Conceptual Ecology for Interdisciplinarity

Abstract: Despite widespread agreement on the value of interdisciplinarity, significant debate persists about its fundamental nature. We propose a framework to address this disagreement by drawing on ideas from philosophy of biology, particularly the work of Karola Stotz and Paul Griffiths (e.g., 2004). Our *conceptual ecological* approach supports a productive pluralism: a pluralism that is organized and can help to address practical issues. Within this framework, concepts of interdisciplinarity are viewed as tools shaped by the niches that they occupy. We illustrate this approach by providing a case study on the Toolbox Dialogue Initiative, a philosophical method for facilitating interdisciplinary collaboration. Finally, we highlight the theoretical and practical benefits of adopting a conceptual ecological approach to interdisciplinarity. (116 words)

Keywords: Concepts of Interdisciplinarity, Conceptual Ecology, Toolbox Dialogue Initiative

Word count: 7,273 (8,532 with notes)

Conceptual Ecology for Interdisciplinarity

The push for assembling diverse bodies of knowledge, beliefs, concepts, methods, values, and perspectives has gained significant institutional support in the form of interdisciplinary research. Initiatives include the NSF's Convergence Accelerator, the NIH's Common Fund, Japan's Research Institute for Humanity and Nature, and the ERC's Synergy Grants. These programs fund interdisciplinary work on such issues as AI, quantum technology, sustainable materials, and public health — an acknowledgement that addressing complex socio-scientific problems requires resources that go beyond any single discipline. It seems that interdisciplinarity is on the rise (cf., Hackett et al., 2017). Despite the widespread agreement on the value of interdisciplinarity, there is much uncertainty about its fundamental nature. Exactly what is interdisciplinarity? While many have views, there is no consensus, leaving the space of interdisciplinary activity and theory in a state of a buzzing, blooming confusion. These are, we think, two distinct but interrelated problems: the daunting diversity of interdisciplinary practice and the dumbfounding diversity of concepts or theories of *interdisciplinarity*. As we will show, these two problems interact in complicated ways; our focus, however, will be on the second problem.

Drawing on ideas from philosophy of biology, particularly those of Stotz and Griffiths (e.g., 2004), we propose a framework to address fundamental disagreements and uncertainties about interdisciplinarity. We argue that their work on conceptual ecologies and diverse gene concepts offer valuable insights for the philosophy of interdisciplinarity. Instead of seeking *the* "true" concept of interdisciplinarity, we propose focusing on understanding the reasons behind the diversity of concepts. This *conceptual ecological* approach supports a productive pluralism: a pluralism that is organized and can help to address practical issues. Within this framework,

concepts of interdisciplinarity are viewed as tools shaped by and often aligned with their *epistemic-axiological niches* — specific research environments defined by such factors as the knowledge practices, methods, values, and goals that shape or influence research projects.[1,2] We should therefore expect that distinct concepts of interdisciplinarity will appear across distinct niches. More generally, then, our suggestion is that philosophical efforts to examine or employ interdisciplinarity may be helped by understanding how distinct concepts of interdisciplinarity reflect their niches and whether they meet the needs and aims of those working in those niches as well as their interactions with those in other niches.

To make this case, we structure the paper as follows: in Section 1, we review the wide range of interdisciplinary activity and concepts. Section 2 introduces conceptual ecology as a form of productive pluralism, reviewing how it has been used to analyze diverse concepts of genes in philosophy of biology and then describing how it can likewise be used in philosophy of interdisciplinarity. Section 3 presents a case study for the use of conceptual ecology. The case focuses on the Toolbox Dialogue Initiative (TDI), a philosophical method for facilitating interdisciplinary work. We draw out TDI's concept of interdisciplinarity, explaining how it aligns with TDI's environment, and critically assess its limitations when placed in other environments. In Section 4, we highlight the theoretical and practical benefits of adopting a

[1] While every niche will inevitably involve both epistemic and axiological factors, it remains possible to emphasize one set of factors over the other in one's theorizing. In this paper, we will focus primarily on the epistemic factors, acknowledging that axiological considerations are nonetheless always present and influential. For an example of axiological factors at work, see footnote 14.

[2] Strictly speaking, a conceptual ecological approach recognizes that concepts, practices, and goals exist in a dynamic interplay: concepts can shape practices and goals just as practices and goals can shape concepts. This mutual shaping bears some resemblance to the method of reflective equilibrium developed by Goodman (1955) and Rawls (1971), where theoretical principles and considered judgments are reciprocally adjusted and refined until they agree with each other. However, a conceptual ecological approach differs from reflective equilibrium in at least two ways. First, it emphasizes the ongoing, evolutionary nature of these interactions rather than focusing on achieving a state of equilibrium. Second, while reflective equilibrium describes a philosophical method of deliberate adjustment and refinement, our conceptual ecological approach is based on a more naturalistic process where concepts, practices, and goals adapt to each other.

conceptual ecological approach to interdisciplinarity. Finally, Section 5 offers concluding thoughts on the future of conceptual ecology in interdisciplinary spaces.

1. Literature Review

We propose that interdisciplinary spaces exhibit two types of diversity. *First-order diversity* relates to the variety of projects that people pursue in an interdisciplinary manner. *Second-order diversity* pertains to the variety of views that philosophers and others develop about the first-order activity.[3] In this section, we explore some of the diversity present at each order.

[INSERT FIGURE 1 ABOUT HERE]

To get a sense of first-order diversity, we only need to consider the range of interdisciplinary activities that enjoy some degree of institutional recognition in the form of journals, conferences, and research centers. Bioinformatics, for instance, blends biology with computer science to analyze genetic data (Baxevanis et al., 2020), while environmental engineering combines chemistry, biology, and engineering to create sustainable environmental solutions (Mihelcic & Zimmerman, 2021). In digital humanities, scholars use computational tools to analyze texts (Berry, 2012); philosophers and others use scientific methods to advance philosophical debates in experimental philosophy (Bauer & Kornmesser, 2024); and neuroeconomics merges neuroscience and economics to study how we make value-based decisions (Glimcher & Fehr, 2013). Additionally, areas like cognitive science draw from psychology, artificial intelligence, linguistics, and philosophy to understand minds (Bermúdez,

[3] Our thanks to [REDACTED] for suggesting an order analysis here. For those who prefer to talk or theorize in terms of levels instead of orders, they are free to do so. As best as we can tell, our distinction can be recast as first-level and second-level diversity without the loss of anything essential to our argument.

2022), while urban studies integrate sociology, architecture, and public policy to address the complexities of urban life (Gottdiener et al., 2016). These examples highlight just some of the diversity within the space of interdisciplinary practice. Other examples are easy to come by, especially so once we shift to more innovative or one-off interdisciplinary undertakings.

Alongside the first-order diversity, there is a lot of second-order diversity, which plays a major role in motivating our conceptual ecological approach. A key aspect of the second-order diversity relevant here is the variety of concepts and definitions of interdisciplinarity found in philosophical and theoretical discussions. Some of this variety is implicit. For example, there appears to be a concept of interdisciplinarity that focuses on the integration of methods and theories from different disciplines to tackle complex, real-world problems. An instance of this concept might be present in environmental studies where ecology, sociology, and economics are blended to support sustainable development (Lélé & Norgaard, 2005). Another understanding appears to emphasize collaboration among experts who mostly stay within their disciplinary boundaries while working together on a shared issue, as in the development of medical technologies where engineers, biologists, and healthcare professionals contribute their specialized knowledge (for discussion, see Rosenfield, 1992). Additionally, some scholars seem to think of interdisciplinarity as an educational approach, where students engage with content from multiple disciplines. An example of this approach might come from liberal arts programs that require coursework in humanities, natural sciences, and social sciences (Fulcher, 1978).

More direct evidence of a variety of interdisciplinarity concepts and definitions is suggested by the multitude of taxonomies that categorize interdisciplinary efforts. Some taxonomies distinguish between building bridges across disciplines versus restructuring disciplinary families based on several disciplinary parts (Squires, 1975). Others differentiate

between “interstitial cross-disciplines” like economic anthropology and the borrowing of concepts, theories, or methods from other disciplines as seen in experimental philosophy (Miller, 1982). And yet others classify interdisciplinary activities as broad or narrow according to the number of disciplines involved and the compatibility of their research methods and philosophies (for a review of interdisciplinary taxonomies, including more on these three, see Klein, 2017). It is important to recognize that these taxonomies are not theoretically neutral. Bunge (1983) notes that taxonomies evolve with theories. This allows theoretical advances to refine initial categorizations. Hjørland (2011) goes even further. He writes, “any classification corresponds to a theory and vice versa” (p. 15). One immediate implication is that each taxonomy of interdisciplinarity activity corresponds to a distinct theory of interdisciplinarity. While that may be too strong, it is reasonable to expect that there are multiple theories of interdisciplinarity at play in these taxonomies, as well as a variety of concepts and definitions.

