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The Production and Reinforcement of Ignorance in Collaborative Interdisciplinary Research

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One way to articulate the promise of interdisciplinary research is in terms of the relationship between knowledge and ignorance. Disciplinary research yields deep knowledge of a circumscribed range of issues, but remains ignorant of those issues that stretch outside its purview. Because complex problems such as climate change do not respect disciplinary boundaries, disciplinary research responses to such problems are limited and partial. Interdisciplinary research responses, by contrast, integrate disciplinary perspectives by combining knowledge about different issues and as a result reduce ignorance about more aspects of the problem. In this paper, we develop this idea and argue that while interdisciplinary research can help remediate damaging ignorance about complex problems, it also creates conditions in which other damaging forms of ignorance can arise. We illustrate this point in detail with three case studies before discussing three implications of our analysis for identifying and managing deleterious ignorance in the context of interdisciplinary research.

Keywords: Epistemology of Ignorance; Interdisciplinarity; Science of Team Science; Feminist Philosophy of Science

1. Introduction

Interdisciplinary research (IDR) is a mode of research that aims to overcome the limitations of disciplinary responses to complex problems (NAS 2004). By integrating

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disciplinary perspectives in the face of such problems, IDR increases the variety of epistemic contributions and promises to expand what can be known, entailing a complementary reduction in our ignorance. Although there is much to like about this characterization, we argue in this essay that things are not so simple. Specifically, we argue that while IDR can remediate ignorance that is attributable to limitation in perspective, the additional complexity of the IDR response also *creates* conditions for the production or reinforcement of ignorance that must be identified and managed if the response is to be successful.

In the next section, we sketch the background of our argument, introducing epistemologies of ignorance and discussing their implications for both disciplinary research and IDR. We argue in the third section that while certain types of ignorance are mitigated by IDR, other types are made possible. In the fourth section, we analyze three case studies that characterize three forms of ignorance produced or reinforced in specific ways within interdisciplinary collaboration: identity-based ignorance, complacent ignorance, and imposed ignorance. We then conclude by discussing three implications that our analysis has for identifying and managing deleterious ignorance in an IDR context.

2. Ignorance and Interdisciplinarity

Sullivan and Tuana (2007) introduce epistemologies of ignorance as 'an examination of the complex phenomena of ignorance which has as its aim identifying different forms of ignorance, examining how they are produced and sustained, and what role they play in knowledge practices' (1). A crucial aspect of this examination, Tuana suggests, is the rejection of ignorance theorized as a simple lack, omission, or gap (2004, 195). Instead, epistemologists of ignorance argue that we can better understand knowledge production by attending to how we ignore certain phenomena and even unlearn things that were once known when manufacturing, maintaining, cultivating, and disseminating knowledge (Tuana 2004, 194, 195). This is to say that ignorance is active, i.e. it is both "actively constructed" by communities of knowledge production and "preserved" by them (Tuana 2004, 195).

Epistemological analyses should not only trace what is not known, and what was once known and lost, but also attend to the politics of such ignorance (Tuana 2004).[1] In other words, when investigating knowledge and knowledge practices, it is important to ask questions such as "why we do not know something, whether it has remained or been made unknown" and "who knows and who is ignorant" in order to track the "movements and productions" of ignorance (Tuana 2004, 196). Tuana stresses that we cannot assume that the epistemic resources for understanding knowledge will allow us to understand ignorance; we must pay careful attention to movements and productions of ignorance in different contexts to further our understanding of its causes and consequences (Tuana 2006).

In this paper, we aim to track various manifestations of ignorance in the context of IDR. Specifically, we argue that IDR occupies a particularly complicated

position with respect to ignorance: IDR is based on the principle that we can respond more effectively to a complex, real-world problem by tessellating disciplines so that each discipline addresses aspects of the problem of which the other disciplines are ignorant (Campbell 1969). This management, however, enables other forms of ignorance to arise or persist, as we will discuss in the next section.

One motivation for IDR is the idea that individual disciplines focus on particular phenomena and ignore myriad others. How a given discipline understands the world is shaped through its history of asking certain questions and remembering the answers, and in pursuing this kind of specialization it defines and legitimizes itself as a discipline. When certain questions are rarely asked, or when certain questions are ignored because they are deemed irrelevant, these questions constitute a lacuna for that discipline. This lacuna, in turn, functions as a mechanism of "disciplining": while acquiring the knowledge characteristic of their discipline (cf. Knorr Cetina 1999), researchers are disciplined to ignore aspects of the world that are deemed irrelevant to the phenomena that interest them (cf. Weingart 2010). Here we follow Frye (1983) in hearing 'the active verb "to ignore" in the word "ignorance"' (119). Disciplinary researchers inherit ways of interacting with the world that are specialized for producing certain kinds of knowledge, and this specialization brings certain kinds of ignorance with it.

When something is ignored in a disciplinary research process, its impact on the phenomena of interest will not be appreciated and whatever knowledge is produced as a consequence will not reflect it. Thus ignorance of what would follow from including it will be an outcome of that process. In some cases, it makes sense to think of this ignorance as produced, arising out of an active decision to ignore something that could be relevant. In other cases, though, there is no active decision to ignore something of which one is aware; rather, something unknown is made harder to discover because of research decisions, and so it is better to understand the ignorance as reinforced (Tuana 2006). In what follows, we will often speak of "produced or reinforced" to accommodate both ways of supporting ignorance.

The knowledge produced by a disciplinary investigation and the ignorance produced or reinforced have ethical and epistemic consequences, and these consequences can differentially affect those with a stake in this investigation. When a disciplinary investigation takes place in the context of a collaborative research project, which is our focus in this paper, we take these stakeholders to include one's collaborators as well as people outside of the project (e.g. community members, policy makers) who have an interest in the results of the collaborative effort. We will call the former group internal stakeholders, highlighting their collaborative participation in the research, and the latter group external stakeholders.

