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Embedding philosophers in the practices of science: bringing humanities to the sciences

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Abstract The National Science Foundation (NSF) in the United States, like many other funding agencies all over the globe, has made large investments in interdisciplinary research in the sciences and engineering, arguing that interdisciplinary research is an essential resource for addressing emerging problems, resulting in important social benefits. Using NSF as a case study for problem that might be relevant in other contexts as well, I argue that the NSF itself poses a significant barrier to such research in not sufficiently appreciating the value of the humanities as significant interdisciplinary partners. This essay focuses on the practices of philosophy as a highly valuable but currently under-appreciated partner in achieving the goals of interdisciplinary research. This essay advances a proposal for developing deeper and wider interdisciplinary research in the sciences through coupled ethical-epistemological research. I argue that this more robust model of interdisciplinary practice will lead to better science by providing resources for understanding the types of value decisions that are entrenched in research models and methods, offering resources for identifying the ethical implications of research decisions, and providing a lens for identifying the questions that are ignored, under-examined, and rendered invisible through scientific habit or lack of interest. In this way, we will have *better science* both in the traditional sense of advancing knowledge by building on and adding to our current knowledge as well as in the broader sense of *science for the good of,* namely, scientific research that better benefits society.

Keywords Philosophy · Interdisciplinarity · Coupled ethical-epistemic analyses · Climate science · NSF · Broader-impacts criterion

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> Interdisciplinarity has been variously defined in this century: as a methodology, a concept, a process, a way of thinking, a philosophy, and a reflexive ideology. It has been linked with attempts to expose the dangers of fragmentation, to reestablish old connections, to explore emerging relations, and to create new subjects adequate to handle our practical and conceptual needs. Cutting across all these theories is one recurring idea. Interdisciplinarity is a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches. (Klein 1990, p. 196)

The value and critical importance of interdisciplinary research in the sciences is widely accepted and supported by the US National Science Foundation (NSF). The NSF, like funding agencies in other countries, not only provides funding for interdisciplinary research in the sciences, but it has also made large investments in interdisciplinary education through its Integrative Graduate Education and Research Traineeship (IGERT) Program. The NSF justifies this expenditure by explaining that "the ability to conduct interdisciplinary research is necessary to maintain US competitiveness in high-value industries and has important economic and societal benefits through inventions and innovations that deliver new products and services or improve the effectiveness and efficiency of existing processes" (van Hartesveldt and Giordan 2008, p. 2). This assessment of the importance of interdisciplinary research is shared by the National Institutes Health (NIH). According to the NIH the scope and complexity of biomedical research problems "demand that scientists move beyond the confines of their individual disciplines and explore new organizational models for team science" (NIH 2011).

The NSF as a federal agency tasked with promoting the progress of science provides a clear snapshot of the current perception of interdisciplinary research in the sciences and how it is valued. The NSF website hosts an "Interdisciplinary Research" webpage (http://www.nsf.gov/od/oia/additional_resources/interdisciplinary_research/), which provides an introductory explanation of the importance of interdisciplinary research from the perspective of the NSF, a definition of interdisciplinary research, and a list of sources of funding support. The National Science Foundation offers two justifications for their support of interdisciplinary research and educational programs. The first justification is based on the fact that important research topics often transcend the scope of a single discipline and thus interdisciplinary research is valuable "in pushing fields forward and accelerating scientific discovery" (NSF 2011b). They underscore this insight by explaining that the content of scientific knowledge as well as research methods are in flux both within and between disciplines. The NSF views interdisciplinary research as an essential resource for addressing such emerging problems. The second justification concerns interdisciplinary training, which the NSF claims is important workforce training that will best prepare scientists and engineers to undertake challenges in innovative ways. According to the National Science Foundation workshop report *Impact on Academic Institutions of Transformative Interdisciplinary Research and Graduate Education*: "The ability to conduct interdisciplinary research is necessary to maintain US competitiveness in high-value industries and has important economic and societal benefits through inventions and innovations that deliver new products and services or improve the effectiveness and efficiency of existing processes" (van Hartesveldt and Giordan 2008).

In this essay I argue that the National Science Foundation appreciation of interdisciplinarity is insufficiently robust in that it, for the most part, fails to fully appreciate the value of the humanities in general, and philosophy in particular, as a crucial partner in interdisciplinary research in the sciences. My goal is to advance a proposal for developing deeper and wider interdisciplinary research in the sciences through what I label "coupled ethical-epistemological research." Coupled ethical-epistemic issues arise in science in a variety of ways. There are often, for example, value decisions embedded in research models and methods that go unquestioned and often unappreciated. These can be both ethically significant, as well has have consequences for what is (and is not) known. Thus, rendering these values transparent and examining their coupled ethical-epistemic significance is an important and often under-appreciated resource for more objective[1] science. In the sections to follow, I argue that this more robust model of interdisciplinary practice that is founded on coupled ethical-epistemological research will result in *better science* both in the traditional science of advancing knowledge by building on and adding to our current knowledge as well as in the broader sense of *science for the good of*, that is scientific research that satisfies the goals of the NSF broader impacts criterion of benefiting society.[2]

1 The world has problems: Universities have disciplines[3]

While valuing interdisciplinary research, on the one hand, there is, on the other hand, recognition both by the National Science Foundation and in the literature on interdisciplinary research of the challenges and barriers to it. These are typically grouped into three broad areas, namely (i) institutional barriers, (ii) disciplinary barriers, and iii) epistemic barriers, though it is often acknowledged that the boundaries between these areas are porous.

