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On the Intersection of Interdisciplinary Studies and Argumentation Studies: The Case of Inference to the Best Explanation

by

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Abstract: This article aims to convince readers of the value of intersecting the scholarship of interdisciplinarity with the field of argumentation studies. The interdisciplinarity literature has not much engaged with the vehicle that carries interdisciplinary learning, languages, and locutions: the argument. On the argumentation studies side, despite the diverse interests of these scholars, not many have studied how reasoning proceeds in interdisciplinary inquiries. To aid bridge-building from both sides, I use the example of interdisciplinary abductive reasoning to show how the two fields can benefit from each other. The article proceeds as thin, comparative case studies thickened by theory. By analyzing two extended cases of inquiry cast in Douglas Walton's argumentation terms, I argue Walton's model is necessary but not sufficient for understanding and dealing with the unique challenges of interdisciplinary abduction. I propose, instead, we add the PEPR model (Pattern Recognition, Explanation Imagination, Pattern Matching, and Reporting) to help us focus on the data to be explained while we lean on Walton's model to understand the people doing the explaining. I conclude argumentation studies and interdisciplinary theory can be mutually enlightening.

Keywords: abduction, causal reasoning, field integration, imagination, inference to the best explanation, interdisciplinary argumentation, pattern recognition, pattern matching, reporting

Introduction

This article aims to convince readers of the value of intersecting the scholarship of interdisciplinarity with the field of argumentation studies. Itself an interdisciplinary field, argumentation studies has roots in philosophy, cognitive psychology, computer science, rhetoric, and sociology. The focus of the field

is the nature and use of arguments in natural settings, i.e., the world beyond symbolic logic. This "world beyond" includes interdisciplinary inquiries, yet both argumentation theorists and scholars of interdisciplinarity have generally overlooked what argumentation might have to say about interdisciplinarity, and conversely, what interdisciplinarity might have to say about argumentation. I make my case for the value of bringing these fields together by showing what argumentation has to say about a particular kind of reasoning often found in interdisciplinary inquiries: inference to the best explanation, also known as abductive reasoning or abduction.[1] I then show that a prominent existing model of abduction from the argumentation field needs to be augmented in order to identify and deal with difficulties in abduction highlighted by interdisciplinary reasoning. I conclude that when we understand interdisciplinary inquiry as reasoning through arguments, we then have many new resources for describing how integration (so key to interdisciplinarity) works *and* for improving models of argumentation.

Definitions

"Interdisciplinary." For the purposes of this article, I adopt the following definitions of "interdisciplinary" and "inquiry." Firstly, I lean heavily on the 2005 National Academies of Science report, *Facilitating Interdisciplinary Research* (National Research Council, 2005). According to this view – a view that accords with the well-known Klein & Newell (1997) definition – interdisciplinary work integrates disciplinary contributions, often to answer complex questions.

What counts as a "disciplinary" contribution is contested, of course. A discipline can be understood mainly either as a socio-institutional structure or an

[1] Abduction is a third major kind of reasoning first so-named by C. S. Peirce (1878). Deduction makes inferences about how a particular member participates in a general set. Such inferences are certain so long as the premises are true. Induction makes general inferences about a set based on observing a number of its members. Such inferences are probabilistic, so long as the observed are actually members of the target set. Abduction, however, makes inferences about *how* the general and member observations are related. Such inferences are plausible – based on presumed causal mechanisms. Peirce's examples help distinguish the three: (1) "Deduction: All the beans from this bag are white. These beans are from that bag. Therefore, these beans are white." (2) "Induction: The beans are from this bag. These beans are white. Therefore, [it is probable] all the beans from this bag are white." (3) "Abduction: All beans from this bag are white. These beans are white. Therefore, [it is plausible] these beans are from this bag." Notice the conclusion of this abductive argument is an explanation for why the beans are white; hence many scholars call abduction "inference to the best explanation" (Douven, 2017).

epistemic culture (Knorr Cetina, 2009, pp. 2-3).[2] Here I intend the latter because I am emphasizing an epistemic activity – inquiry. Therefore, the participants in inquiry that I will discuss here represent different epistemic paradigms; they may or may not have jobs in the same departments, publish in the same journals, or hold the same degrees.[3]

"Inquiry." Secondly, by "inquiry," here, I mean any systematic process of answering a well-formed question.[4] This includes but goes beyond research to include formal evaluations and investigations. Leedy and Ormrod (2005, p. 2) state, "*Research* is a systematic process of collecting, analyzing, and interpreting information (data) in order to increase our *understanding* of the phenomenon about which we are interested or concerned" (emphasis added). However, people use interdisciplinary arguments to answer questions for other purposes than simply to increase understanding. For instance, interdisciplinary evaluations use systematic processes to answer questions about the "merit, worth, and value" of something or someone (Scriven, 1991, p. 1), questions which require not only understanding but also evaluative judgment. Another example of interdisciplinary inquiry is crime investigations, which do not try to understand general phenomena but rather specific instances of them; nevertheless, law enforcers rely upon systematic collection of evidence interpreted through many disciplines, such as physiology, physics, psychology, and sociology. In short, we engage in interdisciplinary arguments for reasons including and exceeding mere understanding. Thus, I use the term "inquiry" rather than "research" to emphasize this broader scope.

"Interdisciplinary Investigators." Interdisciplinary investigators are knowledge workers engaged in interdisciplinary inquiry. They might be academic researchers, professional evaluators, program staff, law enforcement officers, or others, and they may work alone or in groups. Regardless of their differences, many interdisciplinarians share the common goal of generating good explanations for how and why certain problems arise and continue. By understanding root causes and linkages, these practitioners may be able

[2] When emphasizing the "socio-institutional" definition, we see that in some disciplines, such as economics, differences in perspectives within the socio-institutional discipline may be quite small, while in others, such as philosophy, the differences may be huge.

[3] Not sharing these socio-institutional contexts often – but not always – makes interdisciplinary reasoning more difficult, but I will leave these complications for future discussions.

[4] In this article I do not need to restrict my definition of inquiry to that proposed by John Dewey, although his definition does work here: "Inquiry is the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified 'Whole' " (Dewey, 1938, pp. 110-111).

to generate effective solutions. They pursue solutions by approaching their respective problems from various disciplinary perspectives, insights from which they then attempt to integrate to answer the question driving their inquiry.