In aiming for effective and just responses to complex, real-world problems, IDR must manage the epistemic consequences of the contributing disciplines on many levels, considering both internal and external stakeholders. Within an interdisciplinary collaboration, one differential effect of the knowledge produced and the ignorance produced or reinforced by a disciplinary orientation can be that col-

laborators who do not share that orientation will be unable to appreciate these epistemic consequences. The interpersonal ignorance that results from this can have a deleterious impact on project communication and project success, as we will argue in Section 3. When differential effects on internal stakeholders are ethically significant, they become especially problematic. For example, interpersonal ignorance within a collaboration can give rise to decisions that marginalize teammates or power gradients that are unhelpful or even destructive, as we illustrate in Section 4.

Knowledge and ignorance operate throughout the investigative arc—from conceptualization of the problem, through the selection and employment of methods, to the application of findings—and decisions on all of these fronts may unjustly marginalize and thus harm certain stakeholders, depending on their interests and the perspectives they occupy. Given this, care is initially required in conceptualizing the problem.[2] The types of harms generated by a complex research project are shaped by what perspectives (disciplinary or otherwise) figure into the conceptualization. Care also requires anticipating and managing the ignorance produced or reinforced by contributions to the ongoing research effort by particular disciplines. When one form of inquiry is selected by a research team to frame its investigation, the team should appreciate that managing the problem from that point of view can incline them to overlook or even produce harms for one's collaborators or external stakeholders. What bodies of knowledge are employed in a research process and what ignorance is produced or reinforced, then, can have profound consequences, both epistemic and ethical, for collaborators within a project team, as well as for those outside the team who are affected by the team's effort. The complexity of this scene, we argue, explains both why IDR can remediate disciplinary ignorance and why in doing so it can produce other forms of ignorance.[3]

3. Interdisciplinarity and Communication

In this section. we argue in two stages for the conclusion that while IDR is valuable as a means for redressing some damaging forms of ignorance, its complex character is itself responsible for producing or reinforcing other damaging forms of ignorance. In the first stage, we argue that integrative communication of the sort required by collaborative IDR can improve our epistemic situation by managing ignorance in various ways. In the second stage, we use the concept of epistemic situatedness to argue that IDR can itself be the source of ignorance.

3.1. IDR as a Response to Disciplinary Ignorance

IDR is commonly motivated by complex problems that extend beyond the ambit of any one particular discipline (NAS 2004). To succeed, an IDR effort must integrate the various perspectives it involves, and in a collaborative effort this will

require communication among the collaborators (Klein 2013). The interplay between knowledge and ignorance can be highlighted by close attention to the communication dynamics of an interdisciplinary collaboration, i.e. how researchers from different disciplines communicate with one another when they work as an interdisciplinary team on a complex problem (NAS 2004; Thompson 2009). In what follows, we focus specifically on potential problems with collaborative communication that arise in relation to ignorance.

Because complex problems have footprints stretching outside the limited domains of disciplinary attention, no single discipline will be able to address the full nature of such problems (Krohn 2010). One way to avoid the damaging kinds of ignorance that can arise when you address a complex problem with a limiting disciplinary perspective is to increase the number of disciplinary perspectives brought to bear on the problem. Research involving multiple disciplines is appealing here because the combination of different disciplines allows a project to increase its research breadth by highlighting more aspects of the complex problem it concerns (Newell 2007; Bammer 2013). Further, involving additional disciplines increases project depth by involving more expert perspectives. To meet complex problems with complex responses in this way increases awareness of and appreciation for the multidimensionality of problems and their complex causal character. Augmenting project breadth and depth by adding disciplines increases the number of relevant abilities and the amount of information, thereby decreasing ignorance about the complex problem being studied (Kline 1995).

Adding additional disciplinary perspectives to a complex research effort is therefore an epistemic improvement. One must be careful, though—the different disciplines in a project could operate according to their own rules in their own domains without cooperating and combining in any meaningful way, or worse, they could join in hostile competition for explanatory superiority (cf. O'Malley 2013). The whole, in such a case, would be less than the sum of the parts. Although in general it will be an epistemic improvement, adding disciplinary perspectives together doesn't necessarily result in a more integrated and synoptic perspective on the problem.

In the terminology of interdisciplinary theory, adding different disciplinary perspectives to a project guarantees a multi-disciplinary response, but it doesn't guarantee that the response will be interdisciplinary. Interdisciplinary research—as opposed to multi-disciplinary research[4]—requires the *integration* of disciplines (Klein 2012), and so one way to avoid the epistemically unsavory case described in the previous paragraph is to pursue interdisciplinarity. It is well known, however, that disciplinary perspectives may be difficult to combine, or worse, they may be so different that it is unclear where to begin (e.g. combining hydrology with political science—see Rylance 2015). When it comes to disciplines, one cannot simply "add and stir" and count on a richer interdisciplinary understanding of the problem or, for that matter, a better line on its treatment (Klein 1990). If one wants interdisciplinarity, one should pursue interdisciplinary integration, understood as coordination of disciplinary perspectives so that the thoughts and actions of a col-

laborative research team are produced collectively (Pohl et al. 2008). Interdisciplinary integration is a process of organizing multiple disciplinary perspectives by coordinating similarities and commensurable differences, and negotiating incommensurable differences (cf. Bammer 2013; O'Rourke, Crowley, and Gonnerman 2016). Integration pushes a multidisciplinary response toward the interdisciplinary, where the different perspectives complement and mutually reinforce one another in generating a coherent understanding of the problem in which the whole is greater than the sum of the parts (Andersen and Wagenknecht 2013).