A more explicit articulation of variation in interdisciplinary definitions or concepts is given by Schmidt (2022, p. 26-37; see also Schmidt, 2008). He distinguishes four “notions of interdisciplinarity” in his taxonomic framework (2022, p. 37). Each is organized around a different type of phenomenon. The first notion, *object-oriented* interdisciplinarity, is concerned with overcoming disciplinary boundaries (i.e., transferring, circulating, synthesizing, integrating, or unifying disciplinary perspectives, knowledge fragments, or understandings) to explore objects, entities, or structures that lie across or between these boundaries. According to Schmidt, this notion, common in fields like cognitive science and synthetic biology, involves an ontological realism and non-reductionism. The second concept is *theory oriented*. It prioritizes such epistemic objects as knowledge, theories, and models. Schmidt cites systems theory as an area that works with this concept of interdisciplinarity, where the goal is to overcome

disciplinary boundaries by developing a meta-theory that emphasizes structural similarities in the properties of disciplinary objects without being reducible to any disciplinary theory. *Method-oriented* interdisciplinarity is the third notion. It focuses on developing methods that are not reducible to disciplinary methods and that support the transfer, production, and integration of knowledge across disciplines—and, for some, between academia and society. Schmidt points to bionics and econophysics as two areas that prioritize this notion. The fourth concept is *problem oriented*. Those who use it, including people in "[t]echnology assessment, sustainability science, and social ecology" (p. 35), are driven by societal and ethical motives. They overcome disciplinary boundaries by focusing on real-world issues or problems that go beyond the scope of any single discipline, including emerging technologies, climate change, and societal-environmental interdependencies.

Important for our purposes, Schmidt further divides the problem-oriented notion of interdisciplinarity into two concepts: instrumentalist and critical-reflexive. The key difference between them lies in their orientation to dominant modes of knowledge production. *Instrumentalism* views interdisciplinarity primarily as an organizational challenge. It focuses on methods and management procedures aimed at directing dominant modes of knowledge production towards solving predefined problems. Schmidt cites examples like the National Academy of Sciences (2005), Newell (2001), and Repko and Szostak (2017), who emphasize "recipes and organizational guidelines to facilitate interdisciplinarity" as embodiments of this concept (p. 4). Thus, as Schmidt characterizes it, instrumentalism emphasizes four features: (1) effective management of disciplinary diversity; (2) development of practical solutions to given problems; (3) disregard of normative issues related to science and society; and thus (4) adherence

to the value-free ideal.[4] In contrast, *the critical-reflexive* notion of interdisciplinarity scrutinizes dominant modes of knowledge production and their underlying rationalities. It involves grappling with "the cultural background behind the emergence of [wicked] problem[s] — that is to say, the values, ontological convictions, and metaphysical presuppositions underlying the problem[s]" (p. 93). Thus, rather than simply facilitating knowledge production in interdisciplinary spaces, this approach takes a more critical and revisionary stance. It critiques dominant modes of knowledge production and the philosophies underlying wicked problems, while also pursuing and advocating for alternative framings. Jantsch (1970) serves as early articulation of this concept for Schmidt (e.g., p. 3). We largely agree with Schmidt's take on this instrumentalist/critical-reflexive divide and will use it below (for a similar take of this divide, see Klein, 2021).

What the preceding suggests is that interdisciplinary scholarship is doubly diverse. First, as noted at the beginning of the section, it exhibits significant first-order diversity, viz., that of interdisciplinary practice — teams and individuals addressing a wide variety of problems and applying a multitude of disciplinary knowledges, methods, and perspectives to these problems. In addition, there is considerable second-order diversity, including in the theoretical claims made about the first-order activity. For example, as we saw, there are many taxonomies of interdisciplinary activities across different literatures. And, crucially, there are various definitions or concepts of interdisciplinarity trying to capture its "essence" across different contexts.

[4] One influential characterization of the value-free ideal comes from Douglas (2009). She characterizes it as the view that non-epistemic values should not affect the "internal" stages of science, those that center on drawing inferences from evidence.

2. Philosophical Contribution

The goal of this section is to introduce the idea of a conceptual ecology as a framework for understanding interdisciplinarity. We begin by deepening our articulation of the problem that a conceptual ecological approach can address. This requires a brief of survey of ongoing debates about the best way to define interdisciplinarity. We then shift to philosophy of biology, where similar debates have led many to a conceptual pluralism over insisting on a conceptual monism. We close with an overview of conceptual ecology, the form of principled pluralism that we think is best.

In Section 1, we explored some of the wide range of concepts or definitions of interdisciplinarity found in interdisciplinary practice and reflection. One way of trying to resolve a plurality of definitions is to argue against the variety, ultimately concluding with one over the others. Many seem to favor this strategy. For example, Benson (1982) criticizes integrationist approaches to interdisciplinarity of the sort associated with Klein (1990) for being overly vague. Lattuca (2001) argues that these approaches obscure the idea that interdisciplinarity is a critique of disciplinarity. And Fuchsman (2009) points out that they overlook interdisciplinary activities occurring in the spaces between disciplines. Lyotard (1984) rejects definitions of interdisciplinarity premised on disciplinarity. This view is similar to those who advocate for a concept of interdisciplinarity that emphasizes deep interconnections that fundamentally alter disciplinary structures (e.g., Fuller & Collier, 2004). Lastly, Schmidt (2022) critiques the

instrumentalist concept of interdisciplinarity on multiple grounds, including the claim that it is committed to an untenable value-free ideal.[5]

[INSERT FIGURE 2 ABOUT HERE]

The preceding illustrates the kind of definitional skirmishes present in the philosophy of interdisciplinarity — debates over how best to conceptualize interdisciplinarity beyond the idea of crossing disciplinary or academic-societal boundaries (cf., Schmidt, 2022, p. 25). Such skirmishes are common in philosophy, of course. An example relevant to this paper are debates over the concept of genes in philosophy of biology.

Philosophical discussions of genetic phenomena have long grappled with the complexities of defining the concept of genes (Griffiths & Stotz, 2013). Early on, it became evident that genes as defined by classical genetics do not cleanly align with genes as defined by molecular genetics (Muenier, 2023). Research in the 1970s on overlapping genes, split genes, and alternative splicing only deepened the complexities (Tabery, 2023). And matters were hardly any easier for those focusing solely on molecular genetics, since molecular geneticists apply the term to a motley assortment of DNA-involving regions (Waters, 2013). Given these complexities, it is tempting to agree with Kitcher's "overstatement": "A gene is anything a competent biologist chooses to call a gene" (1992, p. 131).

[5] This critique helps to motivate the possibility of "unbundling" the instrumentalist concept of interdisciplinarity, an idea that we develop in Sections 3 and 4. If the core of instrumentalism is primarily facilitative, then it is unclear why an instrumentalism couldn't get combined with a skepticism about the value-free ideal. Surely, a facilitator can agree, for example, with Rudner (1953) that non-epistemic values can play a legitimate role in deciding what counts as sufficient evidence to accept a hypothesis. Moreover, in view of evidence that comparatively few scientists accept the value-free ideal (Robinson et al., 2019; Steel et al., 2017, 2018), the complete conceptual package put forward by Schmidt would appear to have relatively fewer adherents.

In response to these challenges, philosophers of biology have adopted one of two strategies: monism or pluralism (Tabery, 2023). The monistic strategy seeks to define a single concept of genes, at least for large swathes of genetics, one that encompasses many (but perhaps not all) of the molecular complexities. For instance, in developmental genetics, Neumann-Held (2001) advances a "process molecular gene concept", which views genes as processes involving both DNA and non-DNA entities that lead to the production of polypeptides. Similarly, Waters (2000, 2013) defines genes in molecular genetics as, roughly, nucleotide sequences that determine the linear sequence of products like polypeptides and preprocessed RNA molecules. The alternative pluralistic strategy embraces multiple gene concepts. Moss (2003) is an example. On his theory, Gene-P is defined by its predictive relationship to a phenotype, while Gene-D is defined by its molecular structure.