The Gap in Interdisciplinary Theory

To date, interdisciplinary inquiry has rarely been framed as a "reasoning" or "argumentation" task, leaving core issues related to reasoning relatively under-theorized. This is not to say no one has done any work about how interdisciplinarians think, but they have not framed it as argumentative reasoning and have therefore not drawn on the resources from this other field. As discussed above, interdisciplinary inquiry is unique among other kinds of inquiry in aiming for answers that integrate insights from multiple disciplines. Scholars of interdisciplinarity have described this epistemic goal in various ways related to but not directly labeled reasoning or argumentation. Examples include knowledge synthesis (Bammer, 2013; Boix Mansilla, 2010), knowledge integration (Holland, 2013; Klein, 2011; Repko, Szostak, & Buchberger, 2016), interdisciplinary cognition (Derry, Schunn, & Gernsbacher, 2013; Nikitina, 2005), interdisciplinary learning (Augsburg & Chitewere, 2013), integrative learning (Leonard, 2012), integrative thinking (Abbott, 2012), interdisciplinary thinking (Dreyfuss, 2011), and multicultural discourse (Holbrook, 2013). The explanations of each yield slightly different sets of insights and recommendations for the proper conduct of interdisciplinary inquiry. Some focus on the abstract, epistemological structure of disciplinary knowledges (e.g., knowledge synthesis) while others emphasize their concrete communication practices (e.g., multicultural discourse). These are all real, important processes at work in interdisciplinary inquiries. However, I believe we have not been quite as explicit as we need to be about *why* interdisciplinarians use the tools of integrative thinking, learning, and discourse to achieve integrated, synthesized knowledge. We need to talk about the goal of understanding.

If interdisciplinary inquiry is to generate understanding, it requires investigators to know why the final inference is reasonable. That is, these inquiries require epistemic justification. The structure of epistemic justification is captured in arguments, and arguments are constructed through reasoning. Reasoning, in turn, is accomplished through many psychological and social processes, such as the thinking, learning, and discourse processes mentioned above. Therefore, if we want to explain how interdisciplinarians come to understand their synthesized knowledge, we must not only explore how they think, learn, and hold discourse; we must also explore how these processes support reasoning and, in turn, the arguments underwriting justified belief in

interdisciplinary knowledge. To study reasoning and argumentation, we need theories from reasoning and argumentation studies, yet these resources have been largely absent from the interdisciplinary literature. At the same time, interdisciplinarity has not often been studied by argumentation theorists. Those working in each field stand to benefit from those working in the other.

Argumentation and Reasoning Studies

Overview. Of course, humans have been thinking about thinking for millennia. Argumentation and reasoning studies as an academic field, however, is relatively new. It emerged in Western universities in the 1970s. Many teaching philosophers realized the traditional Western university approach to teaching critical thinking was not very successful in preparing students to make rational decisions in daily life. This is because the traditional approach forced students to memorize deductive systems using symbols in proofs: It was formal logic. To make critical thinking more accessible and relevant to the average student, these teaching philosophers developed an alternative: informal logic. Informal logic is concerned with arguments and reasoning as they live in their natural habitats beyond the symbolic logic textbook (Johnson, 2014).

Soon, scholars from non-philosophy fields such as artificial intelligence, human and animal psychology, and rhetoric joined their ongoing studies of reasoning to this informal logic movement (Groarke, 1996). This brought informal logic and argumentation studies together in a heterogeneous academic field called argumentation and reasoning studies, a field that has begun to institutionalize the ancient quest to understand real-life reasoning. Because these scholars study reasoning in many different settings, there are many different approaches, theories, and frameworks involved. They would all agree, however, that they are trying to understand the processes of making inferences in naturalistic settings. But not many have studied how reasoning proceeds in interdisciplinary inquiries.[5]

The Gap in Argumentation Theory. Most theories and case studies in the argumentation literature have focused on disciplinary settings, such as law (Bench-Capon & Prakken, 2010), advertising (Wierda & Visser, 2012), medicine (Pilgram, 2012), and archaeology (Shelley, 1996), or they have focused on everyday, common-sense logic (Johnson, 2014). The resources that have been developed in these disciplinary settings may not apply to interdisciplinary

[5] Unfortunately, the argumentation and reasoning studies field mainly cites Western (occidental) scholarship. There are many non-Western theories of reasoning that would benefit this field and ought to be included. But whether the field becomes more pluralized or not, it will provide great value to those doing interdisciplinary work.

argumentation. Interdisciplinarity offers a reasoning context that argumentation theories ought to be able to illuminate if they are comprehensive theories of argumentation. However, it is not yet clear that argumentation theories apply to interdisciplinarity because interdisciplinary inquiries have been relatively unstudied by most of those in the argumentation field.

There are two exceptions to this gap between interdisciplinarity and argumentation research. First, Michael Hoffmann (2011) has studied interdisciplinary argumentation using argument mapping software, demonstrating that the software aids in argument reconstruction and evaluation in this context. Second, Louise Cummings (2012) has argued that fallacy analysis would be useful in the interdisciplinary field of public health. However, neither study addresses particular *kinds* of interdisciplinary reasoning, such as interdisciplinary abduction. While novel and useful, these two studies are merely two pillars in the potential bridge of research spanning the gap between interdisciplinarity and argumentation studies. To aid bridge-building from both sides, I use the example of abductive reasoning to show how each field can benefit from the other.

The Example of Abduction. In this article, I complement Douglas Walton's (2004, pp. 240-242) dialogical model of abduction with a new model abbreviated PEPR, which stands for Pattern Recognition, Explanation Imagination, Pattern Matching, and Report Publication. Walton's model lends itself to use in interdisciplinary contexts because interdisciplinarity can be understood as a dialogue between and among disciplines (Holbrook, 2013). In fact, even when single investigators engage in interdisciplinary inquiry on their own they are bringing various disciplinary contributions into conversation with each other.

In Walton's model there are two main conversational roles: the respondent, who is seeking the explanation in answer to the inquiry, and the proponent, who offers candidate explanations for consideration. In interdisciplinary abduction, these two roles are played by various disciplinary representatives, and their contributions may be expressed in print, in the internal thoughts of a single investigator, or in the verbalizations of multiple collaborators. As the dialogue progresses, the sequence of exchanges may cause the respondent's and proponent's perspectives to evolve, e.g., to shift, integrate, or otherwise transform. For example, a sociologist may add agricultural causes to her explanation of landscape governance so her perspective becomes something more like rural sociology. Then the proponent becomes rural sociology. This is the nature of interdisciplinary inquiry: We begin with disciplinary inputs and, through progressive exchanges, end with interdisciplinary outputs (O'Rourke, Crowley, & Gonnerman, 2016). Walton's model emphasizes the dialogical nature of this synthesis as it unfolds in a conversation.