Institutional obstacles in the academic setting include such elements as the structure of educational programs and incentive systems. Since it is commonly agreed that interdisciplinary research must be combined with disciplinary training, interdisciplinary training for graduate students often requires additional classes, more time to completion of the program, and are faced with different challenges than they are in their disciplinary training. Even in the Integrative Graduate Education and Research Traineeship (IGERT) Program and dual title graduate programs where graduate students are provided mentorship for conducting interdisciplinary research, years to completion of their degree are often longer, resulting in additional funding issues, for in

[1] My understanding of more objective science here is in line with Sandra Harding's notion of strengthened objectivity (2002).

[2] While advocating the importance of coupled ethical-epistemological research as an important contribution of philosophy to a more robust model of interdisciplinarity, I am not claiming that philosophical contributions to interdisciplinary approaches to science are limited to such research. I acknowledge that there are other contributions philosophy has to offer including metaphysical and aesthetic analysis.

[3] This title was adapted from Gordon Wilson's article "The World has Problems while Universities have Disciplines."

at least some cases there is not sufficient funding to cover the extra year(s) of study. In addition, students are more likely than in traditional disciplinary programs to feel overwhelmed by the additional work or different expectations and requirements of their interdisciplinary training. In a reflection by a group of IGERT students regarding their educational experiences, they call attention, for example, to having confronted "difficult issues, including time limitations, individual and team learning styles, and the iterative process of identity formation." These students list the following issues they confronted while participating in the IGERT process:

> How can I (or do I want to) relate to my interdisciplinary and disciplinary work? To what extent does interdisciplinary research help me complete degree requirements? What are the implications of integrating my disciplinary and interdisciplinary research? Will I attain the rigor and depth necessary in my disciplinary research, given the interdisciplinary contribution to my degree? How much research must I do to obtain legitimacy in my discipline and in urban ecology [the interdisciplinary theme of their IGERT]?…How do I demonstrate disciplinary fluency/proficiency *and* interdisciplinary agility? (Graybill et al. 2006, pp. 760–761)

Faculty face various institutional challenges. The organization of the tenure and promotion process in the United States is a key element since rank is one important marker of success, and in the case of tenure stream assistant professors, developing a dossier that will support a tenure decision is required for retaining one's job. For instance, tenure/promotion committees are typically disciplinary-based and may not appreciate either the publication venues that are prestigious for interdisciplinary research or the challenges of such research, including the extra time it can take for an interdisciplinary project to produce outcomes. The ease of collaboration between faculty from different departments is often limited by the physical structure of the universities, in which faculty are often housed in separate buildings based on disciplinary lines and where research facilities are similarly spatially divided. In addition, there are often few opportunities within the academy for faculty themselves to receive or offer interdisciplinary training, and in many institutions there is typically little institutional support for interdisciplinary research or incentive systems to encourage such work.

Disciplinary training and reward systems give rise to similar barriers. Which journals are considered top rank, how co-authorship is viewed, even how authorship order is treated are often disciplinary specific. There are also disciplinary differences in publication or grants expectations, which can pose challenges both for conducting interdisciplinary research as well as for mentoring students interested in pursuing interdisciplinary training. Academic departments take care to ensure that key curriculum offerings do not conflict with one another, that is, that graduate offerings are scheduled at different times so that students are free to choose between them. However, there are seldom efforts to coordinate curricular offerings with other departments or with interdisciplinary programs, leading to time conflicts for students interested in interdisciplinary training.

Epistemic barriers include dissimilar and sometimes conflicting styles of thought, methodology, research traditions, techniques, and terminology that can make interdisciplinary teaching, research, or collaboration challenging. Each discipline has a conception of what constitutes knowledge, as well as what are reliable avenues for producing valid knowledge claims. Even how such knowledge can be appropriately applied can vary across disciplines.

While not denying the significance of institutional or disciplinary barriers, the epistemic differences between disciplines constitute not only a significant challenge to the success of interdisciplinary research, but, as I will argue in this essay, potential avenues to more successful interdisciplinary collaborations. Disciplinary epistemic practices, while themselves in the process of being created and recreated through training and habituation, nonetheless can provide resources, when put into dialogue, for rethinking and recreating the connections between knowledge practices. Such dialogue has the potential to render transparent the epistemic assumptions of the disciplines through interdisciplinary interaction and provides opportunities to rethink values and assumptions embedded in these practices. In other words, interdisciplinary collaborations provide possibilities for undisciplined practices (Beier and Arnold 2005).

2 Breaching interdisciplinarity

One of the most typical omissions or breaches of interdisciplinary practices in the sciences, particularly those supported by the National Science Foundation, is the underappreciation of humanities disciplines as significant interdisciplinary partners. While it might be argued that it is the role of the National Endowment for the Humanities to support humanities related research, my argument is not that the NSF should support humanities projects, but rather that the humanities disciplines provide important resources for interdisciplinary research in science and engineering that should be part of the mission of the NSF.[4] For the purposes of this essay, my focus will be on the practices of philosophy as a potentially highly valuable but currently underutilized partner in achieving the NSF's goal of "pushing fields forward and accelerating scientific discovery" (2011b).