[INSERT FIGURE 3 ABOUT HERE]

Of the two options[6] — unifying all (or nearly all) the complexities under a single concept or proposing multiple concepts across different research programs — there is some reason to prefer the second choice in situations like that present in philosophy of biology and philosophy of interdisciplinarity. One prevalent theme in philosophy of science (e.g., Feest, 2008), the cognitive sciences (e.g., Machery, 2009), and experimental philosophy (e.g., Nado, 2021) is that

[6] For our purposes it is enough to operate as if there were just two options here. Space permitting, a more thorough analysis should consider positions such as Keestra's (2022) *non-foundational pluralism*, which describes how an apparent pluralism at one level can be related to and ultimately reduced to a single, more fundamental unit at another level. Keestra illustrates this by pointing to a Hegelian analysis of Sophocles' *Antigone*, where the clash between Antigone's value of familial piety and Creon's value of loyalty to the state get resolved by relating them to "another, more fundamental value" (p. 92). Despite its name, non-foundational pluralism appears to be a monism, albeit "a complex form of monism" (p. 92) in that it acknowledges the surface-level plurality while recognizing its potential "reduction … to a single, more foundational unit" (p. 91). Whether and how Keestra's insights can be applied to the topic at hand (viz., a multiplicity of interdisciplinarity concepts) remains an open question — a promising avenue for future research.

concepts are *tools* that play a role in a wide range of cognitive functions, including categorization, inference, and language. Another common theme is that concepts are *flexible* — they are "evolving tools" (Stotz & Griffiths, 2008, p. 2); that is, they exhibit much more variability in their contents and dynamics than many philosophers assume. Factors that appear to make a difference to conceptual contents and dynamics include attention (Nosofsky, 1986), cultural background (Burnett et al., 2005), category instances to which one is exposed (Keil, 1989), and situations of deployment (Yeh & Barsalou, 2006). The final factor may be especially important in complex research contexts. It suggests that concepts will tend to evolve so that they emphasize features that better align with the epistemic and non-epistemic goals of the programs in which they are embedded. One upshot of this claim is that, as we move across research programs in which theoretical terms like 'genes' or 'interdisciplinary' appear, it becomes increasingly likely that the associated concepts will vary, reflecting the diverse aims and needs of each program.

For the preceding reasons, we are inclined towards the view that the best response to this sort of variability is a conceptual pluralism, at least when dealing with complex research contexts, particularly those where theoretical terms appear in distinct research programs with different sets of epistemic and non-epistemic goals. Biological research on genes serves as a useful illustration. We propose that research programs that invoke 'interdisciplinary' are another candidate. After all, as noted earlier, the landscape of interdisciplinary work is massively diverse. Some focus on epistemic aims, such as understanding minds in cognitive science or increased knowledge of the factors that influence philosophical intuitions in experimental philosophy. Others place a greater emphasis on non-epistemic aims, such as creating sustainable solutions for environmental issues in environmental engineering or improving urban living conditions in

urban studies. (For more on interdisciplinary problems, see Schmidt, 2022, pp. 29-31.) Moreover, even within the instrumentalist/critical-reflexive divide — where some interdisciplinary activities are primarily epistemic and others less so — there are substantial differences in their aims and needs. Understanding human cognition, for example, by leaning on psychology, linguistics, and neurosciences is a very different goal from chasing down an understanding of climate-change impacts by combining insights from climatology, economics, and sociology. Likewise, developing renewable energy solutions through engineering, environmental science, and public policy contrasts with addressing urban issues like housing, transportation, and urban sprawl through urban planning, sociology, and economics. All of this is to say that interdisciplinary spaces are particularly conducive to multiple concepts of interdisciplinarity. Thus, for the rest of this paper, we will assume that multiple concepts of interdisciplinarity are at play in both first-order activities and second-order reflections on these activities. More specifically, we will adopt a multiple-concepts perspective as a starting point for our analysis, until compelling reasons suggest otherwise (see Hansen et al., 2019, for more on the theory of presumptions).

A multiple-concepts perspective suggests that debates over *the* right way of defining or conceptualizing interdisciplinarity are misguided. Monistic approaches assume that there is one concept to be uncovered and enforced; thus, they would have us overlook legitimate variability across different research contexts. Indeed, if concepts are tools that tend to evolve to align with

the knowledge practices and the epistemic and non-epistemic goals of their specific research contexts, then insisting on a single definition can be counterproductive.[7]

[INSERT FIGURE 4 ABOUT HERE]

Philosophers of interdisciplinarity are better served by recognizing and embracing the conceptual diversity found in their subject matter. But presumably, our job goes beyond simply cataloging the diversity. As Griffiths and Stotz (2008, p. 13) write:

> If the only aim of philosophy was to accurately characterize how some topic is conceptualized by 'the folk' or by some more specific discursive community, then philosophy would be frighteningly close to sociolinguistics and might, indeed, be best served by a predominantly experimental approach. But philosophers have not traditionally contented themselves with documenting the way a subject is conceptualized and waiting for science or society to change the subject. Philosophers have tried to understand why things are conceptualized in a particular way.

Thus, a more ambitious goal for the philosophy of interdisciplinarity is to employ a version of pluralism,[8] particularly one that examines how varying concepts of interdisciplinarity reflect different sets of epistemic and non-epistemic aims. Griffiths and Stotz (2008) describe this type

[7] As we comment in footnote 2, strictly speaking, a conceptual ecological approach recognizes a dynamic interplay between concepts, practices, and goals. Our overarching point here is that enforcing a single definition across all contexts does not align with this complex interplay between concepts, practices, and goals.

[8] So, pluralism appears to be a more useful perspective. However, there is not a single, unified form of pluralism; pluralism comes in many shades and variants (Keestra, 2022). One form of pluralism about interdisciplinarity would be to merely list all the diverse uses of the term 'interdisciplinarity' without any discussion of the relationship between, perhaps even positing that an organization of the plurality is impossible. Here, we are following the example from philosophy of biology to opt for conceptual ecology as a form of productive pluralism.

of project as providing a *conceptual ecology* — for them, "an attempt to determine some of the pressures that caused the gene concept to diversify into a number of different epistemic niches" (p. 10; see also Griffiths & Stotz, 2007; Stotz, 2009; Stotz & Griffiths, 2004). They connect epistemic niches to epistemic needs, specifically, "the need of scientists to group phenomena together in ways that facilitate reliable inductive generalization" (Griffiths, 2015, p. 173n1). Since interdisciplinary pursuits often, if not typically, involve non-epistemic goals, a better way of characterizing the kind of project we are proposing here is that of identifying the factors leading to diverse concepts of interdisciplinarity across different *epistemic-axiological niches* — specific research environments defined by such factors as the knowledge practices, methods, values, and goals that shape or influence research projects.[9]

Our primary goal is to aid philosophers and theorists of interdisciplinarity in their second-order work by offering a framework that helps to sort through, manage, evaluate, and possibly reconstruct the wide range of interdisciplinary concepts, both explicitly articulated in second-order work and implicit in first-order practices, according to the epistemic-axiological niches in which they are embedded. We will demonstrate this with our case study in the next section. We leave it for future research to determine the extent to which our conceptual ecological framework can improve the situation at the first-order, that is, individuals or teams

[9] We want to stress that nothing in this paper is meant to imply that the factors that help to shape the concepts of interdisciplinarity are limited to epistemic and axiological considerations. Historical factors may also play a key role. Our recognition of the potential importance of historical factors is influenced by Kyle Whyte's work, particularly his analysis of Aldo Leopold's land ethic (Whyte, 2015). Whyte points out that Leopold's land ethic is based on a specific view of settler history. It is a view where humanity is seen as progressing from a focus on individual and individual-societal relationships towards a moral relationship with the land. This view, Whyte argues, overlooks the ethical perspectives of many Indigenous peoples, who often see their ethics as inherited from ancestors with a long-standing, inclusive relationship to the land and non-human entities. It seems plausible that historical paths also influence concepts of interdisciplinarity.

engaged in interdisciplinary practice (as opposed to theorists or philosophers theorizing about interdisciplinarity).