I want to emphasize that Walton designed his model for collaborative contexts, and I am expanding its use to inquiries conducted in the mind of a single individual as well. I believe this expansion is justified because even when alone, we engage in discourse; it is impossible to remove ourselves from distributed networks of knowing, because our own thoughts upcycle the thoughts of others through the artifacts they create (Bakhtin, 1981; Fenwick, 2010). Individual investigators dialogue with other perspectives by reasoning with themselves. We ask questions, play devil's advocate, and challenge our own conclusions. This is necessary for conducting an inquiry systematically. In the absence of a real-time participant, we provide that role by taking others' perspectives, and our own may also evolve. In interdisciplinary inquiry, these different views belong to different epistemic communities, sometimes represented by real-time participants and sometimes by artifacts such as books. Dialogue with representatives of other perspectives is required throughout the interdisciplinary process – whether the dialogue involves real-time others or not – and therefore Walton's dialogical model is appropriate for interdisciplinary contexts regardless of the number of participants. However, to make Walton's model work well, for both individual and collaborative interdisciplinary contexts, we need to adapt it using insights from interdisciplinary theory about the nature of disciplinary data.

Walton's dialogic model proposes four phases of abductive conversation: (1) Dialogue Setting, (2) Formation of Explanation Attempts in Dialogue, (3) Evaluation of Explanations, and (4) Dialogue Closure. The first phase of Dialogue Setting establishes what others have called the "common ground" of the inquiry (Beers, Boshuizen, Kirschner, & Gijselaers, 2006; Campolo, 2005; Davidson, 2002; Repko, 2011). Contents of this common ground include (a) the type of dialogue (e.g., legal abductive? scientific abductive?), (b) the presumed data and shared understanding of the data, (c) defining the initial perspectives that will fill the roles of respondent and proponent, and (d) articulating which speech acts and commitments the contributing perspectives/participants are permitted to make (e.g., Are universal claims allowed? Stories? Only peer-reviewed literature?). According to Walton's model, the respondent then begins the second phase, Formation of Explanation Attempts in Dialogue, with (a) an initial request for explanation to which (b) the proponent gives an initial reply. This alternating sequence continues until terminated when the participants exhaust either the logical or practical possibilities, resulting in (c) a set of candidate explanations. In the third phase, Evaluation of Explanations, each candidate explanation is evaluated for (a) its own plausibility and (b) its plausibility compared to the other candidates. A single candidate is then chosen as the "best explanation," perhaps for further study. In the fourth and final phase of Dialogue Closure, the participants review their work: How complete

has the inquiry been? Are we really ready to close the dialogue now? If so, how much trust can we place in our knowledge? Are we willing to be wrong if contradicting evidence comes forward?

The Gap this Paper Seeks to Fill

Here I ask, *What are the unique challenges of interdisciplinary abduction?* Answering this question will help us develop abduction and interdisciplinary theories directly. Indirectly, answering this question will also illustrate the benefit of integrating the two fields of interdisciplinary and argumentation studies.

I train my scope on the abductive process itself, which can be viewed as an input-process-output (IPO) process. On such a view, the inputs to abduction are the phenomenon under study, the study tools available, and the inquiry participants, who each come with their own perspectives. Then begins the process of abduction proper, which Walton says begins with defining the inquiry's question (Dialogue Setting) and ends with reviewing the answer (Dialogue Closure). The answer then defines the inquiry's output, which may be more understanding, evaluative judgment, or some other product. My focus in this article is noting how features of the inputs, process, and outputs make interdisciplinary abduction uniquely challenging. This focus combines the perspectives of argumentation and reasoning studies with interdisciplinary theory; the former names the input, process, and output entities while the latter describes the unique features of these entities in interdisciplinary settings.

By analyzing two extended cases cast in Walton's terms, I argue Walton's model is necessary but not sufficient for understanding and dealing with the unique challenges of interdisciplinary abduction. I propose that we also use the PEPR model to help us focus on the objects to be explained while we lean on Walton's model to understand the subjects doing the explaining. Such a stereoscopic view will identify more of the difficulties and opportunities facing interdisciplinary investigators and therefore – like three-dimensional magnetic resonance imaging in cancer treatment – allow us to target more effective interventions to support interdisciplinary inquiry.

Disciplinary vs. Interdisciplinary Abduction

To give a sense of the differences between disciplinary and interdisciplinary abduction, I'll apply Walton's model first to a disciplinary, then to an interdisciplinary case of inquiry.

A Disciplinary Example

Phase 1. Dialogue Setting. In 2010, I began a research project in forest hydrology, a single discipline with clear ontology, methodology, and axiology. The data had already been collected, and my task was to answer this research question: What fraction of forest precipitation escaped every year through evaporation versus transpiration (i.e., when trees exhale water vapor)? When I ran the calculations, the answer came up positive. Positive numbers indicated an increase in certain isotopes that mark evaporation – as if there was no loss of evaporated water as had been hypothesized, but rather a gain. Naturally, I abandoned my original "what" question to pursue a "why" question: Why did I get a positive answer where I expected a negative one?

Phase 2. Formation of Explanations. I looked for a plausible explanation: Were my data or calculations incorrect? Were my assumptions wrong? Was my reasoning fallacious? Could there, in fact, have been an addition of evaporated water? If so, how? Why? I returned to the basic theory of isotopes and discovered a possible mechanism that had never been reported in this type of forest, so no one had ever bothered to look for it. This temperate forest seemed to be recycling water vapor.

Phase 3. Evaluation of Explanations. I checked for calculation errors: None. My assumptions were all confirmed by direct data or similar studies. I checked my inferences; they were solid. Finally, my collaborators and I ran calculations and thought experiments on the last explanation that revealed the implications of the new mechanism. Our tests reproduced the observed positive answer *and* other patterns in the larger dataset.

Phase 4. Dialogue Closure. The article was published in a disciplinary journal (Green, Laursen, Campbell, McGuire, and Kelsey, 2016). But, of course, it only reported on a case study, and we weren't able to specify exactly what parts of the forest were doing the water recycling. Case studies generalize only if theoretical assumptions actually obtain, and colleagues haven't determined that yet. Therefore, although my study closed my particular argument, the larger dialogue about the mechanism is still open – as is the original descriptive dialogue I abandoned about evaporation and transpiration.