A clear snapshot of the underutilization of the humanities in general, and the field of philosophy in particular, *and* the worry that when philosophical approaches are supported by the NSF, they are not actual *interdisciplinary partners* can be obtained by considering recent NSF Integrative Graduate Education and Research Traineeship Program awards. The NSF web page lists 168 such awards. Of these only four involve the methods, resources, or knowledge practices of philosophy. And of these four,[5] three are focused on ethics education and are smaller grants,[6] similar to the NSF

[4] I would be remiss not to acknowledge the NSF's Science, Technology, and Society program which specifically includes in their description of the program philosophical methods as a resource for research into the interface between science and society. This program has funded projects that deploy resources from the philosophy of science and technology.

[5] The fourth grant is entitled "The Dynamics of Communication in Context" and is designed to integrate the computational, cognitive and neuroscientific study of communication and communication systems.

[6] Each of these grants were for ± $300,000 in comparison to the typical IGERT ± $3,000,000; a very significant funding difference.

Ethics Education in Science and Engineering (EESE) grants designed to educate graduate students about research ethics.

1. *Integrating ethics education: capacity-building workshops for science and engineering faculty*:To build capacity for faculty to educate graduate students about research ethics in the context of the research environment.
2. *HPL-based ethics education for life science and bioengineering students*: Designed to prepare life sciences and bioengineering students to recognize and address ethical issues in their profession through the creation of case-based educational modules and related materials in life science ethics for use by graduate students and "emphasize themes that are aligned to critical components of an effective ethical framework for the responsible conduct of research (RCR) as defined by HHS Office of Research Integrity (ORI)" (Collins 2010).
3. *Ethics education for professional science master's programs*: To create ethics education materials in the growing area of Professional Science Master's education programs that enhance student awareness of important ethical issues and promote an understanding of ethics and integrity in scientific research outside of the academy.[7]

Although I would certainly underscore the value of ethics education in the sciences, each of these grants, while aiming to integrate ethics into science education and provide science graduates with the skills needed to address ethical issues they might confront, *are not themselves interdisciplinary*. They apply resources from one discipline, in this case ethics, to topics in a science based area to provide students training in case-based ethics education. Rather than becoming an integral component of an interdisciplinary approach to science in these fields, this model of ethics education risks becoming instead a handmaiden to the sciences; *useful knowledge to have to ensure proper research conduct, but not a vehicle to better science*.

Ethics, while an important domain of philosophy, only comprises one area of philosophical study. Philosophical attention to epistemic practices is another domain in which interdisciplinary research could be richly augmented through philosophically directed attention to the assumptions and conceptual frameworks through which the validity of knowledge practices are established in the various sciences and methods are legitimated. However, another valuable path to integrating epistemic analyses into science practices and thereby enhancing interdisciplinarity collaborations is through a truly integrated and interdisciplinary ethical analysis, one that I will argue can lead to coupled epistemic-ethical analyses.

3 Into the breach: the ethical dimensions of scientific research

While acknowledging that the humanities in general, and philosophy in particular, stands as one gap or breach of interdisciplinary research in the sciences, a more robust

[7] This list was constructed by accessing the NSF IGERT list of recently funded IGERT grants which can be found at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=12759.

appreciation of the ethical dimensions of scientific research than is understood in typical research ethics analyses can be an important first step to bridging this gap or omission. However, doing so requires going significantly beyond typical approaches to research ethics, and ultimately requires a more robust interdisciplinary approach to ethical analysis.

Too often research ethics in the sciences focuses on issues in the RCR. RCR topics include research misconduct, i.e., issues of falsification, fabrication, and plagiarism, as well as responsible practice concerning authorship, conflicts of interest, data management, animal welfare, and human subject protections. While these topics, and the typical approach to train scientists in proper "procedures," are certainly important, this vision of research ethics is far too limited a venue to convey an appreciation of the full spectrum of ethics relevant to scientific research. Unfortunately, this approach to the relevance of ethics to science is being reinforced as universities, including my own, respond to the America COMPETES Act (America Creating Opportunities to Meaningfully Provide Excellence in Technology, Education, and Science Act). This Congressional directive requires that:

> each institution that applies for financial assistance from the Foundation [the National Science Foundation] for science and engineering research or education describe in its grant proposal a plan to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduate students, graduate students, and postdoctoral researchers participating in the proposed research plan (United States Congress 2007, Section 7009).

In order for ethics to "go once more into the breach," that is, to be a rallying cry for a more robust interdisciplinarity for the sciences that includes the humanities as an essential element of interdisciplinarity, will require a far more inclusive understanding of the ethical dimensions of scientific research. I have elsewhere argued that this requires an appreciation of both the ethical issues *external* to the production of scientific research as well as the ethical values that are *embedded* within the production of scientific knowledge (Tuana 2010). As a result of an National Science Foundation funded research collaboration with geoscientists, our research team uncovered an approach to integrating ethical analyses into scientific practices that lead to an interdisciplinary practice that was at the same time both broader and deeper. We labeled this enhanced conception "the ethical dimensions of scientific reasoning"(Fig.1) (Schienke et al. 2009).

While Responsible Conduct of Research (RCR), or what we refer to as procedural components of scientific research can often be understood by *adding* an ethical perspective to the sciences and engineering, the other dimensions often require richly interdisciplinary investigation to fully appreciate. Let me begin by providing a brief overview of the three dimensions.[8]

- *Dimension one*: **Procedural ethics** involves ethical aspects of the process of conducting scientific research and is contained within the domain of RCR.