In a context involving the collaboration of disciplinary experts who might not be aware of what is known by other contributors, integration understood as the coordination of perspectives will not happen without successful communication among the collaborators (NAS 2004; Klein 2013). In particular, similarities and differences among perspectives will need to be identified and managed (Brown, Deletic, and Wong 2015). When a single investigator draws on multiple disciplines, that individual may identify and manage the networked implications of multiple perspectives in thought. In this article, though, we concentrate on the collaborative combination of different perspectives, and so similarities and differences among perspectives will need to be managed through interpersonal communication.

The interdisciplinary challenge for a collaborative effort is to foster and maintain open communication about disciplinary perspectives, with each investigator learning what they need to know about the contributions of the others to properly situate their own project contributions (cf. Cooke and Hilton 2015). It will be necessary for collaborators to establish working relationships that support comparison of core beliefs and priorities, as well as the candid exchange of information and intuition.[5] This highlights the fact that open communication is more than simple information transfer; effective communication is dependent on the formation and maintenance of relationships between communicators that are trusting and safe (Thompson 2009; Klein 2013; cf. Wagenknecht 2015). Without these qualities, relationships among collaborators can obstruct rather than enable the transfer of project-related information. If secured, open communication in a collaborative project will support the integration necessary to produce a coherent, interdisciplinary orientation, thereby avoiding the pitfalls of competitive multidisciplinarity and improving our ability to respond to complex problems.

3.2. IDR as a Source of Ignorance

While IDR can improve our epistemic situation by reducing ignorance in certain forms, it does not eliminate it; in fact, it can produce or reinforce ignorance on its own, as is apparent if we evaluate the situatedness of the individual researchers and the group in an IDR project. To say that researchers are "situated knowers" is to acknowledge that their knowledge is shaped by history, economics, politics, geography, culture—in short, the full complexity of their situation. Knowers are

always "limited and enabled by the specificities of their locations" (Code 1993, 39).

This challenges epistemologies that presume all knowers are epistemically equivalent. As Alcoff (2007) remarks, 'such epistemologies share the assumption that any person in an identical situation with identical access to perceptual data will form the same conclusions if she or he is performing epistemic operations in a responsible way' (40). This assumption of epistemic equivalence is problematic once we realize that every knower is epistemically situated and how they are situated influences their epistemic judgments. According to this perspective, when a knower is asked to pass judgment on something, her specific experiences will play an important role in her decision (Alcoff 2007). These specific experiences are not limited to a knower's position in time and space—they also involve her "social locations, modes of perceptual practices and habits, styles of reasoning, and sets of interests"; further, these specific aspects of a knower's position influence what she regards as epistemically coherent, relevant, consistent, plausible, and credible (Alcoff 2007, 42). Thus, if a knower's epistemic judgments will be both enabled and limited by the specificities of her situation, a collaborator in an IDR group will be enabled and limited by how she is situated as well.[6]

Acknowledging that IDR collaborators are epistemically situated and therefore have different epistemic perspectives on their common project allows us to shed light on how they communicate with one another and how this can produce or reinforce ignorance. Since IDR aims to integrate different disciplines, each collaborator will be expected to contribute their disciplinary perspectives to the collaboration. In conceptualizing the problem and searching for a solution, collaborators will be constrained by how their disciplines shape their epistemic judgments. Without careful attention to how their epistemic contributions are situated, researchers can unknowingly engage in the active production or reinforcement of ignorance, such as when the lone social scientist in a project ignores certain social questions that would only be included in the project were she to introduce them (Tuana 2004).

While the individual researcher can be one vector of harmful ignorance into IDR efforts, the coordinated team itself can also contribute to the active production or reinforcement of ignorance. In other words, ignorance can emerge as a function of how the group is collectively situated. Just as situatedness at the level of the individual researcher helps us assess how she was simultaneously enabled and limited in her contributions, it can also help us understand the capabilities and limitations of the group. Borrowing from Alcoff (2007), we can speak of group situatedness in terms of their social location, reasoning styles, interests, and communication dynamic, a constellation of determinants that structure their research deliberation and action.

Communication is especially important here—how the group is epistemically situated is reflected in patterns of communication that influence collective deliberation and decision about what perspectives should be included in the group and how those perspectives should be integrated (Hall and O'Rourke 2014; Wagen-

knecht 2015). Given this, the group should pay attention to the formation of deliberate and non-deliberate alliances that reinforce specific interpretations of the problem they're investigating. If the group is not attentive to its collective situation, communication patterns can emerge that marginalize the perspectives of certain disciplinary representatives, producing or reinforcing ignorance about what they could contribute (cf. Harding 1991; Alcoff 2007). On the other hand, close attention to collaborative communication can enhance the efficiency and quality of the research and open new avenues for investigation (Cooke and Hilton 2015).

The collective, project-oriented communication within an IDR team will be a political process that demonstrates who has the power to speak or "who gets to speak" (Frodeman 2013, 107). This process is determined by how the team evaluates a collaborator's credibility, which will be influenced by how that collaborator's epistemic location is perceived (cf. Rolin 2015). How an IDR team approaches a complex problem depends not only on how collaborators decide what is important about their problem but also which collaborators are going to be most influential during the research process, and both of these are expressions of how the group is situated. Thus, social and political processes of negotiation and decision-making, which are constitutive of emergent, group-level situations and are reflected in communication styles and tendencies, can lead the group to ignore individual perspectives and thereby do harm to those who represent them. This result highlights how the pursuit of knowledge and the consequent production or reinforcement of ignorance in collaborative IDR can have ethical and epistemic consequences for internal stakeholders, and it is one that we will illustrate in the first case study of the next section.