A Contrasting, Interdisciplinary Example

Now, I'll apply Walton's dialogic model to an interdisciplinary case of inquiry and show the model does not capture key differences between this case and its disciplinary counterpart.

Phase 1. Dialogue Setting. In 2011, I started a single-investigator,

interdisciplinary project studying social-environmental systems. My original research question was given to me: What are the characteristics of the bioenergy information networks in this county? I value treating my subjects as agents rather than sources, providing actionable and resilient answers, and finding those answers by integrating insights from multiple perspectives. I rejected the original research question as against these values, but then struggled to find a new question that supported them. Every theoretical perspective I examined, of course, prompted me to ask a different question. Finally, after a year, I decided on this: What is the adaptive, collaborative management (ACM) capacity of the local resource experts, and what might explain that level of capacity?

My source theories included evaluation, forestry, social network analysis (SNA), governance, and resilience. Thus, I next collected social network data about the information patterns of the experts in the networks, observations of their interactions in meetings, interviews about their management roles, and observations of the physical landscape. These were very different kinds of data; they included relational matrices, field notes, interview notes and transcriptions, and photos, each collected and/or analyzed from a different disciplinary perspective with different tools. Each dataset contained its own patterns, and these combined to form many more patterns among all of the datasets. I was quite lost with my multiple source theories acting separately. After another six months, I managed to integrate them into a new theory that told me I should look at one particular pattern to assess ACM capacity. At this point, my interdisciplinary project looked very similar to my disciplinary project: In both I had amassed piles of patterns but selected only one to explain.[6]

Phase 2. Formation of Explanations. The pattern I selected in my interdisciplinary project evinced a rigid division of information and work between forestry and agriculture experts. That is, they were not interacting so as to affect each other's management decisions. There were many viable ways to explain this pattern: Certain network measures predicted others; the landscape topography lent itself to this division; some experts had been involved longer than others; the governing committees played power games; and a historic policy event had initiated a series of events that interacted with these other factors.

Phase 3. Evaluation of Explanations. How was I to infer the *best* explanation among these? Again, as an interdisciplinary scholar, I prioritize explanations that integrate multiple chains of reasoning from different

[6] Both of my examples in this article are confirmatory studies; that is, which patterns were worth observing were determined based on theory prior to data collection. Exploratory studies may also seek inferences to the best explanation, but such studies would work differently than confirmatory studies. Exploratory studies would have an extra step at the beginning for determining which patterns were important to observe.

disciplines. I assumed the best explanation would integrate many of the candidate explanations. Therefore, I decided not to choose only one among the many viable explanations because this would have reverted to a disciplinary approach; each of the viable explanations required a different discipline to justify it, and I knew each disciplinary explanation was only partial. As an engaged scholar, I also prioritize explanations that are useful to local people, but some explanations provide no useful insights for local change. For example, in this case, we had no local officials who could understand the algorithms behind the social network analysis (SNA) measures that predicted each other, and some of the variables in the algorithms were not actionable. Thus, an explanation based purely upon SNA was not the best explanation.

I developed an argument I presented as a story that combined most of these explanations in such a way that they could all be true and understandable. The story showed how each of these key explanations – sometimes singly, sometimes together – caused various plot twists and in the end yielded the observed division between forestry and agriculture, which suggested an explanation for their merely moderate capacity for governing their multifunctional landscape. This is not, of course, the only story one could weave from my findings, so it may not in fact be "the absolute best" explanation. Nevertheless, it was satisfactory; it was the best given the constraints of the project.

Phase 4. Dialogue Closure. A report on the work was published, and my community stakeholders found new ways to think about their self-governance (Laursen, 2013a; Laursen, 2013b). As with my disciplinary example, the local dialogue was closed with this study, but the larger dialogue continues about the extent to which the story I identified may be playing out similarly in other times and places.

Summary of Examples

Walton's four-phase model worked well in capturing the major turning points in both the above examples of abduction. There were definite phases of Dialogue Setting, Formation of Explanations, Evaluation of Explanations, and Dialogue Closure. However, the two cases differed in their details within each of these phases, and Walton's model is not specific enough to distinguish these details. As these examples show, then, Walton's model doesn't quite give us the conceptual resources we need to understand and enhance interdisciplinary abduction.

Table 1: Challenges to Abductive Reasoning in Disciplinary and Interdisciplinary Cases

	Disciplinary Cases	**Interdisciplinary Cases**
1. Dialogue Setting	**Short & easy**	**Long & arduous**
Type of dialogue	*Likely agreement*	*Possible disagreement*
Proponent(s)	Colleagues using one perspective	Colleagues using multiple perspectives
Respondent(s)	Investigator(s) using same perspective as proponent(s)	Investigator(s) using different perspective from proponent(s)
Common Starting Points	*Consensus on starting points achieved quickly & easily*	*Consensus on starting points achieved through extended struggle*
Question	Easily agree on question of interest	Perhaps strongly dispute question of interest
Presumption	Easily agree on presumed data & salient patterns	Perhaps strongly disagree on presumed data & salient patterns
Common Understanding	*Large amount of common understanding*	*Small amount of common understanding*
Proponent's Understanding	Mostly the same as the respondent's; small gap	Mostly different from the respondent's; large gap
Respondent's Understanding	Mostly the same as the proponent's; small gap	Mostly different from the proponent's; large gap
Empathy	Much more	Much less
Shared Language	Much more	Much less
2. Formation of Explanations	**Well-structured search**	**Ill-structured search**
Initial Question	Immediately salient to proponent	Perhaps not immediately salient
Initial Answer	Immediately salient to respondent	Perhaps not immediately salient
Repeated Q&A Sequence	Likely to be linear with relatively small scope; well-structured	Likely to be complex with relatively large scope; ill-structured
Sequence Termination	Likely agreement supported by traditional epistemic values	Likely disagreement supported by competing epistemic values