[8] The definitions of the three domains of ethics are derived from Schienke et al. (2009). I have used our definitions in this essay with only minor revisions.

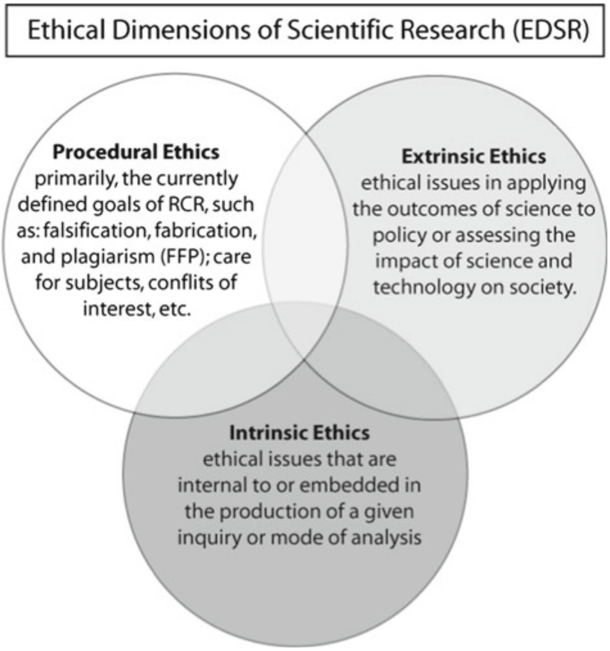

Fig. 1 Diagram of the ethical dimensions of scientific research. Although each domain is presented separately, it is important to stress that there are often instances where the ethical significance of the problem crosses between the various domains

This dimension of ethics includes investigation of the ways in which interests can pose a conflict to research objectivity, the relationship between trust and the interests of science, as well as aspects of data management. Unfortunately, most research programs for science and engineering are limited to this dimension of ethics

- *Dimension two*: **Extrinsic ethics** involves the domain of ethical issues that are external to the production of scientific research such as applications of scientific findings to policy or the impact of scientific discoveries on society as well as the impact of societal interests on science.

Ethical issues arise in the extrinsic dimension when, for example, considering the impact of scientific research on society. These arise in a variety of venues such as the effects of technological innovations on social ends such as health and well-being, and the role of science in policy-making. This domain of ethics also includes ethical concerns arising from the impact of society upon science, for example the impact of funding on research trajectories or the ways in which wide-spread societal biases can impact research trajectories, as they arguably did with eugenics research. It also includes such topics as the proper interpretation and application of the precautionary principle, furthering epistemically and ethically adequate societal understandings of issues of scientific uncertainty and risk, the role of scientists in the development of policy relevant research, and the ethical responsibilities of scientists whose research reveals risks, for example, to human health or ecosystem sustainability.

- *Dimension three*: **Intrinsic ethics** involves those ethical concerns and values that are embedded in or otherwise internal to the production of scientific research and analysis.

This dimension involves ethical issues arising from, for example: the choice of certain equations, constants, and variables, the analysis of data, the handling of error, and degree of confidence in projections. This domain of ethics often involves clarifying the presence of, reasons for, and implications of over-confidence or bias in scientific models. It also is involved in the identification of values and assumptions that are embedded in the very context of hypothesis development, data-gathering and analysis, governing equations, models, strategies for addressing uncertainty, and the like.

It is in the second and the third dimensions, and their frequent intersections, that epistemic issues are often coupled with ethical issues. Disciplinary epistemic practices often embed values and assumptions that can be brought to light and reexamined through coupled epistemic-ethical analyses. This has the potential to bring to light new insights for rethinking scientific assumptions and knowledge practices. It is in these domains that wider and deeper couplings between scientists and philosophers can lead to undisciplining practices, which provide resources for new knowledges and new knowledge practices.

While philosophical analysis of issues of research ethics, what we have labeled procedural ethics, is important, limiting research to this dimension of ethics overlooks many of the complex ethical issues facing scientists. This paper is a call for a broader and deeper interdisciplinary approach in the sciences that includes a focus on coupled ethical-epistemological analysis. This important task will best be accomplished through inclusion of philosophers who specifically trained to help identify and analyze coupled ethical-epistemological issues on scientific teams. While there are many domains of scientific research, and arguably perhaps every domain of scientific research, that would benefit from strengthened interdisciplinary practices that include this coupled ethical-epistemological focus, one in which it is essential is research in the area of the science of anthropogenic climate change.