3. Case Study

We have thus far outlined our general case for a conceptual ecology of interdisciplinarity. In this section, we further support our conceptual ecological proposal with a case study: the Toolbox Dialogue Initiative (TDI). To recap, our proposal so far has been that to better understand and productively organize the second-order diversity of concepts of interdisciplinarity, and not the diversity of interdisciplinary practice per se, we should employ a conceptual ecological approach. This approach requires us to consider the ecology of each concept of interdisciplinarity — that is, the particular epistemic-axiological niche it inhabits — and examine how well it fits within the niche. This case study does precisely this task for TDI and its concept of interdisciplinarity. It is not an endorsement of TDI, any more than an ecologist's study of zebra mussels as an invasive species is an endorsement of zebra mussels. The goal is to identify TDI's concept of interdisciplinarity, assess its fitness relative to TDI's niche, and perhaps discover limitations for moving into other niches.[10]

In the next subsection, we will place TDI within a broader context of related projects. We believe this approach will (i) demonstrate that our conceptual ecology proposal is relevant to a wide variety of projects and (ii) encourage others to apply our proposal to these projects. Ultimately, our goal is to show that the conceptual ecology approach is effective not only in the

[10] To be clear, our focus is here on TDI's own concept of interdisciplinarity. This should be distinguished from TDI's (potential) role in helping teams of interdisciplinary practitioners articulate and coordinate *their* various concepts of interdisciplinarity. While TDI can serve as a facilitator of conceptual coordination among participants, our analysis examines the concept of interdisciplinarity implicit in TDI's approach to facilitation.

TDI case but also in a range of similar projects, thereby complementing the argument presented in Section 2. With that said, we acknowledge that this argumentative strategy has its limitations. A single case cannot establish a general proposal like the one we have advanced here. However, a case study can still enrich a more general argument. It can also motivate further investigation of the applicability of our general proposal.

3.1 Facilitating Interdisciplinarity

Much contemporary interdisciplinary work is closely tied to disciplinarity and academic disciplines. Schmidt (2022), for instance, underscores this connection by claiming that the core of interdisciplinarity involves recognizing disciplinary boundaries and the idea that they can be overcome (p. 25). It's worth mentioning that if our conceptual ecology story is right, then variations in how disciplines are understood is a potential source of variation in interdisciplinarity concepts. Numerous characterizations of disciplines can be found across different literatures (Crowley et al., 2016, pp. 346-347). Some scholars highlight intellectual aspects, describing disciplines as epistemic cultures (cf., Knorr-Cetina, 1999). Others focus on institutional aspects, portraying disciplines as social organizations (Wildman, 2010).

Given its connections to disciplines the interdisciplinarity we are considering will involve thinking about ways of making knowledge or enhancing understanding that mitigate the challenges posed by factors that encourage the self-contained islands of epistemic activity that constitute disciplinary thinking. Thus, to the extent that it involves integrating inputs from various disciplines — that is, creating coherent combinations of diverse disciplinary methods, findings, theories, values, etc. (O'Rourke et al., 2016) — interdisciplinarity can become exceedingly difficult (Donovan, 2020). Differences in research philosophies, such as varying

standards for what constitutes knowledge or different views about non-epistemic ends, can hinder mutual understanding (Daniel et al., 2022; Hubbs et al., 2020b; Noblet et al., 2013). Specialized terminology can complicate communication between disciplinary representatives (Jacobsson & Jacobsson, 2014). Also, institutional structures and professional incentives often reinforce disciplinary containment, making it harder for interdisciplinarians to find venues for their work (Pfirman et al., 2005). And, although there are journals devoted to interdisciplinary outputs, they are often viewed as less prestigious, especially by members of the author's home discipline, whom they may need to impress to advance their career (Campbell, 2005).

The challenges of this sort of interdisciplinarity have given rise to a practice and literature aimed at its facilitation. We will call this literature the *facilitation literature* and the related community *interdisciplinarity facilitators*. Organizations that support interdisciplinary facilitation include the Association for Interdisciplinary Studies (AIS), the International Network for the Science of Team Science (INSciTS) and the Global Alliance for Inter- and Transdisciplinarity (ITD-Alliance). Their efforts have developed frameworks and strategies to mitigate or overcome some of the challenges of interdisciplinary activity. They focus on improving communication, fostering collaborative environments, and creating shared goals and understanding among interdisciplinary teams. They also provide platforms for training and support to help scholars navigate the complexities of interdisciplinary terrains, and thereby contribute to the goal of integrating across diverse disciplinary perspectives.

The facilitation community is especially well-suited for motivating our conceptual ecological approach. While it is possible to facilitate interdisciplinary teamwork without explicitly defining it, most facilitation projects have some such definition. Our conceptual ecological proposal would suggest that the definition of interdisciplinarity used by a project

aligns with its goals: roughly, a facilitative project's understanding of interdisciplinarity takes the shape it does, in part, to help ensure that its techniques remain relevant and effective for the specific challenges to which they are leveraged.

3.2 Toolbox Dialogue Initiative

A prominent presence in the facilitation literature are facilitative efforts that emphasize dialogue (e.g., McDonald et al., 2009; see Laursen et al., 2021, Appendix for more examples). These approaches are an obvious response to many of the challenges of collaborative interdisciplinarity because they support information exchange across disciplinary islands and mutual understanding of disciplinary differences. One more specific form of dialogical facilitation focuses on *philosophical* dialogue. Examples include Tuana's embedded philosophy (e.g., Tuana, 2013) and Fischer's Socio-Technical Integration Research (Fischer et al., 2015). Here, we turn to another philosophical dialogical facilitation approach or intervention method: the Toolbox Dialogue Initiative (TDI) (Hubbs et al., 2020). It is a widely used approach and well-known by the authors. As such, it makes for a good case study for our conceptual ecological approach. It also serves as an illustrative example of a series of nested categories: philosophical dialogical, general dialogical, and general interdisciplinary facilitation approaches. We start by sketching the history, methods, and goals of TDI.

TDI was established to address the challenges of interdisciplinary education and research faced by federally funded projects in the U.S. (Crowley & O'Rourke, 2020; Hubbs, 2020; O'Rourke et al., 2024). It originated from an NSF-funded Integrative Graduate Education and Research Traineeship (IGERT) project at the University of Idaho, which aimed to train PhD students from various agricultural and natural resources disciplines, with an emphasis on

enhancing their interdisciplinary collaborative skills (Bosque-Pérez et al., 2016). Students were organized into interdisciplinary teams to select a common topic and develop their dissertations, each of which had to include a team-authored chapter. During this process, the students faced many of the challenges of cross-disciplinary collaboration, particularly issues related to navigating diverse research philosophies (for evidence of varying philosophical views across disciplines, see Beebe et al., 2019; Beebe & Dellsén, 2020; Robinson et al., 2019; Starmans & Friedman, 2020). To address these challenges, the students requested a seminar on philosophy of science and interdisciplinary research. In 2005, entomologist Sanford Eigenbrode and philosopher Michael O'Rourke conducted this seminar. It focused on communicative challenges in cross-disciplinary collaboration, drawing on students from multiple disciplines like physics, philosophy, evolutionary biology, and social sciences. The seminar's outcome was the first Toolbox method (Eigenbrode et al., 2007).

At TDI's core is the *Toolbox workshop*, where dialogue is guided by a survey-like instrument with prompts that outline various research perspectives, orientations, or philosophies (O'Rourke & Crowley, 2020). *Toolbox instruments* are designed to foster dialogue by encouraging participants to reflect on and express their research perspectives while also learning about their collaborators' orientations (Rinkus & O'Rourke, 2020). The goal of TDI is to enhance both self-understanding and mutual understanding through its workshop dialogues. Self-understanding is fostered in two stages: first as participants develop and reflect on their own reactions to instrument prompts and second as they share these reactions with team members. The sharing stage is especially valuable for promoting self-understanding, as it challenges participants to articulate, explain, and defend their perspectives in ways that make sense to others, which helps to clarify to themselves their own theoretical frameworks, beliefs, and values

(Gonnerman et al., 2015; Keestra, 2017). In addition to deepening self-understanding, this dialogue also supports mutual understanding (Rinkus & O'Rourke, 2020; Robinson & Gonnerman, 2020). By providing a platform for sharing research orientations, TDI encourages perspective-seeking behaviors such as questioning, elaborating on ideas, and respectful disagreement. These processes enrich mutual understanding without requiring agreement, which helps at leveraging the advantages of diversity in cross-disciplinary contexts (Crowley & O'Rourke, 2020). Importantly, during the workshop, a TDI member only lightly facilitates the group discussion. This approach helps ensure that the focus remains on the group's joint project rather than the facilitator's interests (O'Rourke & Crowley, 2013).