	Disciplinary Cases	Interdisciplinary Cases
3. Evaluation of Explanations	**Clear & closed-ended**	**Fuzzy & open-ended**
Baseline Plausibility	More easily determined due to fewer variables	Less easily determined due to more variables
Overall "Best" Explanation	Likely agreement supported by traditional epistemic norms; more tendency to aim for a global "best"	Likely disagreement supported by competing epistemic norms; more tendency to "satisfice"
4. Dialogue Closure	**Quicker, easier, & broader in scope**	**Slower, harder, & narrower in scope**
Judgment of Completeness	Much easier to determine completeness	Nearly impossible to determine completeness
Reconsideration of Closure	Less likely	Always likely
Knowledge Base Assessment	Likely consensus and higher certainty	Likely disagreement and lower certainty
Openness to Defeat	High, but constrainable so scope of findings is potentially broader	Very high, and hard to constrain so scope of findings is seen as limited

Challenges for Interdisciplinary Abduction that Complicate Walton's Model

Table 1, while long, is actually a shorthand and probably incomplete list of likely differences between disciplinary and interdisciplinary processes of inquiry in the four phases of abductive argumentation. It reflects hypotheses based on a combination of my personal experience and theories of interdisciplinarity from the literature. They should be tested against empirical data, yet they serve well enough as the basis for further discussion here. The first column in Table 1 lists the important features of each phase as Walton identified them in his 2004 book. The second and third columns mention ways interdisciplinary abduction is likely more confusing, disputed, and ill-structured than its disciplinary counterpart. The contents of the table reveal a pattern of differences that Walton's model can't address. Below, I unfold these differences and show that they arise from what is arguably the defining feature of interdisciplinary projects: the diversity of the data they engage. To clarify these differences, I then introduce a complementary version of Walton's model that is phrased in terms of the objects to be explained – data patterns – rather than the subjects doing the explaining – the proponents and respondents, in Walton's terminology.

Phase 1: Dialogue Setting is Long and Arduous

Data patterns are the result of a long, arduous first phase I will eventually call Pattern Recognition. This phase begins simply with a phenomenon under study, some study tools, and some curious participants. With these inputs, participants agree upon a question to drive their inquiry, they collect data to answer that question, and they summarize the data into patterns that beg for an explanation. In interdisciplinary abduction, the (1) nature of the phenomenon under study and the diversity of (2) tools and (3) participant perspectives make this first phase perhaps the most difficult.

First, the nature of the phenomenon under study influences the tools and perspectives used to study it. The materiality of the phenomenon limits the tools we can use to collect data from it; after all, one cannot collect electron bubble tracks from a social network. Moreover, interdisciplinary inquiries often focus on complex phenomena. Here I use the term "complex" to refer to "components actively connected through predominantly nonlinear relationships" (Newell, 2001, p. 9). Complex phenomena are tricky to understand. When interdisciplinarians want to study them, their complexity adds many options for data to track and explain.

Second, disciplinary tools have a wide variety of formats made from many kinds of materials. These differences matter because they create data in many formats and materials. The material differences layer atop inquiry challenges due to the phenomenon itself. For example, due to the nature of both the phenomena and the tools used, GIS data have columns containing spatial coordinates, timeseries data have columns containing timestamps, and interview data have columns of verbatim text. It is not obvious how to integrate those datasets, especially when each has a different set of standards for how missing data, mistakes, and aggregation are handled.

Third, the deep differences in disciplinary perspectives create a large gap in shared understanding from the beginning of the phase Walton calls Dialogue Setting. Participants not only may not fully understand each other's languages; they may even disagree on what the original research question is; that is, they may disagree about the type of abductive dialogue they are having. For example, a network analyst might have framed the question central to my second study described above this way: What network variables predict collaboration outcomes? But a forester might have asked, Which ecosystem features are governed by which management policies? The network analyst wants to have a quantitative abductive dialogue appealing to network entities through statistical standards of evidence. The forester,

however, thinks they should have a policy-based abductive dialogue that will appeal to policy entities through pragmatic standards of evidence. Based on their diverse training, researchers in interdisciplinary inquiries are likely to ask different research questions and therefore want to collect and analyze different data using different methodologies (Eigenbrode et al., 2007; Leedy & Ormrod, 2005; Norgaard, 1989; Palmer, Kramer, Boyd, & Hawthorne, 2016)**.** Coming to consensus on which questions and data will be pursued can require extended dialogical struggle depending on how deep the differences in epistemologies, ontologies, and axiologies are (Laudan, 1986; Patterson & Williams, 2008)**.** Choosing my interdisciplinary research question took an entire year. Indeed, similar lengthy time investments are common at the start of interdisciplinary projects (National Research Council 2005; 2015).

But even after a research question is chosen, a study is designed, and the dataset is collected, the abductive dialogue has not yet been fully determined. At this point, the investigators have a set of data points, and likely these data points are of different types (e.g., spatial, temporal, qualitative). Nevertheless, there is nothing to explain (in the next phase of the project) until those points have been summarized as forming one or several curious patterns. Investigators do not try to explain separate data points. Rather, they wonder why this data point looks different from the others or why these data points indicate a trend: In other words, they are looking for patterns. Here again, differences in research perspectives associated with different disciplines may inhibit shared understanding and consensus about which patterns are (a) real, (b) salient, and (c) worth investigating.

Granted, the research question will narrow the patterns of interest but often not enough for researchers to decide which patterns to explain. Other selection criteria must be worked out. Which pattern is eventually chosen for further study may depend upon negotiation of further cognitive, pragmatic, and social values each investigator brings to the project (Douglas, 2009; Eigenbrode et al., 2007; Elliott, 2017; Hall & O'Rourke, 2014). One values-based choice is choosing what standards of evidence to use when drawing conclusions about the reality of a pattern based on limited data; one may require more evidence if the risk of being wrong is very high, such as declaring a chemical to be safe when it's not (Douglas, 2009; Elliott, 2017). Another values-based choice is choosing which real patterns are worth further study; do you choose to develop the one more likely to get published, be understood by citizens, or match funder interests? In disciplinary inquiry, these epistemic and non-epistemic values are relatively well-defined, albeit implicitly (Eigenbrode et al., 2007). But in interdisciplinary cases,

the relevant values may not only be implicit but may also differ across disciplinary lines. This often requires negotiation of values not only among types of *values* (e.g., pragmatic, social, epistemic) but also among types of *investigators* (e.g., sociologists, physicists, philosophers), who each may hold different positions about these different types of values.