4 Deeper and wider interdisciplinary research in the sciences through coupled ethical-epistemological research[9]

The National Science Foundation and other funding agencies have already recognized the centrality of interdisciplinary research in the field of climate change science. Alongside more disciplinary research opportunities, the NSF has established various funds to encourage deeply interdisciplinary research into coupled natural and human systems. To pick just one example, the NSF recently partnered with the US Department of Agriculture (USDA) and the Department of Energy (DOE) to combine resources to provide

[9] My reference here is to the work of Robert Frodeman, Carl Mitcham, and Arthur B. Sacks, who in their essay "Questioning Interdisciplinarity" argue for a wider interdisciplinarity that bridges the sciences and the humanities and a deeper practice by promoting significant public participation in science policy. In this essay, I embrace their conception of wide interdisciplinarity, but modify their conception of deep interdisciplinarity to focus rather on a rich appreciation of the complex interconnections of science and society.

up to fifty million dollars in 2010 to fund proposals through its crosscutting initiative, Decadal and Regional Climate Prediction Using Earth Systems Models (EaSM). This program was established in recognition of the significant impacts climate variability and change can have in relatively short time periods on precipitation, sea level rise, and ocean currents, and how these changes in turn can lead to loss of agricultural and forest productivity and stresses on both natural and managed ecosystems. These three agencies partnered to support research that would assist in both understanding the nature of these impacts and proactively planning for their consequences by encouraging the advancement of models that "include coupled and interactive representations of ecosystems, agricultural working lands and forests, urban environments, biogeochemistry, atmospheric chemistry, ocean and atmospheric currents, the water cycle, land ice, and human activities" (NSF 2010). The Decadal and Regional Climate Prediction Using Earch Systems Models program is referred to as an "interdisciplinary grand challenge" with the requisite interdisciplinarity described as follows: "The realization of these goals demands the engagement of diverse interdisciplinary teams of experimental, theoretical, modeling and computational researchers, including but not limited to, biologists, chemists, computer scientists, geoscientists, material scientists, mathematicians, physicists, cyberinfrastucture specialists, and social scientists" (NSF 2010).

Once again the absence of the humanities is clearly underscored. Recognizing that coupled natural/human interactions can, and in the case of climate related impacts, *will* raise profound questions of both spatial and temporal justice (e.g., distributive justice and intergenerational justice), as well as complex questions of procedural justice, the absence of philosophers is difficult to understand. However, this omission can be shown to be even more glaring through appreciation of the complex coupled ethical-epistemic issues relevant to the domain of research to be covered by the The Decadal and Regional Climate Prediction Using Earch System Models program program, including how to frame scientific uncertainty in these contexts as well as decisions regarding how to adequately quantify risk. In many of these domains *epistemic decisions*, such as decisions regarding how to set up climate impact models, which data to include or exclude, can have important *ethical impacts*.

Let me provide an illustrative example of a coupled epistemic-ethical issue to underscore the importance of the humanities to interdisciplinary challenges and *the huge loss to knowledge that will result from framing the interdisciplinarity valued by agencies like the National Science Foundation in such a way as to exclude the humanities*. Consider the example of ice sheet models. While recent improvements in ice sheet modeling may be shifting this decision (c.f. Rignot et al. 2011), data on ice sheet dynamics has not been included in models forecasting sea-level rise. This decision was made due to scientific consensus on the limitations of ice sheet models, for example to be able to reliably forecast increase in ice sheet movement, or predict dynamical changes in a warming ice sheet, or to adequately reproduce ice streams. A coupled ethical-epistemic analysis would render transparent the epistemic decisions regarding reliability and robustness of this data, examine the question of an adequate decision process (including questions regarding "adequate for who and for what") for determining whether and what data is sufficiently robust to include in models and how best to do so, and provide resources for better understanding the implications of not including this data into integrated assessment models (IAMs). For example, the Intergovernmental Panel on Climate Change (IPCC) projections of sea level rise for the twenty first century have not so far included this data.[10] As a result, the models are overconfident, predicting a significantly lower sea level rise during this century, than is warranted, *an intrinsic ethical issue*, which in turn has an impact on how this aspect of climate science is deployed to inform adaptation policy such as decisions to build levees or dykes in coastal cities, *an extrinsic ethical issue.* Coupled ethical-epistemological research can thus provide the vehicle for realizing the call for a wider and deeper interdisciplinarity issued a decade ago by Frodeman et al. when they argued for

> new forms of interdisciplinarity…to respond to the epistemological and political limits of disciplinarity. These two new approaches to interdisciplinarity may conveniently be described as wide and deep. The former would attempt to bridge the sciences and the humanities, the latter to involve the non-disciplinary public (2001, p. 3).

In the practices our National Science Foundation funded research teams have begin to develop, we are finding that the inclusion of philosophy through the lens of attention to coupled ethical and epistemological questions has not only provided resources for better understanding the values embedded in climate modeling and making transparent the value and limits of climate science for adequately informing climate policy, *it has also led us to new and original scientific hypotheses and transformed the questions we ask of our disciplines*. But this call for a wider and deeper interdisciplinarity will also require new practices to create productive links between the sciences and the humanities. From my own experience in developing this research, it will require *embedding philosophy within scientific research in such a way as to transform practice*.

5 Embedded philosophy, fluid practices

Interdisciplinary practice while sometimes simply resulting from the combination of various disciplinary practices, in other instances has the outcome of transforming the epistemological and methodological practices of the disciplines involved. Many theorists of interdisciplinarity and transdisciplinarity have debated the proper subject of these terms, limiting the former to the integration of disciplinary practices and the latter to transformations of disciplinary divides (Klein 1990, 1996, 2000; Robinson 2008; Beier and Arnold 2005). My purpose is not to debate terms but to consider how to encourage richer practices of interdisciplinarity, that is, how to encourage new habits that render fluid the practices of those disciplines. My own practice, and what I focus on in this paper, involves the fluidity of practices that interlink philosophy and the sciences through coupled ethical-epistemological analysis. I am not claiming that this is the only vehicle to richer practices of interdisciplinarity, but rather that this is one mode that while effective, has been too often overlooked in studies of interdisci-

[10] With advances in ice sheet modeling, this may change with the Fifth Assessment Report (AR5) which is now underway. However, such studies likely remain uninformed by the types of coupled epistemic-ethical analyses I here advocate.

plinarity. Even more significant, this is an important, and I believe epistemically and ethically essential, model of interdisciplinary practice that has not been adequately appreciated by funding agencies.

