethical reflection?

Conley and Calleja-Lopez think so, because the acquisition of expertise helps the embedded humanist's put her himself in the scientist or engineer's shoes. The central tenet of moral imagination is this ability to see another's point of view, not just in terms of knowledge but also in terms of the underlying values that frame the laboratory. Moral imagination requires deep conversations about why, not just how and what.

Calleja-Lopez went into a laboratory that had a 'science is in society' perspective already. It is part of ASU's Bio-Design Institute, which focuses on bio-inspired and use-inspired design for solving problems in healthcare, sustainability and society (http://biodesign.asu.edu/about). Calleja-Lopez did not have to introduce thinking about societal implications into this lab. His work and conversations amplified an ongoing process of reflection.

While working together at the bench, Conley and the members of her genetics lab discussed a variety of ethical issues like the realization that informed consent is a process, not a document—it involves continuous conversation and communication with stakeholders. The context of this conversation is of particular interest to the midstream modulation approach: Conley reflected back to lab member the practices of sampling and analyzing each other's blood as part of their research. Until Conley's probing of the practice agreements about the practice and the status of the samples was very largely tacit and implicit. The reflexive modulation that resulted in this instance was profound and rapid: new explicit protocols were developed, answering many unresolved, poorly formulated and unformulated bioethical concerns.

Future research

The engagement experiences reported and analyzed in this paper suggest three hypotheses. Embedding a humanist or social scientist into a science or engineering laboratory can:

1. Improve the ability of the laboratory to reflect on the ethical implications of their work and the way in which it fits into social systems.
2. Improve the science by opening up the possibility of new research directions based on the laboratory's increased ability to reflect.
3. Increase our understanding of the laboratory via this mutual reflection. The engagement experience is a good complement to the years of important observational work on laboratories.

To determine whether these hypotheses have any validity, we need additional methods for rigorously comparing these engagement experiences, including:

1. Having the embedded humanist or social scientists keep diaries like the one created by the cognitive scientist Jeff Shrager, who documented the way in which he acquired the expertise necessary to become a molecular biologist (Shrager, 2005). Unless there is some standardization in the format and content of such diaries, it will be hard to compare them. This standardization could be achieved by developing categories worth recording and by having each student's mentor read the diaries and prompt for more information on key topics. Collection of purely quantitative temporal data along with the diary entries will facilitate comparison and generalization across laboratory engagement experiences, while preserving the unique character of each.
2. Daan Schuurbier's chronological flowchart of the activities he observed in his

engagement, including not only what was done in each of the laboratory activities, as he observed it, but also some of the ethical and societal questions raised by the activity (see his chapter in this volume for a more detailed explanation).

3. Problem-behavior graphs that represent the progression of each student's attempts to learn laboratory procedures. This method involves creating flow-chart like graphs that show the behaviors and solutions used to make progress towards solving a problem—and also all the steps that turn out not to lead to the solution. (Ericsson & Simon, 1984). Gorman used this method to graph Alexander Graham Bell's progress towards both a telephone patent and a working device (http://www2.iath.virginia.edu/albell/albell.html), using each change in a device as a node on the graph and Bell's response to the result from testing the device to determine whether the graph led towards or away from his stated goal (Gorman, 1997).. The method has also been used on Michael Faraday's discoveries (Gooding, 1990). These problem behavior graphs could be produced by an observer listening to a laboratory researcher think aloud as he or she did a procedure or an experiment, or could be done by a social scientist or humanist in an effort to keep track of her or his own attempts to gain procedural knowledge. Such graphs could be associated with higher-level stages in Schuurbier's flowcharts. For example, a box in a higher level diagram that says "make STM tip" could be linked to a detailed problem behavior graph of the procedure.

   Problem-behavior graphs could also be used to chart the path of a scientific or engineering project, documenting the places where the humanist or social scientist has input and noting what happens as a result. Such objects can create a kind of visual creole that facilitates detailed discussions and comparisons of integration experiences.

4. Critical incident interviews (Klein, 1999)(Hemlin 2009) would involve asking students to describe in detail key episodes in their integration into their laboratories—and compare their stories with those of a key laboratory participant with whom they worked. These kinds of comparisons are hard to do post hoc, because episodic memory is reconstructive (Ericsson & Simon 1984); when asked to recall, human beings give plausible reconstructions that often put them in the best light (Neisser 1982). Problem behavior graphs and chronological flowcharts can act as a check on these reconstructions.

5. To our knowledge, there is no current method for tracking development of a trading zone, micro or macro. We believe that by using some combination of all three methods it is possible to study the way in which linguistic and cultural barriers between social scientists, scientists and engineers were surmounted. The key is to track exchanges between participants, specifically shifts in allocations of time, resources knowledge and affective tone. One way of tracking these changes is the collection and analysis of metaphors and analogies that are enlisted or developed in the process of gaining interactional expertise. Critical incident interviews could reveal the coincidence of linguistic creativity and conceptual leaps associated with specific critical incidents-- for example, Groves'

redescription of the “landscape” of research. Mapping such episodes could become especially fruitful when set in the context of a chronological problem-behavior graph. Mahootian has suggested that metaphoric redescriptions of laboratory engagement processes could be helpful in better understanding and facilitating them. Specifically he suggests (Mahootian, forthcoming 2012) that a) metaphoric images (like that of the mountain in Groves’s example, and the honeycomb/row houses in Calleja-Lopez’s) have the potential of broadening the scope of alternative perspectives relevant to research and outreach; b) the lab itself is a non-equilibrium system consisting of reaction cycles and dynamic regimes that can be tracked to reveal the formation and dissipation of trading zones in a temporal landscape.

A mixed-methods approach to the possibilities described above could be built on the basis of the idea that an embedded observer-participant *become*s a boundary object the moment s/he enters a research lab. Their very presence stirs things up (as STIR investigators have consistently reported). Shifting interpretations of the status, purpose and activities of the embedded observer-participant can be tracked as s/he negotiate his/her way through the system that is the research lab. The complex of personal, social and material agencies that swirl around the boundary object can be tracked with something as simple as the duration and frequency of contacts between the embedded humanist/social scientist and the lab researcher. Tracking shifts in these temporal pattens could be very revealing when these are compared to shifts in the interactional expertise of the embedded humanist/social scientist. Both Conley’s and Calleja’s cases provide examples of such shifts in terms of laboratory procedures and routines. Detailed tracking of these coincident changes might be achieved by adapting Schuurber’s chronological flowchart and inserting documents, interviews and diaries in sequence as they occurred. By experimenting with ways of organizing the flowchart to suggest patterns we may learn more about various processes and conditions that can enhance or hinder the formation of interactional expertise and the formation of active trading zones. Rather than seeing these methodological possibilities as efforts to reduce laboratory engagement to a linear experience, we should consider such flowcharts as extended metaphors that serve a heuristic function. The hoped for end result may indeed be multiple diagrams of a given laboratory experience from different complementary and sometimes irreducible perspectives.

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