Accompanying TDI's goals of promoting self- and mutual-understanding, and thus supporting the communicative, integrative, and collaborative potential of interdisciplinary teams, is its understanding of interdisciplinarity. Here are two characteristic statements:

> "*Interdisciplinary collaboration.* Interdisciplinary research requires a greater degree of coordination among disciplines than multidisciplinary research, from problem formulation through analysis and interpretation. Research questions often span several spatial and temporal scales, such as those germane to interacting human and biological systems. Methods and analytical approaches may be synthetic. Collaborators accept, understand, and sometimes apply one another's disciplinary methods and approaches. More than multidisciplinary coordination, interdisciplinary integration can lead to new questions and new methodologies." (Eigenbrode et al., 2007, p. 56)

> "These terms [i.e., 'multidisciplinary', 'interdisciplinarity', and 'transdisciplinary'] correspond to different ways in which disciplinary inputs can be combined. If the inputs alter little (e.g., in a report that includes sections on culture, economics, and hydrology), then the work is multidisciplinary. If the ideas alter more significantly (e.g., cultural, economic, and hydrological factors all included in a single model), the work is interdisciplinary. Finally, if the ideas alter to the point of novelty (e.g., the cultural, economic, and hydrological perspectives give rise to a new field), the work is transdisciplinary." (Crowley & O'Rourke, 2020, p. 6)[11]

These two passages suggest that TDI primarily locates interdisciplinarity in collaborative research contexts.[12] As such, for TDI, paradigmatic instances of interdisciplinarity require significant coordination among disciplinary representatives and substantial integration of disciplinary inputs. This coordination and integration span multiple research stages. In addition, TDI characterizes interdisciplinarity in ways that stress the acceptance, understanding, and sometimes adoption of methods and approaches other than one's own.

The preceding helps to highlight similarities between TDI's concept of interdisciplinarity and Schmidt's instrumentalism. Recall that, according to Schmidt, an instrumentalist concept

---

[11] We recognize that Crowley and O'Rourke's use of 'transdisciplinary' here is somewhat idiosyncratic and does not correspond with others' use of the term to mean work done with extra-academic stakeholders. Here we are not endorsing Crowley and O'Rourke's definition but pointing it out. That they have an idiosyncratic use is what our conceptual ecological approach expects: a group working and theorizing about interdisciplinarity will develop their own distinct notions and uses of terms to fit their particular epistemic-axiological niche. This is precisely what Crowley and O'Rourke have done here.

[12] Primarily locating interdisciplinarity in collaborative research contexts does not prevent TDI from recognizing individually conducted interdisciplinary work. Rather, it will tend to shape what TDI sees as important — and perhaps even necessary — in individual cases: the meaningful engagement with and integration of different disciplinary perspectives, approaches, and insights.

emphasizes four factors: (1) effective management of disciplinary diversity; (2) development of practical solutions to given problems; (3) disregard of normative issues related to science and society; and thus (4) acceptance of the value-free ideal. TDI's concept of interdisciplinarity aligns well with the first two features of Schmidt's concept. Two considerations support this claim. First, if we had to pinpoint TDI's *raison d'être*, it would likely be the challenge of getting individuals with diverse research perspectives to work well together. As Donovan (2020, p. 49) notes, "Cross-disciplinary work is innately challenging, but one dimension of difficulty that is especially important for TDI concerns the complex epistemic issues that arise when diverse perspectives meet." Thus, TDI's understanding of interdisciplinarity emphasizes the difficulties of effectively managing diverse perspectives, which is typical of interdisciplinary work. Second, TDI proposes the beginnings of a practical solution to this management problem, at least insofar as the philosophical dimensions constituting or undergirding diverse perspectives are concerned. It uses structured dialogue to support self- and mutual understanding of the diverse philosophies found on the team, thereby improving the team's communicative, integrative, and collaborative capacities (Rinkus & O'Rourke, 2020; Robinson & Gonnerman, 2020).

Importantly, however, TDI's concept of interdisciplinarity is only partially instrumentalist. Unlike Schmidt's instrumentalism, TDI's understanding of interdisciplinarity does not wholly disregard normative issues related to science and society, nor does it accept the value-free ideal. One of the most often used Toolbox instruments includes a module that asks workshop participants to reflect on the question of whether values negatively influence scientific research (see Hubbs et al., 2020b, Appendix A; for analysis of responses, see Robinson et al., 2016, 2019; Steel et al., 2017). Moreover, there are works in the TDI oeuvre that explore how its approach can help in the detection and coordination of value differences in collaborative

environmental science (Laursen et al., 2021), improve students' awareness and reasoning about values in environment research (Hall et al., 2018), and foster greater metacognition (Robinson & Gonnerman, 2020).[13]

With this account of TDI's instrumentalist-like concept of interdisciplinarity, we can now explore some of the epistemic and axiological pressures that helped to shape it. TDI was created in the context of federally funded academic research in the U.S., as its origins in an NSF-funded IGERT indicate. And, while it has since been used in other countries (e.g., Hubbs et al., 2020a, pp. 188-192) and with non-academic stakeholders (e.g., Cwik et al., 2022), support for U.S. academic research is still central to its work. This background explains why TDI's primary goal is to help interdisciplinary research teams according to the criteria set by their funders, particularly by U.S. federal agencies such as the NSF and NIH. A major element of success, defined by these agencies, is publication volume in high-impact academic journals. Consequently, for TDI facilitating interdisciplinarity is mainly an epistemic task. It is about encouraging the development of shared mental models that encompass the project's goals, methods, key concepts and terminology, roles and responsibilities, and expected timelines. This common (or at least sufficiently similar) understanding helps to ensure that collaborators have a joint framework for pursuing their project. Given this background, it is unsurprising that TDI aims to promote self- and mutual understanding of divergent research perspectives and philosophies. By helping collaborators understand their perspectives, TDI strives to improve their ability to integrate around their differences, and thereby achieve closer alignment in project goals, methods, concepts, etc. In effect, then, TDI's epistemic pursuits were designed to serve a

[13] In view of work pointing to the importance of metacognition in interdisciplinary collaboration (e.g., Keestra, 2017) and interdisciplinary education (e.g. Brooks et al., 2019), TDI's role in fostering metacognition may be especially important for interdisciplinary contexts.

particular purpose: to help interdisciplinary research teams to traverse the path from ideation to high-impact publication.

To sum up, we take ourselves to have shown that TDI's concept of interdisciplinarity aligns well with its project goals of supporting federally funded research in the U.S. This alignment is what a conceptual ecological approach would predict, making the TDI case study evidence in favor of the approach. Further, since TDI represents a standard form of dialogue-based interdisciplinary facilitation, we have some reason to generalize from the success of a conceptual ecology here to its success with similar facilitation projects.

[INSERT FIGURE 5 ABOUT HERE]

Before moving on to consider some of the benefits associated with adopting a conceptual ecological approach, we want to briefly consider a further line of evidence in favor of our approach, broadly speaking. This is a line of thought that can be found in the work of Klenk and Meehan (2015). They argue that transdisciplinarity (see footnote 11) is seen as appealing in climate-change-related science because it supports 'knowledge convergence around climate action' (p. 161) and is understood as essentially involving the epistemic integration of different forms of knowledge making (p. 162). However, they also suggest that in practice transdisciplinarity can be approached in other ways (section 4) and that focusing on epistemic integration results in "depoliticizing science" (p. 162). It is only a small additional step to view the integrative understanding of transdisciplinarity as shaped by the epistemic-axiological niche (i.e., Western, government-funded research) occupied by most climate change researchers. Furthermore, in section 4, Klenk and Meehan present three alternative (non-integrative) approaches to transdisciplinary climate science. They note, "Each alternative has its limitations,

since no single approach to transdisciplinary knowledge production is immune to power dynamics, and no single model suits all settings and contexts." (p. 163). In short, the right way to think about transdisciplinarity is to acknowledge its variety and to conceive of it in ways that are appropriate to particular settings and contexts; but that just is conceptual ecology.

4 Relevance Reflection

We have now introduced the conceptual ecological approach and argued, both theoretically and through a case study, that the second-order study of interdisciplinarity aligns with the approach. In this section, we outline some of the benefits of adopting the approach.

At a theoretical level, a conceptual ecological approach helps to move us beyond debates over the correct way of conceptualizing interdisciplinarity. Such debates are misguided if multiple concepts are at play in first-order activities and second-order reflection. Moreover, a conceptual ecological approach enriches our taxonomies of the multiple concepts, like the one given by Schmidt (2022). It does so by explaining the diversity of interdisciplinarities in terms of their fit with the epistemic-axiological niche in which they are embedded, rather than merely describing the plurality.