The model that the National Science Foundation has advanced and supported through grants opportunities is to provide opportunities for scholars to cross disciplinary boundaries. The philosophy behind these opportunities is well reflected in a new funding opportunity to encourage interdisciplinary research in the field of Science, Technology, Engineering, and Mathematics education. The NSF's FIRE Program, Fostering Interdisciplinary Research on Education, arises from the NSF conviction that there are a number of complex problems facing the nation that can only be solved through interdisciplinary research that catalyzes new approaches. "Theories, methodologies, analytic techniques, and findings robustly understood in one field can have a catalytic effect when brought into contact with those of another. Moreover, interdisciplinary endeavors also increase the human capacity of the nation to address difficult problems" (NSF 2011a). While philosophy should be playing a key role in such efforts, NSF calls for interdisciplinary research for complex problems do not include philosophy. And yet, my own experience in developing coupled ethical-epistemological analyses has demonstrated that this type of work is best accomplished in the context of research collaborations with scientists and engineers. It is only in this context that philosophers, deeply embedded in research teams, can begin to partner with scientists and engineers to render transparent the types of value decisions that are entrenched in research models and methods and identify the ethical implications of research decisions, as well as begin to examine the questions that are ignored. under-examined, and rendered invisible through scientific habit or lack of interest.

This lacuna in the funding profile of the National Science Foundation is yet another institutional barrier that must be removed. The paths to doing this are already in place in the NSF. One is the NSFs two-fold commitment, on the one hand, to interdisciplinary research in the sciences, and, on the other hand, to funding ethics research in the sciences and engineering through programs like Ethics Education in Science and Engineering. Unfortunately, the NSF has not yet appreciated the ways in which these two commitments can mutually inform one another. However, the NSF's commitment to the broader impacts criterion may provide a solution to this divide.

The NSF currently employs two criteria to assess grant applications. The first of these focuses on the intellectual merit of the proposed project and research capability and capacity of the investigators; the second criterion requires consideration of the broader social impacts of the research. These two criteria are designed to assist the NSF balance excellence in scientific and engineering research with the broader impacts of that research (i) upon the educational and research infrastructure, (ii) as it leads to a more diverse and globally oriented group of scientists and engineers, as well as (iii) supporting projects with positive social impact.

Since the broader impacts criterion already requires that scientists and engineers be attentive to "connections between their discoveries and their use in service to society," there is already a commitment to being attentive to extrinsic ethical concerns and to issues of justice through questions of what constitutes benefit to society as well as who is impacted, both positively and negatively, by discoveries, as well as what interests are ignored or rendered invisible. The broader impacts criterion thus provides one justification for a robust inclusion of philosophical perspectives. This justification lends support to my argument that a fully interdisciplinary approach in the sciences and engineering requires the type of attention to coupled ethical-epistemic issues that will be aided by the inclusion of philosophers on research teams. [For a more complete discussion of this tenet, see (Tuana 2010).]

Furthermore, many scientists and engineers are well aware of the ethical dimensions of their work. In the field of climate science, it is clear to scientists that the knowledge they produce concerning geophysical dynamics and the impacts of climate change on social and physical systems has clear links both to policy as well as to issues of justice and equity. As just one example, Mann and Kump in their guide to the findings of the Intergovernmental Panel on Climate Change, *Dire Predictions: Understanding Climate Change*, include a section on the ethics of climate change. As they note:

> The international media has paid considerable attention to the economic implications of global climate change. They have, by contrast, paid little attention to the equally important ethical considerations (2008, p. 190).

They note as well that policy agreements such as the Kyoto Protocol's commitment to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system" itself raises ethical questions concerning what counts as "dangerous interference" and for whom and for what? In other words, it raises questions of distributive and intergenerational justice, questions of moral worth (do we have an obligation to protect species or ecosystems?), as well as complex issues of responsibility for harms and duties to protect.

However, ethical issues, such as those noted by Mann and Kump are not simply "additions" to the scientific research, to be added as a task for philosophers to sort out while the scientists work out the geophysical models. As I am arguing in this essay, we will have *better science* both in the traditional sense of advancing knowledge by building on and adding to our current knowledge as well as in the broader sense of *science for the good of,* namely, scientific research that, in the terms of the NSF broader impacts criterion, better benefits society, through embedding philosophy into the practices of science to help ensure attention to coupled ethical-epistemic issues in interdisciplinary research.