For example, both sociologists and physicists hold epistemic values about "interesting patterns" that they must balance with pragmatic concerns, such as timelines for publication. But in addition, a sociologist may believe an "interesting pattern" is epistemically complicated while a physicist may believe it is epistemically simple. An inappropriate, biased way of handling these different values would be to ostracize the sociologist and never consider complicated patterns to be real or worthy of study. An appropriate way to negotiate these values might include an attempt to come to consensus or compromise and to report the negotiated standards of pattern choice in a section of the write up entitled "Conceptual Framework." Declaring significance – what is worthy of note – within a discipline can be difficult, and it can be even more difficult in interdisciplinary contexts because there are many standards of evidence that might apply and they can be difficult to compare and compromise upon (Eigenbrode et al., 2007).

The above-mentioned differences (in phenomena, tools, and perspectives) are together manifest in the *data* presumed to ground the inquiry (Benda et al., 2002; Kuhn, 1970; O'Rourke, Crowley, Eigenbrode, & Wulfhorst, 2014; O'Rourke, Crowley, Laursen, Robinson, & Vasko, 2018). The data therefore become both instantiations of and proxies for all that is unique about interdisciplinary inquiry. Data differences go much deeper than the split between quantitative and qualitative approaches, both of which can express the same perspective (e.g., a structural view of social capital can be expressed in both a quantitative matrix and in a narrative). Interdisciplinary data collection can be like going to the supermarket, and data analysis can be like trying to compare apples and oranges. At the supermarket, the cashier uses the same scale to weigh all produce. Some tool like that is needed to interface different kinds of data in interdisciplinary inquiry. But unlike a scale, a mere mechanical transliteration (e.g., qualitative to quantitative) will not be enough; meanings must be negotiated and translated much as one interprets *The Iliad* in an attempt to reconstruct the history of Troy. The interpretation process begins by identifying the shared features of the data types to be combined, but what they share may not be obvious without a perspective change. A perspective change reframes the data in a way that helps align meanings that once seemed incommensurable.

Phase 1 Difficulties Exemplified. Because interdisciplinary inquiry

contains so much data complexity and diversity from the start, settling on the relevant data patterns may require layers of integration before explanations can even be considered in phase 2. In my interdisciplinary case I had four data types and innumerable data points and patterns. These arose from my initial question about adaptive capacity, which took a year to define based on the complex phenomenon I was studying and the diversity of tools and perspectives available. But adaptive capacity can be observed in many ways. To narrow down the patterns to consider, I took a step upstream and integrated my five source theories (representing five disciplines) into a single theory that indicated a single pattern to look for. However, that pattern would only be visible once it emerged from the integration of several kinds of data. So, I began integrating my datasets point by point. For example, I paired an interviewee's quote with an observation I jotted in my field notes at a committee meeting between the local politicians and the experts: "Theme: stick to the agenda. Do not offend." I reasoned that the employees' fear of retaliation from offending their supervisors squelched any non-authorized collaboration among the experts. But I also paired this data point from my notes with a photo I had taken of the landscape that showed hard edges between forests and croplands. Together with other points, these formed a pattern of divisive policies. There were many other such examples of data combination and resulting patterns. I couldn't explore them all; I had to choose one or a few patterns to attempt to explain.

In my work, I knew which pattern I was looking for, but this is not always the case. As different data sets are woven together, perhaps point by point, the number of possible patterns increases dramatically. Moreover, just as with comparing apples and oranges, the patterns one notes depend on what one is looking for. Size? Weight? Appearance? Interdisciplinarity provides many different perspectives on a problem. Thus, for every possible combination of data, there is also a permutational set of ways to examine it for patterns. The total search space is vast, and each investigator can only see part of it, creating a huge logistical problem that can manifest in communication, epistemic, and cognitive errors as well as in insights.

To proceed from what is found in this vast search space, investigators must choose one or a few patterns to try to explain in phase 2. Selection is necessary because (a) some patterns are spurious, and (b) project resources are limited. Interdisciplinary investigators might choose one pattern that has already integrated several disciplinary perspectives, or they might choose several disciplinary patterns to try to integrate through the explanation process in phase 2. In my interdisciplinary case, I chose a single interdisciplinary pattern, and I judged it was worth explaining

based on several of my epistemic and non-epistemic values: theoretical coherence, utility of the findings to stakeholders, and ease of analysis; or, as my colleague put it, "whatever was most interesting and obvious." I chose the pattern showing lack of collaboration between forestry and agricultural experts. Not everyone would have chosen the same way; again, there are many ways to observe adaptive capacity. Looking back, I can see I didn't fully understand how my values were driving my theorizing, and I had a hard time choosing and defending my integrated theory because of this lack of clarity. Training to increase clarity about such selection is important; it can help interdisciplinarians understand what's at stake in each phase of abduction, even and maybe especially in this first phase.

Phase 1 Renamed: Pattern Recognition. In addition to "Dialogue Setting," this phase can also be understood as the Pattern Recognition phase. This name emphasizes that although the distal target is the phenomenon – we want to understand something in the world – the proximal objects to be explained are data patterns – what we've *observed* about the world – and therefore, the dialogue is subject to all of the challenges related to pattern recognition. These challenges include interfacing different data types, identifying implicit biases, and misunderstanding what colleagues propose. Such re-framing and re-naming of this phase makes way for insights from cognitive psychology, rhetoric, computer science, and other fields that study human pattern recognition. With Walton's model alone, it is not clear that these apply.

Phase 2: Formation of Explanations is Ill-structured

Once a pattern has been recognized and selected for explanation, it is time to form candidate explanations. This phase of a project is also more difficult for interdisciplinarians compared to their disciplinary counterparts. Interdisciplinary investigators are likely to *disagree* on what counts as an explanation as well as what makes an explanation plausible (a) in itself and (b) compared to others. In fact, investigators may not even be able to know what determines plausibility in many of the complex problems tackled by interdisciplinary inquiry (Bammer, 2013, pp. 63-76)**.** The ensuing brainstorm may therefore cover many domains and types of explanations. There are few logical restrictions on which disciplinary explanations might be true simultaneously and how they might be integrated into a coherent explanation. Any narrowing of scope that was achieved in phase 1 may again explode in phase 2 with the number of possible explanations, and this is due not only to the power of the human imagination but also to the math

of permutational combination. There is no single "right" way to integrate disciplinary explanations; the imaginative process is often ill-structured in interdisciplinary inquiries.[7]

Phase 2 Difficulties Exemplified. My governance project exemplified this ill-structured proliferation of explanations. Even with some simplifying assumptions, the proliferation can be overwhelming. Suppose there were at least five different processes driving adaptive capacity, as revealed by the five different disciplines I used (viz., evaluation, forestry, social network analysis, governance, and resilience). Suppose also that these processes didn't overlap: no simultaneous processes. Suppose lastly that integration could mean a mere juxtaposition of processes (which is a *very* simplifying assumption). Order matters when assembling the pieces of a causal explanation because causality is unidirectional, so we are looking at permutations not combinations. These assumptions indicate there were (at least) ${}_5P_5$ choices for viable explanations of the forestry-agriculture divide. That's $5!/(5-5)! = 5! = 5x4x3x2x1 = 120$ different integrative explanations I should have evaluated to find the best explanation for my chosen data pattern.