IDR deserves special consideration, given its increasing importance for addressing complex problems (Rylance 2015) and the fact that the complexity of the IDR response is recapitulated in the complex ways in which ignorance remains in play. In particular, integrative communication within an IDR group can be responsible for the production and reinforcement of ignorance because of the ways that the group, and individuals within the group, are situated. This ignorance could lead the IDR group to overlook critical aspects of the problem, resulting in negative consequences for stakeholders internal to the project, or, perhaps more significantly, negative consequences for communities whose perspectives are not adequately represented. Thus, awareness that the epistemic limits of disciplines are not fully mitigated by the combination of disciplines should incline an IDR group to be mindful of the potential for harmful consequences of ignorance. Being aware of where ignorance can manifest, how it can be produced or reinforced, and how it can be managed are therefore centrally important to successful IDR.

4. Case Studies

Our aim in this section is to analyze three brief case studies that each illustrates a specific way in which ignorance can compromise collaborative IDR. Although the

three forms of ignorance that we analyze can also compromise disciplinary research, we argue that interdisciplinary collaboration is either (1) susceptible in particular ways to a form of ignorance or (2) equally susceptible, but able to give rise to particular sorts of consequences in light of the interdisciplinary nature of the collaboration. We chose case studies that demonstrate how communication dynamics that emerge in an IDR effort can produce ignorance in the pursuit of integration. A typical IDR project will combine disciplines that rely on different methodologies, confirmation regimens, and ontologies (Eigenbrode et al. 2007), and it will do so through the communication of epistemically situated investigators who, in representing these various perspectives, must establish effective working relationships that contribute to how the group is epistemically situated. Both individual-level and group-level situatedness constrain collective deliberation and decision-making, creating the potential for ignorance that will depend on the context for its form and content. Thus, although interdisciplinary responses to complex problems allow us to redress damaging epistemic limitations that attach to disciplinary responses through the addition of information and expertise, the complexity of these responses itself creates conditions for damaging ignorance. By illuminating how these conditions can manifest in project organization and operation, our case studies suggest what might be done to guard against these types of ignorance in IDR efforts.

4.1. Identity-based Ignorance and Qualitative Research

One form of ignorance that can arise within IDR efforts results from what Tuana (2006) calls the "construction of epistemically disadvantaged identities"—we refer to this form of ignorance as identity-based ignorance. Those who possess epistemically disadvantaged identities "are constructed as untrustworthy" and have their testimony and memories called into doubt; they are rendered as "not knowers" and are unable to participate fully in epistemic activities such as research (Tuana 2006, 13). Identity-based ignorance arises out of differences in power between those with full standing as epistemic agents and those who are disempowered and denied the degree of epistemic responsibility required to count as full-fledged epistemic agents. Within the context of collaborative IDR, a researcher's discipline can serve as the basis for granting full standing or for marginalizing one's epistemic contributions. As many social scientists have observed, collaborative IDR is frequently dominated by the biophysical sciences according to biases that remain unexamined and uncriticized (e.g. Schoenberger 2001; MacMynowski 2007). This domination can lead to the production and reinforcement of ignorance regarding, in these cases, the social dimensions of complex problems.

Gardner (2013) offers a detailed case study of the way that disciplinary identity inflected communication in the context of collaborative IDR, and how these communication dynamics shaped the production and reinforcement of knowledge and ignorance by the team. Gardner acknowledges that work between social and bio-

physical scientists commonly inherits assumptions about which disciplines are "hard sciences" and which are "soft". These presuppositions reinforce a hierarchy where disciplines categorized as hard sciences are granted more epistemic agency while disciplines categorized as soft are often relegated to the margins. This hierarchy was chronicled by Gardner in the context of the "Sustainability Project", a five-year project at a mid-sized university investigating ecological sustainability from the perspective of 42 affiliated faculty from over 25 distinct disciplines (p. 246). Speaking to the contribution that their discipline made to the collaboration, one researcher reported, 'I think I'm easily dismissible (to the hard scientists) because I don't really have a strong claim on objectivity, simply because of the various distances we have between the production of knowledge and … the contours of what counts or not (as knowledge)' (248). In contrast, another researcher admitted, 'At the risk of being too forthright, I think that a lot of the biophysical types feel that the social science types are pretty squishy,' adding, 'there is danger in people not giving due respect to people from other disciplines or people outside their field' (248). These passages corroborate Gardner's finding that 'almost universally, the faculty who did not identify as hard-pure scientists expressed concern about their role in the project, with some even expressing feelings of marginality within the larger effort' (248).

The dismissal and marginalization of particular disciplines shaped the production of knowledge in the context of the Sustainability Project. Collaborators reported that the so-called hard scientists staked a claim to full epistemic agency (Gardner uses the apt phrase "epistemic sovereignty"), offering "the dominant perspective," while the social scientists on the team played a "subservient role" (249). We would add that disciplinary hierarchies influence the knowledge produced as well as the ignorance produced and reinforced. Social scientists who are hesitant to voice their perspective, or whose voices are ignored because of biases harbored by those with power in the group, cannot contribute effectively to IDR.

In these cases, interdisciplinary approaches to complex problems will favor biophysical interventions regardless of whether these approaches would be most warranted if the communication dynamic were more egalitarian. When social science would reveal better ways of addressing a complex problem but social scientists are ignored, the communication dynamic is responsible for deleterious ignorance. Because IDR collaborations cannot know in advance whose knowledge should be dominant and who should play a more subsidiary role, open communication at the start of the project is crucial (see Section 5.3 below). Gardner complicates the hard-soft binary with a much richer categorization of disciplinary assumptions. Understanding the rationale for these assumptions can help collaborators justify the centering and decentering of different disciplinary perspectives in IDR. While biased communication dynamics can threaten the promise of IDR, communication can also encourage the reflexivity that is crucial to delivering on this promise.