6 Coupling science and philosophy through coupled ethical-epistemic analysis: the example of geoengineering

To accomplish the goal of ensuring attention to coupled ethical-epistemic issues in interdisciplinary research in the sciences has, for the interdisciplinary research teams for which I am a part, required embedding philosophy into the practices of the sciences. This has meant a relatively long (in this case 6 years) commitment to working together. In my experience there is often a period of 1–2 years needed to learn common vocabulary, appreciation of methods, and so on, in order to be able to begin to work together on coupled epistemic-ethical analyses.[11] Once possibilities become clear,

[11] The research team on geoengineering is one example and includes myself, Klaus Keller, Geosciences, Jacob Haqq-Misra, Meteorology and Astrophysics, Ryan Sriver, Meteorology, Peter Irvine, Geographical

then research trajectories can be formulated, grant proposals to bring in funding can be written, and the research team can be constituted to ensure the expertise needed to support all necessary elements of the project. This is not a different trajectory than most interdisciplinary research in the sciences. The difference is the explicit inclusion of the methods of the humanities into the research team, in this case, those of philosophy. This brings with it additional challenges for while some scientists have the training to bridge their science and relevant social sciences, very few have the training needed to bridge their science and the relevant disciplines in the humanities. Indeed, I suspect many scientists would simply be puzzled by the very suggestion that the humanities have important resources to put into dialogue with the sciences through interdisciplinary research.

By embedding the practices of philosophy into our relatively mature climate science research team, that is, one that already had a certain level of facility with collaborative research through our practices of working together on various projects, we have begin to render fluid the disciplinary logics we had become habituated to and have begin to develop different practices. These have produced exciting new knowledges. In this way, our work has become *unbounded* and, indeed, *undisciplined* in the sense of neither trying to bring together different disciplines nor transforming our disciplines, but rather practicing new ways of thinking together that aim at new knowledges, including rendering transparent what has been overlooked by past practices or make unknowable by disciplined practices.[12] As well argued by Beier and Arnold in their article "Becoming undisciplined:"

> We must identify and account for the choices we make about what we think is and is not worth including in our work and, equally, our choices about how best to approach that which we include (2005, p. 59).

Space does not permit providing a comprehensive example of how attention to coupled ethical-epistemic issues can transform scientific and philosophical practices, but the following analysis of climate geoengineering will serve as an illustration.[13] I will offer a flavor of our recent work. For a more complete account, I refer readers to our essay "Towards Integrated Ethical and Scientific Analysis of Geoengineering: A Research Agenda" (Tuana et al. 2012). In this essay, we provide the latest results from research by our climate modeling team on proposals to geoengineer the climate. In the past decade, scientific and engineering proposals to deliberately modify the climate through solar radiation management (SRM) have burgeoned. Fueled, at least in part, by worries about threshold climate events and beliefs in the ineffectiveness of political efforts to mitigate greenhouse gases, some have concluded that geoengineering "may be the only human response that can fend off rapid and high-consequence climate impacts" (Keith et al. 2010, p. 426). While geoengineering proposals are typically

Footnote 11 continued
Sciences, Toby Svoboda, Philosophy, and Roman Olson, Geosciences. Professor Keller and I have been collaborating on research for the past 6 years.

12 Here I refer to a wealth of recent work in the field of epistemologies of ignorance. As just one example see Proctor and Schiebinger 2008.

13 This example is discussed in more depth in Tuana et al. (2012)

designed to be coupled, at least ideally, with robust mitigation efforts, nonetheless, there is a growing movement in support of at least research and field testing of geoenginering strategies as a form of "insurance" against climate catastrophes.

One such form of geoengineering involves increasing Earth's albedo by deploying sulfate aerosol in the stratosphere or by increasing cloud cover in order to change the Earth's albedo in such a way as to scatter and reflect sunlight, with the ultimate goal of cooling the planet. Those studying this form of geoengineering are well aware that it can have potentially harmful impacts such as changing regional precipitation and evaporation patterns around the world (Irvine et al. 2010; Matthews and Caldeira 2007; Robock et al. 2008). And since there will likely be regional variations where some regions may receive overall benefits, while others may not benefit and may even suffer greater harm, issues of distributive justice are clearly raised. Ricke et al. (2010), for example argues that "the relative appeal of different levels of solar radiation management depends on the region considered and the variable (temperature or precipitation) that is deemed most important" (p. 538). These and other potentially harmful impacts of SRM with aerosol injections have resulted in a general appreciation of the fact that research on and potential deployment of geoengineering raises important ethical issues (Keith 2000; Kiehl 2006; MacCracken 2006; Robock 2008; Shepherd et al. 2009; Svoboda et al. 2011). Morgan and Ricke, for example, (2011, p. 19) note that "social, behavioural, legal and ethical issues will be important" in many cases of solar radiation management research and Crutzen (2006, p. 217) states that, "Scientific, legal, ethical, and societal issues, regarding the climate modification scheme are many."

In response, many studies supporting solar radiation management research have stressed the need for international governance of such research (see Morgan and Ricke 2011). While important, these proposals are often lacking a fully developed account of the ethical and justice issues that should motivate the policy needs. While it is important to develop this analysis, our team was concerned instead with the fact that almost all the studies on solar radiation management remain silent on the ethical issues *surrounding this research*. We argue that "ethically significant decisions are often embedded in the scientific analysis itself, as well as in how scientific models represent impacts and vulnerabilities." Our goals, then in our recent paper and the aims of our current research are "(i) to delineate the complex *coupling of scientific and ethical issues* involved in solar radiation management research, namely, computer modeling and natural event analyses) and pre-deployment for testing, as well as the ethical issues to be addressed prior to and during deployment for geoengineering, and (ii) to provide a research agenda for coupled ethical-scientific research in the area of SRM" (Tuana et al. 2012).