None of this is to say that conceptual ecologists should ignore debates about the correct definition of interdisciplinarity. For one, it is possible that the best definition of interdisciplinarity for a specific niche is not the one used by those working in the niche. Their aims might be better served by another definition discussed in the literature. For another, debates about the correct definition of interdisciplinarity can inform conceptual ecological work. For example, refinements of and counterexamples to existing definitions can help to capture candidate concepts of interdisciplinarity and the boundaries of their relevant niches.

A similar point holds for taxonomic work. Existing taxonomies tend to be hierarchical and/or to define their categories in terms of neat and tidy sets of necessary and sufficient conditions. For example, as we saw, Schmidt (2022) describes instrumentalism as requiring an emphasis on effective management of disciplinary diversity, development of practical solutions to given problems, disregard of normative issues related to science and society, and adherence to the value-free ideal. In contrast, a conceptual-ecological approach invites us to view the taxa as partially distinct but overlapping. Consequently, as discussed with TDI's instrumentalist-like concept of interdisciplinarity, we can "unbundle" a given taxon, and thereby come to recognize projects that adopt some but not all the features assigned to a concept of interdisciplinarity according to their epistemic-axiological niche.

Another potential benefit from adopting a conceptual ecological approach to interdisciplinarity pertains to the facilitation literature. If concepts and niches tend to align as we have suggested, then discussions about which concept of interdisciplinarity feels natural to a team can help them understand the features, blind spots, and challenges of their project. This idea aligns with the work of epistemologists of ignorance, who aim at "identifying different forms of ignorance, examining how they are produced and sustained, and what role they play in knowledge practices" (Sullivan & Tuana, 2007, p. 1). One claim highlighted in this area is that ignorance is "actively constructed" and "preserved" by knowledge-making communities (e.g., Tuana, 2004, p. 195; for more on how interdisciplinary research can contribute to harmful forms of ignorance, see Piso et al., 2016). What we are suggesting is that the concepts used in a project can contribute to practices of constructing and preserving ignorance. Specifically, if a project's concept of interdisciplinarity omits certain features of interdisciplinarity (broadly construed), then it will incline the project to overlook those features in its work. This is one place where

interdisciplinary facilitation can play a crucial role. TDI-style dialogical interventions, for example, can help teams in identifying their conceptual blind spots by introducing prompts that reveal different understandings of interdisciplinarity. While no project can pursue all ends of inquiry or action worthy of pursuit, engaging in a dialogical exploration of conceptual possibilities ensures that the chosen concept of interdisciplinarity and the associated goals are chosen collectively and reflectively, rather than being determined unilaterally or implicitly.

In addition, understanding how a project's concept of interdisciplinarity fits with a specific epistemic-axiological niche can help to explain why the project faces certain challenges. Consider TDI again. As discussed in Section 3, TDI operates mainly within the U.S. government-funded interdisciplinary research context, where success is often measured by publication volume in high-profile outlets. This niche pushes facilitators toward an understanding of interdisciplinarity that emphasizes the difficulties of navigating diverse perspectives and finding practical solutions to this navigation problem. If you think that the difficulty of navigating diverse perspectives stems largely from a lack of mutual understanding of each other's perspectives, and if you are looking for a practical solution to this gap in mutual understanding, then odds are that you will land on something like the facilitation techniques of TDI: prompt-structured workshop dialogues where implicit and unspoken disciplinary differences become explicit and shared, and thereby progress will hopefully be made towards the epistemic goal of advancing mutual understanding.[14] But, while this approach might be effective

[14] We take it that TDI is an example where epistemic factors significantly shape its concept of interdisciplinarity. However, non-epistemic values also play a role. These include procedural considerations such as inclusivity and respect of all participants' perspectives and contributions. These values are not purely epistemic (for more on the blurry boundary between epistemic and non-epistemic values, see, e.g., Longino, 1990). And they contribute to TDI's concept of interdisciplinarity. Given that TDI's aim is to help in the development of research environments where interdisciplinary teams can collaborate effectively, and that such environments require much more than just mutual understanding, TDI's instrumentalist concept also includes procedural aspects of managing collaborations.

for surfacing disciplinary perspectives and supporting self- and mutual understanding, it is less well-suited for addressing power imbalances and nuanced social dynamics on interdisciplinary teams. We know that interdisciplinary projects can involve significant power disparities. Gardner (2013), for example, provides a case study where social scientists were disregarded and relegated by biophysical scientists in a large ecological-sustainability project. And, of course, power imbalances can also stem from such factors as gender, race, and career stage. How will a dialogue structured around prompts designed to reveal and surface disciplinary perspectives address these issues? Sure, TDI could design prompts to uncover attitudes related to power dynamics. But if engagement with such prompts is going to help, it is likely going to require a substantial change in how TDI engages with interdisciplinary teams. Light facilitation will likely have to become intensive facilitation, with facilitators actively guiding discussions, ensuring balanced participation, and directly addressing conflicts.[15] After all, lightly facilitated discussions can reinforce existing hierarchies if dominant voices overshadow others or if disadvantaged collaborators are marginalized. Additionally, the scope of TDI's engagement with interdisciplinary teams will likely have to go well beyond a three-hour workshop. Power dynamics are deeply ingrained and complex, often requiring ongoing effort to identify, understand, and transform power relationships (e.g., Maguire, 2015).

[15] As TDI's work has evolved, some of the changes described here have been implemented to an extent. Within the TDI community, there is a distinction between early versions of the Toolbox (Toolbox 1.0) and later versions (Toolbox 2.0 and counting) (O'Rourke & Crowley, 2020). Our discussion primarily relates to Toolbox 1.0. That said, our general point about conceptual ecology applies to both Toolbox 1.0 and 2.0. We just lack the space to discuss both versions.

5 Future Outlook

Current debates about the nature of interdisciplinarity can feel frustrating and fruitless. This paper offers a diagnosis. If there are multiple legitimate concepts of interdisciplinarity across various contexts of interdisciplinary activity, then it makes sense that these debates can feel frustrating and fruitless. Different contexts may require distinct understandings, making a drive towards a single, universal definition counterproductive. This paper proposes a way of averting this feeling: stop pursuing a single, universal definition of interdisciplinarity.

Importantly, the view we are presenting is not a "lazy pluralism" in which diverse concepts are acknowledged without active engagement or critical examination. Taxonomies of interdisciplinarities can help in understanding and examining various concepts, but they fall short of explaining why the variety exists or persists. In contrast, a conceptual ecological approach can explain the diversity of concepts of interdisciplinarity, helping to guide second-order theorists away from misguided debates about the "true" concept of interdisciplinarity. The extent to which this approach will also help first-order interdisciplinarity in managing their challenges is a question we leave for future research.

Our introduction of Griffiths and Stotz's account of conceptual ecology to the philosophy of interdisciplinarity — along with our application to TDI — offers new perspectives for philosophical discussions of interdisciplinarity to take up and critique, and thereby advance these discussions. Additionally, adopting a conceptual ecological approach can give interdisciplinary facilitators a richer understanding of the potential and limitations of various facilitation methods. This enhanced understanding, informed by the concept of interdisciplinarity shaped by the niche

in which the method is embedded, can improve facilitators' ability to match resources to project needs.

References

Bauer, A. M., & Kornmesser, S (Eds). (2024). *The compact compendium of experimental philosophy*. Berlin: De Gruyter.

Baxevanis, A. D., Bader, G. D., & Wishart, D. S. (Eds.) (2020). *Bioinformatics* (4th ed.). Hoboken, NJ: Wiley.

Bermúdez, J. L. (2022). *Cognitive science*: *An introduction to the science of the mind* (4th ed.) Cambridge: Cambridge University Press.

Berry, D. M. (Ed.) (2012). *Understanding digital humanities*. London: Palgrave Macmillan.

Brooks, B., Schaab, K., & Chapman, N. H. (2019). Integration and metacognition: Engaging metacognitive capacity building strategies to enhance interdisciplinary student learning. *Issues in Interdisciplinary Studies*, *37*(1), 22-53.

Bunge, M. (1983). *Treatise on basic philosophy. Vol. 5: Epistemology & methodology I: Exploring the world*. Dordrecht: D. Reidel Publishing Company.

Burnett, R. C., Medin, D. L., Ross, N. O., & Blok, S. V. (2005). Ideal is typical. *Canadian Journal of Experimental Psychology*, *59*(1), 3–10.