It is more aligned with interdisciplinary theory, however, to say that integration requires more than mere juxtaposition but also something like multiple causation or simultaneity. If we continue this thought experiment, supposing processes can overlap in any number of layers (viz., 2, 3, or more simultaneous processes), the math approaches infinity because the permutation goes recursive; each possible permutation of layers adds to the number of possible layers, which adds to the possible permutations of these layers, *ad infinitum*. The first round of 120 was overwhelming enough, but infinity is impossible to explore. Yet, in principle, the quest for the best interdisciplinary explanation of a complex phenomenon should consider the entire search space to find the globally optimal explanation. What should interdisciplinarians do? While an exhaustive search isn't feasible, an investigator ought to conduct the search systematically to counteract cognitive and/or unjust biases, a process that will help ensure the best possible explanation is among those considered, even if this "best possible" is not the global but only a local optimum. At the same time that one must be systematic, one must also be creative. It takes wisdom and insight to focus one's limited resources on a promising section of the infinite, ill-structured

[7] See work by Rand Spiro and others on problems in ill-structured domains, such as socio-environmental issues (Feltovich, Coulson, Spiro, & Dawson-Saunders, 1992; Jacobson & Spiro, 1995; Kulinich, 2016; Miyashita, 2002; Spiro, Coulson, & Anderson, 1988; Spiro, Feltovich, Jacobson, & Coulson, 1992).

explanation space.

But even with a wisely narrowed explanation space, it is still impossible to test the plausibility of every explanation imagined within that space. Rather, of the many explanations imagined, the few explanations that make it to phase 3 for plausibility testing are chosen, as with Pattern Recognition, based on a variety of values that participants must negotiate. For instance, an investigator may favor the simplest process, or the one with the most external evidence, or the one that provides leverage points for action. Again, these values are often more similar among those who share disciplines than among those who don't, which makes interdisciplinary abduction harder than its disciplinary counterpart.

Phase 2 Renamed: Explanation Imagination. To emphasize the creativity involved in phase 2, the phase Walton calls Formation of Explanations, I prefer to call it Explanation Imagination. This label focuses our attention on the factors that influence our imaginations as well as what we think counts as an explanation. The main factor that is different between disciplinary and interdisciplinary Explanation Imagination is the diversity of data driving the imagination process in the latter case, which also changes the number and kind of relationships that can be imagined among these data (Bennett, 2011). Diversity of data also influences which explanations can feasibly be carried forward into plausibility testing in phase 3.

Phase 3: Evaluation of Explanations is Fuzzy and Open-ended

Because the explanations imagined in phase 2 of an interdisciplinary inquiry are likely very different from one another and possibly novel, it is not clear how to evaluate the plausibility of each or how to compare that plausibility to that of the other candidates. The evaluation procedure is fuzzy, and I mean this in both its colloquial and technical senses. Colloquially, it is simply unclear how to judge the adequacy of interdisciplinary explanations. Technically, such evaluation requires fuzzy logic – allowing infinite degrees of truth and group membership – to accommodate the inherent uncertainty and ambiguity of meaning invoked in interdisciplinary explanations. Steven Gray, Fikret Berkes, and others have used fuzzy logic to integrate interdisciplinary knowledge in several kinds of socio-environmental problems (F. Berkes & Berkes, 2009; S. A. Gray, Gray, Cox, & Henly-Shepard, 2012; Papageorgiou, 2014). Given both kinds of fuzziness, the evaluation of explanations is rather open ended. Moreover, interdisciplinary explanations often focus on complex socio-environmental problems that have many interdependent variables, making it even harder to evaluate

the plausibility of an explanation. That is, when there are so many things going on, it is hard to tell what causes what. This uncertainty contributes to the fuzzy and open-ended nature of the explanation selection process in interdisciplinary settings.

Therefore, as with Pattern Recognition, in phase 3 investigators who hope to be effective must navigate a range of cognitive, pragmatic, and social values when choosing which explanation is the *best* explanation for the pattern that has been recognized as most worth attention. These standards must be explicated and negotiated. Investigators must determine how good the explanation needs to be to warrant reporting, which requires consideration of funder expectations, journal conventions, stakeholder needs, paradigm diversity, and many other value-laden features of the inquiry context. However, by this point investigators may well be exhausted from all the sifting and winnowing they've already done, and they may be unlikely (as I was) to take the time to explicate these value choices.

Phase 3 Difficulties Exemplified. In my interdisciplinary case, with at least 120 different integrative explanations to consider, I couldn't give each equal consideration. Some were ruled out by logic, but most were not. Unfortunately, I had no systematic process for choosing among the remainder. My choosing was influenced by values from the five disciplines I was combining, along with values from funders, stakeholders, and myself – a milieu of values so layered I couldn't explicate what was actually determining my choices. I did not have the time, expertise, or support to write more than one explanatory narrative. I'm sure that without a sorting tool, I succumbed to some biases in determining which of the 120+ explanations were viable. My result may have been satisfactory but sub-optimal.

Phase 3 Renamed: Pattern Matching. A helpful way to think about this phase of the abduction process is that it is aiming for a Pattern Match between the imagined explanations and the original data pattern (Marquart, 1990; Trochim, 1985; 1989)**.** That is, the explanations imagined in phase 2 are trying to re-create or match the pattern(s) recognized in phase 1. Sometimes this means running a real experiment and sometimes just a thought experiment. When investigators get the results of the experiment, they assess the degree to which those results match the original pattern we are trying to explain. Good explanations create strong pattern matches. A strong match has a high degree of similarity between what the explanation predicts and what we earlier observed. The stronger the correlation, the more confident we are that an explanation is real. We are even more convinced that the match did not happen by chance if the pattern we observed and matched is complicated. Interdisciplinary patterns are often complicated, so

interdisciplinary explanations that predict or reproduce these patterns can warrant strong confidence, even if this pattern match is only accomplished through a thought experiment.