What our research practices have made clear is that the value of philosophical practices in general and ethical analysis in particular is not simply as a vehicle for making judgments once the scientific and social scientific analysis is completed. On the contrary, our integrated practices create fluidity in our "disciplined" methods and expectations, and open opportunities for new knowledge production. Our research team has, in practicing new ways of thinking together, come to appreciate the importance of new domains of research that are not typically addressed in natural and social science assessments. As we explain in that paper, "whether a particular geoengineering proposal satisfied the requirements of inter- and/or intra-generational justice can hinge on geophysical factors involving (i) very long time scales (centuries to millennia), (ii) differences in regional impacts, and (iii) potential low-probability / high impact events. These events are, thus far, quite poorly represented in the current generation of Earth system models (Meehl et al. 2007; Keller and McInerney 2008; Urban and Keller 2010). Hence, the coupled ethical-epistemic analysis points to open and decision-relevant research questions in the natural and social sciences" (Tuana et al. 2012).

In our work we identified nine key fields of coupled epistemic-ethical analysis relevant to solar radiation management, namely:

1. Whether SRM can in fact be tested.
2. What are the coupled scientific-ethical issues relevant to SRM pre-deployment for testing?
3. Are there political risks of conducting SRM research?
4. What are feasible climate trajectories?
5. How do we value different climate trajectories?
6. What knowledge, institutions, and decision processes are needed for responsible decision-making
7. What are the distributions of benefits and harms along the trajectories for what entities? Will those harmed be compensated?
8. How fast (if at all) could we learn?
9. How is geoengineering to be controlled? (Tuana et al. 2012).

While this limited overview of our research cannot hope to be adequate to the complexity of our work, to illustrate it a bit more fully, let me provide more information about our work on the first two of these fields.

Regarding the question as to whether solar radiation management can in fact be tested, what we label a "meta-theoretical question," we argue that natural experiments (volcanic eruptions) and proposed small-scale field studies involving partial deployment may not be sufficient for inferring system response at the global level. Non-linear internal feedbacks can lead to bifurcations of the climate system, where for small forcing, the climate remains stable, but as the forcing increases, the climate system can reach a critical threshold where it transitions to unstable conditions. Given this, knowledge regarding such non-linear feedbacks may not be testable. In addition, we demonstrate that delayed system response to forcing may also not be "testable" in that ocean and atmosphere response time to external forcings such as SRM is fundamentally different hence "findings from regional deployment will not apply to full-scale deployment due to differences in the temporal response time between spatial scales" leading to "concerns about the viability of field tests to determine the safety of SRM deployment" (Tuana et al. 2012).

Given these conclusions, namely, that we may not know with confidence how the planetary system will respond to solar radiation management until full-deployment, and perhaps long after deployment has ended, this led us to the identification of a series of coupled ethical-scientific research questions relevant to solar radiation management pre-deployment for testing. In this domain we identified a series of coupled research issues including:

- What can be inferred from the limited scale experiments about the potential of a full-scale experiment, and what cannot? Will this knowledge be adequate for making a responsible decision? Will this knowledge be sufficient to warrant the risks of field-testing?
- Is it possible to estimate the large-scale system response from a small-scale field test?
- What "side-effects" will result from pre-deployment and can they be predicted?
- What are the costs of the "side-effects" of field-testing?
- What are the bounds of permissible field testing in terms of spatial and temporal extent as well as the degree of environmental modification and intrusion?
- Are there field tests, i.e., SRM pre-deployment for testing that would incur only modest risks of significant "side-effects"? What level of confidence would be ethically adequate to conduct such tests? What can be learned from such tests?
- What scientific and ethical knowledge is required to responsibly decide whether to start SRM field-testing? What is the basis for deciding on acceptable risk levels for field-testing? What level of learning would justify risks of side-effects?
- What measures of impacts would be used to determine that the costs of field-testing are higher than the benefits of field-testing and should be halted?
- What is the boundary between field-testing and deployment?
- Will some regions be more harmed by SRM field testing than others?
- Will those nations/regions/individuals harmed by SRM field-testing and/or deployment for geoengineering be compensated?
- Who will be responsible for potentially required compensation and how will compensation be determined? (Tuana et al. 2012)

The general conclusion of our coupled scientific-ethical analysis of solar radiation management strategies led us to the general conclusion that: (i) this type of research practice with its attention to coupled ethical-epistemic analyses is an essential element of improving research in this area of science; and (ii) that given the importance and value of this type of research, funding agencies should modify funding mechanisms to encourage and support these types of coupled research practices.

7 Conclusion

Widening and deepening interdisciplinary practices in science and engineering through inclusion of the methods and practices of the humanities has the potential for better achieving the aims of agencies like the National Science Foundation who are supporting such research. However, much needs to be accomplished to move from our current practices to the approaches I propose here. In this paper, I outlined a series of institutional, disciplinary, and epistemic barriers that require attention to achieve the types of practices I detail in this essay. Although, arguably, all are important, most salient in my judgment for successfully embedding the practices of philosophy within the practices of science is a commitment to transformations of training practices that we see in efforts like the NSF Integrative Graduate Education and Research Traineeship program, *but with an emphasis on programs that integrate the humanities with the sciences and engineering*, as well as a corresponding appreciation of the importance of the practices of the humanities in general to interdisciplinary research in the sciences. Only then will we achieve the vision of a wide and deep interdisciplinarity that will result in truly good science.

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