4.2. Complacent Ignorance in the Construction of Solvable Problems

Interdisciplinary communication can also produce or reinforce ignorance when the group comes to endorse certain norms that uncritically privilege particular perspectives. Since in these cases the collaborators are collectively the cause of ignorance, we designate this complacent ignorance (cf. Tuana 2006, on "willful ignorance"). Characteristically, complacency produces ignorance when the collaboration collectively and uncritically adopts epistemic norms that emphasize some types of knowledge over others. This stands in contrast to identity-based ignorance because, in cases of identity based ignorance, ignored collaborators may resist their marginalization. Further, complacent ignorance need not map onto disciplinary training (as it characteristically does in identity-based ignorance); in the example below, ecologists are ignored not because they study ecology, but because the scale of their research is not commensurate with the research scales of their collaborators. With complacent ignorance, the epistemic norms structure reasoning styles that are partially constitutive of how the group is situated, making it more likely that future project communication will reflect the bias of past communication.

Consider the case study chronicled by Benda et al. (2002), which explicitly tackles the challenge of integrating diverse epistemologies. This article examines the integration of the knowledge produced by the disciplines of hydrology, geomorphology, and riverine ecology in studying interdisciplinary questions about land use impacts on riverine ecosystems. The authors emphasize that the disciplinary situations of these three sciences render them best suited to answer questions that are keyed to specific spatial and temporal scales. One result of these different situations is that the scale and precision of riverine ecology is misaligned with the scale and precision of hydrology and geomorphology (1129). This mismatch impedes what Benda et al. refer to as "constructing solvable problems", which represents the "primary operational mandate of many scientists", given that initial research questions are commonly formalized into solvable problems (1134). This formalization enables the integration of epistemic contributions of participating disciplines.

The article recommends a number of strategies for constructing solvable problems in the face of difficulties such as scalar mismatch, or differences in precision and accuracy. These include modifying precision and dimensional scales (1130–1132). For our purposes, two recommendations stand out. First, the collaboration might ignore or "omit" a discipline in the analysis phase. For example, scientists might perform a watershed analysis, where biological consequences are not separately assessed under the assumption that these consequences are tightly coupled with the physical conditions that are assessed (1133). Second, models might be constructed that employ the strategy of coarse graining, whereby finer grain effects, though knowable, are self-consciously "ignored" (1134).

If utilized without ongoing communication about what is ignored, disciplinary omission and coarse graining offer clear examples of strategies that could create

complacency within the project team, producing ignorance in the service of constructing solvable problems. Once again, there will be consequences for internal and external stakeholders. Internally, Benda et al. note that watershed analysis can "bypass the details of complex cumulative watershed effects" while "avoiding intermediate causal factors" (1133); both "bypassing" and "avoiding" require trade-offs that involve ignoring aspects of the complex problem that could and perhaps should be included in the team's investigation. Externally, although the construction of solvable problems is a key objective in scientific practice, it should not distort research questions so that they are no longer responsive to the values of non-scientific communities. For example, if a non-scientific community deems ecological impacts to be the most significant effect of different management strategies, then they will not regard formalization of the problem that ignores those ecological impacts as a solution.

Where complacent ignorance threatens, the research team must cultivate a communication dynamic that supports sustained critical reflection on the norms by which they center and decenter particular epistemic contributions. This critical reflection involves considering how team norms produce or reinforce ignorance with various ethical and epistemic consequences for internal and external stakeholders. Certainly all collaborative research should cultivate this dynamic, but IDR presents a unique challenge given the disciplinary situations of the individual collaborators. If a subset of constituent disciplines is uncritically privileged, then an IDR response may not deliver on its promise of reducing ignorance by mobilizing diverse disciplinary perspectives. Indeed, the communication dynamic in the Benda et al. (2002) case indicates that IDR can produce responses to problems that could be more harmfully ignorant than alternative uni- or multi-disciplinary responses. Interdisciplinary teams should not seek to trade ignorance for knowledge by favoring integrative approaches that produce ignorance of the harmful sort. For example, without appreciating the values of communities impacted by the research, watershed analysts cannot know whether an ecological approach to watershed management would produce less harmful ignorance than an interdisciplinary approach that is complacent in ignoring ecology.

Communication is once again critical to careful consideration of tradeoffs in knowledge and ignorance. Practitioners and theorists of interdisciplinarity, and in particular interdisciplinary integration, have developed a suite of techniques for facilitating communication when collaborators find themselves struggling with epistemic decisions (O'Rourke 2017). These techniques intervene in the communication dynamics of collaborations by bringing under critical scrutiny the philosophical assumptions that can privilege the production of particular knowledge while reinforcing ignorance. Dialogue facilitation can help structure recognition of the values of internal and external stakeholders and evaluation of tradeoffs in the pursuit of diverse values.

4.3. Imposed Ignorance and the Conservationist Agenda

A third type of ignorance manifest in IDR results from actors and influences external to the collaboration; because this ignorance results from without, we refer to it as imposed ignorance (cf. Tuana 2006, on ignorance "they do not want us to know"). How the team situates itself when conducting research will inevitably reflect external influences, such as its institutional context and its historical moment. In the case of imposed ignorance, the communication dynamic of collaborators is influenced by the collaboration's relation to external actors who constrain what knowledge the collaboration can produce. Given the importance within contemporary science of extramural funding and publication, for example, external forces such as funding agencies and journal editors can wield significant influence over decision-making within an IDR collaboration. The desire to obtain funding or publish results could lead the research team to make project decisions while ignoring factors that are directly related to the research and are central for some who have a stake in it. Again, external forces influence the priorities of disciplinary research as well as IDR, though the case study below suggests unique circumstances that can afflict IDR collaboration.