Campbell, L. M. (2005). Overcoming obstacles to interdisciplinary research. *Conservation Biology, 19*(2), 574–577.

Crowley, S. J., Gonnerman, C., & O'Rourke, M. (2016). Cross-disciplinary research as a platform for philosophical research. *Journal of the American Philosophical Association*, *2*, 344-363.

Crowley, S., & O'Rourke, M. (2020). Communication failure and cross-disciplinary research. In G. Hubbs, M. O'Rourke, & S. H. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 1–16). Boca Raton, FL: CRC Press.

Cwik, B., Gonnerman, C., O'Rourke, M., Robinson, B., & Schoonmaker, D. (2022). Building community capacity with philosophy: Toolbox dialogue and climate resilience. *Ecology & Society*, *27*(2). https://doi.org/10.5751/ES-13282-270221

Daniel, K. L., McConnell, M., Schuchardt, A., & Peffer, M. E. (2022). Challenges facing interdisciplinary researchers: Findings from a professional development workshop. *PLoS One, 17*(4), e0267234.

Darwin, C. (1845). *Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. Beagle round the world, under the command of Capt. Fitz Roy, R.N.* (2nd ed.). Murray.

Donovan, S. (2020). The landscape of challenges for cross-disciplinary activity. In G. Hubbs, M. O'Rourke, &S. H. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 48–57). Boca Raton, FL: CRC Press.

Douglas, H. (2009). *Science, policy, and the value-free ideal*. Pittsburgh: University of Pittsburgh Press.

Eigenbrode, S., O'Rourke, M., Wulfhorst, J. D., Althoff, D. M., Goldberg, C. S., Merrill, K., Morse, W., Nielsen-Pincus, M., Stephens, J., Winowiecki, L., & Bosque-Pérez, N. A. (2007). Employing philosophical dialogue in collaborative science. *BioScience*, *57*, 55–64.

Feest, U. (2010). Concepts as tools in the experimental generation of knowledge in cognitive neuropsychology. *Spontaneous Generations: A Journal for the History and Philosophy of Science*, *4*(1), 173-190.

Fisher, E., O'Rourke, M., Evans, R., Kennedy, E. B., Gorman, M. E., & Seager, T. P. (2015). Mapping the integrative field: Taking stock of socio-technical collaborations. *Journal of Responsible Innovation*, *2*(1), 39-61.

Fuchsman, K. (2009). Rethinking integration in interdisciplinary studies. *Issues in Integrative Studies*, 27, 70-85.

Fulcher, J. (1978). Liberal education: Interdisciplinary study of integrative topics. *Improving College and University Teaching*, *26*(1), 44–49.

Fuller, S., & Collier, J. H. (2004). *Philosophy, rhetoric, and the end of knowledge: A new beginning for science and technology studies* (2nd ed.). Mahwah, NJ: LEA.

Gardner, S. (2013). Paradigmatic differences, power, and status: A qualitative investigation of faculty in one interdisciplinary research collaboration on sustainability science. *Sustainability Science, 8*(2), 241–252.

Glimcher, P. W., & Fehr, E. (Eds.) (2013). *Neuroeconomics: Decision making and the brain* (2nd ed.). London: Academic Press.

Gonnerman, C., O'Rourke, M., Crowley, S. J., & Hall, T. E. (2015). Discovering philosophical assumptions that guide action research: The reflexive Toolbox approach. In H. Bradbury Huang & P. Reason (Eds.), *The SAGE handbook of action research* (3rd ed., pp. 673–680). Thousand Oaks, CA: SAGE Publications.

Goodman, N. (1955). *Fact, fiction, and forecast*. Cambridge, MA: Harvard University Press.

Gottdiener, M., Budd, L., & Lehtovuori, P. (2016). *Key concepts in urban studies* (2nd ed.). Los Angeles: Sage.

Griffiths, P. E. (2015). Conceptual change and conceptual diversity contribute to progress in science. In G. Bammer (Ed.), *Change! Combining analytic approaches with street wisdom* (pp. 163-176). Acton, Australia: ANU Press.

Griffiths, P. E., & Stotz, K. (2007). Gene. In D. Hull & M. Ruse (Eds.), *The Cambridge companion to the philosophy of biology* (pp. 85–102). Cambridge University Press.

Griffiths, P. E., & Stotz, K. (2008). Experimental philosophy of science. *Philosophy Compass*, *3*, 10.1111/j.1747-9991.2008.00133.x

Griffiths, P. E., & Stotz, K. (2013). *Genetics and philosophy: An introduction*. Cambridge: Cambridge University Press.

Hackett, E. J., Parker, J. N., Vermeulen, N., & Penders, B. (2017). The social and epistemic organization of scientific work. In U. Felt, R. Fouché, C. A. Miller, & L. Smith-Doerr (Eds.), *The handbook of science and technology studies* (4th ed., pp. 733-764). Cambridge, MA: MIT Press.

Hall, T. E., Piso, Z., Engebretson, J., & O'Rourke, M. (2018). Evaluating a dialogue-based approach to teaching about values and policy in graduate transdisciplinary environmental science programs. *PLOS ONE*, *13*, e0202948.

Hansen, H. V., Kauffeld, F. J., Freeman, J. B., & Bermejo-Luque, L. (Eds.). (2019). *Presumptions and burdens of proof: An anthology of argumentation and the law*. Tuscaloosa, AL: The University of Alabama Press.

Hjørland, B. (2011). The periodic table and the philosophy of classification. *Knowledge Organization*, *38*(1), 9-21.

Hubbs, G. (2020). A narrative history of the Toolbox Dialogue Initiative. In G. Hubbs, M. O'Rourke, & S. H. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 37–47). Boca Raton, FL: CRC Press.

Hubbs, G., O'Rourke, M., Eigenbrode, S. E., Rinkus, M. A., & Malavsi, A. (2020a). Toolbox workshop case studies. In G. Hubbs, M. O'Rourke, & S. H. Orzack (Eds.), *The Toolbox*

Dialogue Initiative: The power of cross-disciplinary practice (pp. 179-202). Boca Raton, FL: CRC Press.

Hubbs, G., O'Rourke, M. & Orzack, S. (Eds.) (2020b). *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice*. Boca Raton, FL: CRC Press.

Jacobsson, T., & Jacobsson, S. (2014). Conceptual confusion – an analysis of the meaning of concepts in technological innovation systems and sociological functionalism. *Technology Analysis & Strategic Management*, *26*(7), 811–823.

Keestra, M. (2017). Metacognition and reflection by interdisciplinary experts: Insights from cognitive science and philosophy. *Issues in Interdisciplinary Studies*, *35*, 121-169.

Keestra, M. (2022). Configurations of pluralisms. Navigating polyphony and diversity in philosophy and beyond. In K. Stenning & M. Stokhof (Eds.), *Rules, regularities, randomness* (pp. 87-99). Amsterdam, The Netherlands: Institute for Logic, Language and Computation.

Keil, F. C. (1989). *Concepts, kinds, and cognitive development*. Cambridge, MA: MIT Press.

Kitcher, P. (1992). Gene: Current usages. In E. F. Keller & E. A. Lloyd (Eds.), *Keywords in evolutionary biology* (pp. 128–131). Cambridge, MA: Harvard University Press.

Klein, J. T. (1990). *Interdisciplinarity: History, theory, and practice*. Detroit: Wayne State University Press.

Klein, J. T. (2017). Typologies of interdisciplinarity: The boundary work of definition. In R. Frodeman (Ed.), *The Oxford handbook of interdisciplinarity* (2nd ed., pp. 21-34). Oxford: Oxford University Press.

Klein, J. T. (2021). Beyond disciplinarity: Boundary work, communication, and collaboration. Oxford: Oxford University Press.

Klenk, N. & Meehan, K. (2015). Climate change and transdisciplinary science: Problematizing the integration imperative. *Environmental Science and Policy, 54*, 160–167. https://doi.org/10.1016/j.envsci.2015.05.017

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Lattuca, L. R. (2001). *Creating interdisciplinarity: Interdisciplinary research and teaching among college and university faculty*. Nashville, TN: Vanderbilt University Press.

Laursen, B. K., Gonnerman, C., & Crowley, S. J. (2021). Improving philosophical dialogue interventions to better resolve problematic value pluralism in collaborative environmental science. *Studies in History and Philosophy of Science*, *87*, 54-71.

Lélé, S., & Norgaard, R. B. (2005). Practicing interdisciplinarity. *BioScience*, *55*(11), 967–975.