Campbell (2005) writes about her experience as a social scientist working with biologists in the field of sea turtle conservation. In Campbell's experience, sea turtle conservation initiatives are frequently dominated by biologists who ordinarily advocate for conservation. She reports that 'At many of the Costa Rican sea turtle nesting beaches where I work, natural scientists are members of and are supported by nongovernmental organizations that also advocate sea turtle conservation' (576). Campbell maintains that it is possible for these scientists to separate their advocacy from their research, but reports that not all do, and that the appropriate separation can be difficult to achieve. "[A]lthough most biologists would defend the objectivity of their own research," Campbell notes, 'they may have unconscious or assumed expectations about what results of socioeconomic research will show … I was once asked to conduct research that would "show" that tourism was more valuable than an extractive-use project' (576).[7]

Because biologists can receive support for this work from non-governmental organizations and sea turtle conservation efforts, they are often the authors of research proposals and so assume control over the integration of disciplinary perspectives during funded collaboration. These biologists' commitments constrain how tensions between conservation and local land use might be conceptualized and addressed, as 'social and natural scientists often approach conservation from different perspectives, both in terms of defining the problem and determining the appropriate approach to understanding it' (575). Campbell finds asymmetries in the contributions of social and natural scientists, and attributes many of these asymmetries to the power that natural scientists wield in light of the social and political context external to the collaboration.

Easier access to funding, and the control it affords to the primary investigators of funded projects, is only one dimension of imposed ignorance. When researchers

are transparent about their conservationist agenda, it can close off certain inquiries and produce ignorance of particular dimensions of complex problems. As a geographer, Campbell depends on interaction with human subjects to speak to the social, political, cultural, and economic aspects of sea turtle conservation, and being an advocate can compromise her relationships with these subjects (576).

Relationships with external actors not only inflect the conceptualization of a research project and the collection of data, but also shape how research is reported and disseminated. Biases that favor biology are exacerbated by interdisciplinary peer review processes that favor biological perspectives over sociological perspectives and thus privilege values more easily realized through biological approaches to sea turtle management (575). In this case, external constraints reinforce ignorance of the social dimensions of the problem by privileging the biological dimensions and the interests served by a biological approach. This ignorance is reinforced by actors external to the group, such as funding agencies or peer review processes that are biologically focused.

Campbell's experience attests to the ways that external pressures shape the role that she is asked to play in IDR projects. Of course, external pressures can be both a positive and negative force in the composition and communication dynamics of IDR teams, sometimes at the same time. But in cases of imposed ignorance, collaborations must acknowledge the pressure that external actors exert on the direction of knowledge production, and in some cases work toward mitigating these pressures. Campbell reports that for some IDR projects she 'suspected that a social scientist was being tacked on to meet funding requirements and if the project were funded, [she] would have little to no involvement' (575). Here, external pressures encouraged the inclusion of a social science perspective, even if they cannot ensure substantial inclusion of that perspective. An IDR project team cannot address every pressure that might be relevant to their work, of course, but cultivation of open communication about external influences can create sensitivity within the project to damaging forms of imposed ignorance. For example, upholding the conservationist agenda may require both external pressures and internal communication dynamics that privilege biological approaches. As long as communication dynamics reinforce ignorance of the harms that conservation inflicts on local communities, however, biology-dominated collaborations should not claim that they have "solved" the social-ecological problem.

5. Discussion

In the previous sections, we have argued that while IDR can remedy some of the epistemic limitations of disciplinary responses to complex problems, others are generated or exacerbated by integrative communication processes that reflect the situatedness of individual researchers and the group as a whole. Identifying and managing these new limitations is key to sustainable IDR success, since unappreciated ignorance can undermine project success by marginalizing key perspectives,

creating lacunae, and reinforcing biases. In this section, we discuss three topics related to the identification and management of deleterious ignorance in IDR: the socio-political consequences of IDR for external stakeholders, the implications our analysis has for a taxonomy of ignorance, and the role that ignorance plays in structuring the epistemic transactions of IDR collaborators.

5.1. Addressing the Impact on External Stakeholders

Each IDR case study in the previous section can yield lessons for researchers interested in identifying and managing damaging ignorance. As Harding (1998) observes, 'systematic ignorance is always produced along with systematic knowledge' (68); thus, when an IDR team chooses to investigate a particular problem, the systematic knowledge it produces will also generate systematic ignorance, and this ignorance could marginalize or obscure. '[D]ifferent interests produce not just different pieces of the puzzle of nature's regularities and their underlying causal tendencies,' Harding argues, 'but fundamentally incompatible knowledge claims' (1998, 66). These incompatible knowledge claims can be generated by investigating and addressing the problem from different disciplinary points of view. IDR can help in this case, bringing these different points of view together in integrative combination and thereby forcing a reconciliation of at least some of the incompatibilities; however, as we have argued, it can induce its own systematic disadvantages that are felt both within the project team and within external stakeholder groups, including affected communities.

As we noted in the previous section, our case studies can yield insight into potential negative consequences of ignorance for both internal and external stakeholders. Here we offer two general lessons about the ethical and epistemic impact on external stakeholders, and on affected communities in particular. First, ignorance within an IDR project can reinforce structural inequalities in affected stakeholder communities. Against a background of structural inequality within a community, researchers should be sensitive to the consequences their research has for groups within that community. Because the production of knowledge benefits the groups it serves, these groups can become better positioned to commission more knowledge production on behalf of their goals and interests. If these groups are already privileged by virtue of gender, race, or class, the IDR team can unwittingly reinforce structural inequalities that support this unjust privilege.[8] Researchers who transgress these structures by interrogating existing ignorance can play a crucial part in ethical and epistemic reconstruction (cf. Klein 2014).

Second, while systematic knowledge production also produces systematic ignorance, this does not excuse researchers from attending closely to conditions that produce harmful ignorance. This attention could be facilitated by awareness of the forms of ignorance described in the case studies above; together, these forms could figure into a diagnostic framework illuminating crucial community-based conditions that could produce damaging ignorance if left unchecked. Such a framework

could help researchers cultivate a sophisticated appreciation for several relevant considerations: (a) who does and does not benefit from their research, (b) how their interdisciplinary collaboration relates to other engagements with the problem within the community, and (c) what forums are available to ensure the community accountability of the research. Diagnosis is an essential step toward IDR that balances the tradeoffs associated with integrating multiple disciplinary approaches to a complex problem without creating deleterious ignorance in the process.

5.2. Toward a Dimensional Taxonomy of Ignorance

A framework for diagnosing deleterious ignorance in IDR projects will need to be sensitive to the complexity of ignorance, especially as it impacts the form, timing, and extent of interdisciplinary integration. What this suggests is a need for a taxonomy of ignorance that is applicable to IDR. Outside of the IDR context, many have developed taxonomies of ignorance meant to represent its complex nature and variety (e.g. Smithson 1989; Faber, Manstetten, and Proops 1992; Townley 2006; Tuana 2006; Proctor 2008). Most of these taxonomies can be separated into two types—"bucket" taxonomies and "branch" taxonomies. Bucket taxonomies divide varieties of ignorance into discrete categories (e.g. Townley 2006; Tuana 2006; Proctor 2008), while branch taxonomies divide varieties of ignorance into major categories and then divide these into finer grained categories, similar to a taxonomy of biological organisms (e.g. Smithson 1989; Faber, Manstetten, and Proops 1992).

While in our case studies we approached ignorance in the IDR context more in line with a buckets approach, we propose that a third type of taxonomy—one based on the idea that ignorance is a multidimensional phenomenon—could be of value in diagnosing and classifying varieties of ignorance in the IDR context. More specifically, we suggest adapting a proposal of Han, Klein, and Arora (2011), who have developed a 3-dimensional taxonomy for uncertainty, a relevantly similar concept. A multidimensional approach to ignorance could acknowledge the categories identified by the buckets and branches taxonomies while also allowing for identification of additional complexity, in the form of hybrid combinations of those categories.[9] This approach emphasizes the observation that ignorance has several interrelated aspects and that subtle changes in those aspects can produce subtly different forms of ignorance. Thus, we suggest that ignorance can be seen as Han, Klein, and Arora (2011) see uncertainty, namely, as a 'multidimensional phenomenon with theoretically distinct domains and constructs that are potentially measurable and related to different outcomes, mechanisms of action, and management strategies' (835).

While it is beyond the scope of our work in this paper to offer a comprehensive dimensional taxonomy, we can gesture toward one with the help of our case studies. Consider Gardner (2013). Presented above as an instance of identity-based ignorance, this case combines a number of distinguishable dimensions of ignorance

that could be teased apart and considered separately. Perhaps the most prominent of these is the *distribution of power*, which in this case would appear to be imbalanced in favor of the biophysical scientists. Power will always be distributed in an IDR effort and will be a key part of the group-level situatedness of the team; different distributions of power will produce different understandings of a problem with different social and political consequences, both internal and external. But additional dimensions are at work in this case, such as the *source of ignorance*, which in this case is the team itself; this contrasts with ignorance that is external in origin, such as in cases of imposed ignorance, and so could be represented as a second dimension along which ignorance varies. A third dimension could correspond to the *mode of production of ignorance*, i.e. how the ignorance is produced within the team. In this case, the project team is actively involved in the production of ignorance, which contrasts with passive involvement as exhibited by complacent ignorance. For a given instance of ignorance in a collaborative IDR project, identification of its source and its mode of production as well as its relationship with the distribution of power on the team will be key to managing the ignorance. Additional dimensions, perhaps corresponding to the content of the ignorance or its function (Townley 2006), could be added to a diagnostic framework as needed to capture additional determinants.

5.3. Teaching and Learning in an Interdisciplinary Context

While ignorance can be damaging if left unappreciated and unmanaged, awareness of it often motivates us to search for knowledge. Research in general, and IDR in particular, are forms this search can take. As we have noted, collaborative IDR involves communication about the research among the collaborators. Much of this communication will focus on the integration of disciplinary perspectives, and as such will require both teaching and learning—in the context of an integrated, interdisciplinary project, collaborators are teachers *and* learners at the same time and in parallel (cf. Andersen and Wagenknecht 2013). Collaborators represent their perspective in the group and make it possible for others to learn about how things look from that perspective. Given their collaborative connection, they will have an interest in figuring out how their perspective is similar to and different from others, and this kind of epistemic accounting will inform how they interact with their collaborators going forward. For example, certain issues might be non-negotiables for a collaborator but relatively unimportant to oneself; in this case, deference or yielding could be the correct move. On the other hand, this kind of learning process might reveal the need for negotiation and compromise in some aspects of the project.

We have emphasized the harmful effects that ignorance can have on an IDR effort, but ignorance can also play a productive role in motivating and structuring the epistemic transactions of collaborators if it is properly managed. Interdisciplinary collaborators can acknowledge the need to learn about the different

research worldviews of their collaborators and draw on the team science literature to structure interactions designed to create a culture of epistemic exchange. This literature is helpfully summarized in Cooke and Hilton (2015), a recent synthesis report from the National Academies that compiles evidence-based suggestions for managing various aspects of collaborative research, with a special emphasis on inter- and transdisciplinary research. This monograph offers various recommendations for managing collaborative projects, including a number that can help teams enhance their communication dynamic.