Longino, H. (1990). *Science as social knowledge*. Princeton: Princeton University Press.

Lyotard, J. F. (1984). *The postmodern condition: A report on knowledge* (G. Bennington & B. Massume, Trans.). Minneapolis: University of Minnesota Press.

Machery, E. (2009). *Doing without concepts*. Oxford: Oxford University Press.

Maguire, K. (2015). *Margaret Mead: Contributions to contemporary education*. New York: Springer.

Mihelcic, J. M., & Zimmerman, J. B. (2021). *Environmental engineering: Fundamentals, sustainability, and design* (3rd ed.). Hoboken, NJ: Wiley.

Meunier, R. (2023). Gene. In E. N. Zalta & U. Nodelman (Eds.). *The Stanford encyclopedia of philosophy* (Fall 2023 Edition). Retrieved from https://plato.stanford.edu/archives/fall2023/entries/gene/

Miller, R. (1982). Varieties of interdisciplinary approaches in the social sciences. *Issues in Integrative Studies*, *1*, 1-37.

Moss, L. (2003). *What genes can't do*. Cambridge, MA: MIT Press.

Nado, J. (2019). Conceptual engineering via experimental philosophy. *Inquiry*, *64*(1–2), 76–96.

National Academy of Science (2005). *Facilitating interdisciplinary research*. Washington, D.C.: The National Academies Press.

Neumann-Held, E. (2001). Let's talk about genes: The process molecular gene concept and its context. In S. Oyama, P. E. Griffiths, & R. D. Gray (Eds.), *Cycles of contingency: Developmental systems and evolution* (pp. 69-84). Cambridge, MA: MIT Press.

Newell, W. H. (2001). A theory of interdisciplinary studies. *Issues in Integrative Studies*, *19*, 1-25.

Noblet, C. L., Lindenfeld, L. A., & Anderson, M. W. (2013). Environmental worldviews: A point of common contact, or barrier? *Sustainability, 5*(11), 4825-4842.

Nosofsky, R. M. (1986). Attention, similarity, and the identification–categorization relationship. *Journal of Experimental Psychology: General, 115*(1), 39–57.

O'Rourke, M. (2017). Comparing methods for cross-disciplinary research. In R. Frodeman, J. T. Klein, & R. Pacheco (Eds.), *Oxford Handbook of Interdisciplinarity* (2nd ed., pp. 276-290). Oxford: Oxford University Press.

O'Rourke, M., & Crowley, S. J. (2013). Philosophical intervention and cross-disciplinary science: the story of the Toolbox Project. *Synthese*, *190*, 1937–1954.

O'Rourke, M., & Crowley, S. (2020). How it works: The Toolbox dialogue method in practice. In G. Hubbs, M. O'Rourke, & S. H. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 17-36). Boca Raton, FL: CRC Press.

O'Rourke, M., Crowley, S., & Gonnerman, C. (2016). On the nature of cross-disciplinary integration: A philosophical framework. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *56*, 62-70.

O'Rourke, M., Donovan, S., Engebretson, J., Gonnerman, C., Goralnik, L, Imbruce, V., Kjellberg, P., Rinkus, M. A., & Robinson, R. (2024). Addressing perspectives with the Toolbox Methodology. In R. Stzostak (Ed.), *Handbook of interdisciplinary teaching and administration* (pp. 171-193). Cheltenham, UK: Edward Elgar Publishing.

Piso, Z., Sertler, E., Malavisi, A., Marable, K., Jensen, E., Gonnerman, C., & O'Rourke, M. (2016). The production and reinforcement of ignorance in collaborative interdisciplinary research. *Social Epistemology*, *30*, 643-664.

Pfirman, S. L., Collins, J. P., Lowes, S., & Michaels, A. (2005). To thrive and prosper: Hiring, supporting, and tenuring interdisciplinary scholars. *The Chronicle of Higher Education, 51*(23), B51.

Rafols, I., Leydesdorff, L., O'Hare, A., Nightingale, P., & Stirling, A. (2012). How journal rankings can suppress interdisciplinary research: A comparison between innovation studies and business & management. *Research Policy, 41*(7), 1262–1282.

Rawls, J. (1971). *A theory of justice*. Cambridge, MA: Belknap Press.

Repko, A., & Szostak, R. (2017). *Interdisciplinary research: Process and theory* (3rd ed.). Thousand Oaks, CA: Sage.

Rinkus, M. A., & O'Rourke, M. (2020). Qualitative analyses of the effectiveness of Toolbox dialogues. In G. Hubbs, M. O'Rourke, & S. H. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 142–161). Boca Raton, FL: CRC Press.

Robinson, B., & Gonnerman, C. (2020). Enhancing cross-disciplinary science through philosophical dialogue: Evidence of improved metacognition for effective collaboration.

In G. Hubbs, M. O'Rourke, & S. Orzack (Eds.), *The Toolbox Dialogue Initiative: The power of cross-disciplinary practice* (pp. 127-141). Boca Raton, FL: CRC Press.

Robinson, B., Gonnerman, C., & O'Rourke, M. (2019). Experimental philosophy of science and philosophical differences across the sciences. *Philosophy of Science*, *86*, 551-586.

Robinson, B., Vasko, S., Gonnerman, C., Christen, M., O'Rourke, M., & Steel, D. (2016). Humanistic values and the values of humanities in interdisciplinary research. *Cogent Arts and Humanities*, *3*, 1123080.

Rosenfield, P. L. (1992). The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. *Social Science & Medicine*, *35*(11), 1343–1357.

Rudner, R. (1953). The scientist qua scientist makes value judgments. *Philosophy of Science*, *20*(1), 1–6.

Schmidt, J. S. (2008). Towards a philosophy of interdisciplinarity: An attempt to provide a classification and clarification. *Poieses & Praxis*, *5*(1), 53-69.

Schmidt, J. C. (2022). *Philosophy of interdisciplinarity: Studies in science, society and sustainability*. London: Routledge.

Starmans, C., & Friedman, O. (2020). Expert or esoteric? Philosophers attribute knowledge differently than all other academics. *Cognitive Science*, *44*(7), e12850.

Steel, D., Gonnerman, C., McCright, A., & Bavli, I. (2018). Gender and scientists' views about the value-free ideal. *Perspectives on Science*, *26*, 619-657.

Steel, D., Gonnerman, C., & O'Rourke, M. (2017). Scientists' attitudes on values and science: Case studies and a role for quantitative survey methods in philosophy of science. *Studies in History and Philosophy of Science*, *63*, 22-30.

Stotz, K. (2009). Experimental philosophy of biology: Notes from the field. *Studies in History and Philosophy of Science*, *40*(2), 233-237.

Stotz, K., & Griffiths, P. E. (2004). Genes: Philosophical analyses put to the test. *History and Philosophy of the Life Sciences, 26*(1), 5–28.

Sullivan, S., & Tuana, N. (Eds.). (2007). Introduction. In S. Sullivan & N. Tuana (Eds.), *Race and epistemologies of ignorance* (pp. 1–10). Albany, NY: SUNY Press.

Squires, G. (1975). *Interdisciplinarity: A report for the Group of Research and Innovation in Higher Education*. London: The Neufeld Foundation.

Tabery, J. (2023). Genetics. In E. N. Zalta & U. Nodelman (Eds). *The Stanford encyclopedia of philosophy* (Fall 2023 Edition). Retrieved from https://plato.stanford.edu/archives/fall2023/entries/genetics/

Tuana, N. (2004). Coming to understand: Orgasm and the epistemology of ignorance. *Hypatia, 19*(1), 194–232.

Tuana, N. (2013). Embedding philosophers in the practices of science: Bringing humanities to the sciences. *Synthese*, *190*(11), 1955–1973.

Waters, C. K. (2000). Molecules made biological. *Revue Internationale de Philosophie*, *54*, 539-564.

Waters, K. (2013). Molecular genetics. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2013 Edition). Retrieved from https://plato.stanford.edu/archives/fall2013/entries/molecular-genetics/

Whyte, K. (2015). *How similar are Indigenous North American and Leopoldian environmental ethics?* Available at SSRN 2022038. https://doi.org/10.2139/ssrn.2022038

Wildman, W. (2010). *Religious philosophy as multidisciplinary comparative inquiry*. State University of New York Press.

Yeh, W., & Barsalou, L. W. (2006). The situated nature of concepts. *The American Journal of Psychology*, *119*(3), 349–384.