Dialogue, understood as communication that involves the co-creation of an interpretation, is an especially useful communication modality that can be used to diagnose conditions that could result in damaging ignorance (McDonald, Bammer, and Deane 2009). A specific dialogue method designed to help teams identify and negotiate differences among core beliefs and values is the Toolbox approach. This approach uses philosophical concepts and methods to structure dialogue among collaborators that can support teaching and learning, engendering project-wide reflexivity that can help a team manage the conditions that frame its production of both knowledge and ignorance (Eigenbrode et al. 2007; O'Rourke and Crowley 2013).

6. Managing Ignorance and Successful IDR

IDR is a powerful alternative to disciplinary solutions that fall short in analyzing and addressing complex problems. Through the integration of different disciplines, IDR leverages disciplinary insights while seeking to remediate the ignorance that reflects their essential epistemic limitations. Still, IDR must engage forms of ignorance that arise in interdisciplinary contexts. When interdisciplinary endeavors exclude relevant disciplinary perspectives, ignorance persists. When interdisciplinary endeavors don't achieve the sorts of relationships whereby collaborators can teach and learn from one another, ignorance persists. And even when all relevant disciplinary perspectives are present and appreciated, different strategies for integrating these perspectives can produce or reinforce ignorance. Decisions about which disciplines dance the lead and which are relegated to the margins of the investigation bear on whom the "solution" to the problems serves or ignores.

As our case studies indicate, integration can fail both at the level of inclusion and at the level of organization. In addition to potentially deleterious effects on the collaborative dynamic internal to the project, persistent ignorance within an interdisciplinary collaboration can have significant social and political consequences for those external to the project. It might be imagined that a fully collaborative and integrative IDR project could avoid these forms of ignorance; however, we submit that even in those rare cases where a project adopts integrative strategies that do not threaten to produce or reinforce deleterious ignorance, diligence must be maintained to ensure that ongoing project decisions do not create conditions in which debilitating ignorance can arise. Thus, becoming aware of

how ignorance can manifest within collaborative projects, how it can be produced or reinforced, and how it can be managed are centrally important for successful IDR.

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Notes

[1] One of the areas where a link to power becomes visible is in the workings of racism, where a racially privileged group is determined to stay ignorant of the lives and practices of a racially underprivileged group and by doing that "deliberately cultivates" that ignorance (Sullivan and Tuana 2007, 3). This ignorance continues to support systems of privilege while harming underprivileged groups. For example, following Frye (1983), Sullivan and Tuana (2007) cite the ignorance most white Americans have of American Indian tribes, of histories of Asian peoples living in the United States, and of Black language as instances of determined practices of ignorance that are prevalent within racially unjust systems and institutions (2, 3). See Sullivan and Tuana (2007) for more cases of existent practices of not-knowing that intersects and supports racism.

[2] One way to identify ignorance that is problematic for what we are calling external stakeholders is to involve members of the communities impacted by the research in the research process. Methodologies such as participatory action research, collaborative research, and citizen science all appreciate the importance of public values in just inquiry. Scholars have offered excellent analyses of the challenges to such transdisciplinary initiatives (Backstrand 2003; Jordan, Gust, and Scheman 2005). In the next two sections, we develop an analysis of interdisciplinarity that is more focused on the internal relationships between researchers in a project rather than on the external relationships between researchers and non-researchers, offering it as a complement to scholarship on transdisciplinarity that emphasizes external relationships (Klein 2010).

[3] One might criticize the argument of this section by contending that we conflate two independent senses of "ignorance", namely, one associated with the ethical prejudices that arise out of oppressive beliefs about phenomena such as gender or race and another associated with the epistemic commonplace that an expert in one discipline will typically be ignorant of what an expert in another discipline knows. One of the main claims for which we argue in this article, however, is that these are *not* independent—that epistemic differences among disciplines can give rise to biases and prejudices that manifest inside projects in ways that marginalize and harm collaborators, and further, that these consequences internal to a project can have damaging effects on external stakeholders as well.

[4] The distinction between aggregative *multi*-disciplinary research and more integrative *inter*-disciplinary research has become a commonplace in the interdisciplinary literature. For discussion, see Kline (1995), Eigenbrode et al. (2007), Morse et al. (2007), and Klein (2010).

[5] This point is emphasized by the National Academies: 'At the heart of interdisciplinarity is communication—the conversations, connections, and combinations that bring new insights to virtually every kind of scientist and engineer' (NAS 2004, 19).

[6] For Alcoff and Code, all knowers and epistemic practices are situated. Situatedness can be analyzed along many significant axes (e.g. gender, race, class), and we offer *disciplinarity* as another axis, one that is especially significant for IDR. While we focus on disciplinary situatedness, we want to acknowledge that these other axes also shape the communication dynamics of IDR. The case studies below acknowledge but do not fully elaborate on these other axes, and an intersectional analysis that include these categories alongside disciplinarity would provide a stronger understanding.

[7] This quote indicates how imposed ignorance can give rise to the creation of epistemically disadvantaged identities in the context of an IDR project. Pressure from without to emphasize certain types of outcomes over others could incline the team to make project decisions biased in favor of those outcomes, marginalizing team members who may not have much to contribute to the project oriented in that way.

[8] This is a problem for all research, though IDR is inflected by communication dynamics that may exacerbate identity-based, complacent, or imposed ignorance.

[9] The previous section supplies fodder for the suggestion of hybrid combinations: (a) identity-based ignorance can become complacent ignorance if the team becomes complacent in their ignorance of the disadvantaged perspectives, and (b) imposed ignorance can lead to identity-based ignorance if the team decides to privilege certain perspectives over others to appeal to a specific funder or journal editor.

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