In my interdisciplinary case, the explanation I generated as a narrative predicted the same ending as the ending I actually had observed: a split between forestry and agricultural experts. It was a complicated narrative, so even though I couldn't re-create the situation in real life, my thought experiment gave me strong enough confidence in my explanation to move ahead with publishing the results of my work.

Phase 4: Dialogue Closure is Slow, Hard, and Narrow in Scope

Discussion of the first three phases of the abduction process has shown why uncertainty and disagreement are often more characteristic of interdisciplinary than disciplinary projects (Bammer, 2013)**.** This uncertainty and disagreement mean phase 4, the one Walton calls Dialogue Closure, will likely be slow and difficult in an interdisciplinary project. In order to achieve closure, the investigators will need to restrict the scope of their dialogue to an explanation they have more certainty and agreement about, despite having explored a large cognitive terrain.

Phase 4 Difficulties Exemplified. In the case of my own interdisciplinary example, I felt confident stating my conclusions about what caused the split between forestry and agriculture, but I could not also explain another interesting pattern I had found: the high reliance on non-personal information sources such as websites for some expertise areas (e.g., soils) but not others (e.g., dairies). None of my contributing disciplines had quite enough to say to predict that pattern of information sources. This uncertainty forced me to limit the scope of my conclusions, avoiding any conclusions about what caused the pattern of information sources, even though I desperately wanted to theorize about the cause. I also limited comments on the role of governance policies; while governance as a field would propose that all patterns can be explained in terms of policies, forestry as the science of silviculture would deny that, pushing back and reminding governance that the materiality of trees – how and where they grow – is also essential. In my view, the goal of interdisciplinary Dialogue Closure is to be convinced one has found an explanation that allows all of the disciplinary contributions to be true in some sense or scope.[8] Finding that sense or scope can take a long

[8] The "they could all be true" test for integration differs from that endorsed by Newell: "Each discipline should contribute to that understanding, but no one disciplinary perspective should dominate it. The goal is to achieve a balance among disciplinary influences on the more comprehensive understanding" (Newell, 2007, p. 261). It is

time and a lot of effort, and sometimes it may not happen.

Phase 4 Renamed: Report Publication. In systematic inquiries such as those discussed in this article, there is almost always some report made of the findings once the dialogue is closed. The report summarizes the individual or group's position on the final questions Walton suggests be asked: How complete has the inquiry been? Are we really ready to close the dialogue now? If so, how much trust can we place in our knowledge? Are we willing to admit we're wrong if contradicting evidence comes forward? The report represents an official statement of the best explanation that is then often used as "evidence" in "evidence-based practice," which is an immensely important yet controversial strategy for addressing wicked problems (Greenhalgh & Russell, 2009). By renaming this final phase of the abduction process, calling it Report Publication instead of Walton's label, Dialogue Closure, we emphasize again the data (and phenomena) to be explained rather than the mental attitudes of the investigators. By acknowledging that interdisciplinary abduction ends with Report Publication, we clarify how interdisciplinary reasoning connects with societal and policy change through lenses such as "evidence-based practice."

Summary of Unique Interdisciplinary Abduction Challenges

The above analysis shows there are unique challenges to interdisciplinary abduction we need to articulate: disagreement on the type of abduction and particular question under consideration, disagreement on what count as legitimate points and patterns in the dataset, an ill-structured and enormous range of possible explanations, and difficulty in reporting the strength and scope of a pattern match from each of the viable explanations. All of these challenges stem most directly from the unique diversity of data in interdisciplinary inquiries. Since data diversity, in turn, stems from the inputs to abduction – the complexity of phenomena and diversity of tools and participant perspectives – no phase of the inquiry is untouched by these difficulties.

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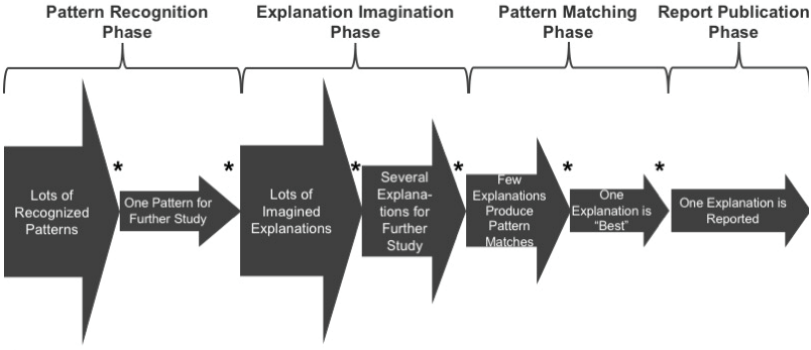
not clear that integration places limits on the relative proportions of the inputs. To use the familiar smoothie metaphor for integration (Nissani, 1995), I can have a fully blended strawberry-banana smoothie that nonetheless has many more bananas than strawberries. The "they could all be true" test allows such "unbalanced" instances to still count as integration – even good, desirable integration. There are at least two reasons to allow for such integration. Firstly, it is possible a phenomenon is driven mainly but not solely by one kind of driver and therefore its explanation would be dominated by one discipline. Secondly, explanations that emphasize a single driver or discipline may serve other communication goals for the research, such as getting uptake from policy makers or inspiring grassroots action.

A New Perspective: The PEPR Model Complements Walton's Model

While Walton's dialogic model notes the importance of data, it emphasizes the participants and leaves us with poor vocabulary for articulating these unique data-driven challenges. Without a way to describe these challenges in detail, we lack a way to describe how to meet these challenges. To address this need, I have attempted to show that there is another way to think about abduction that focuses on the proximal objects to be explained – the data – rather than the subjects doing the explaining – the participants. I propose additional names for each of the four phases that correspond to this shift in emphasis. Dialogue Setting is also Pattern Recognition; Formation of Explanations is also Explanation Imagination; Evaluation of Explanations is also Pattern Matching; and Dialogue Closure is also Report Publication. This data-driven model of abductive dialogue can thus be abbreviated the PEPR model (Figure 1).

Figure 1: The "PEPR" Model of abduction, derived from the practice of disciplinary and interdisciplinary inquiry.



* At every arrow transition there is an evaluative filter that introduces bias if not handled explicitly and appropriately.

In our quest to understand interdisciplinary abduction, focusing on the data is helpful for several reasons. First, the tangible data embody the intangible differences in research worldviews, making it easier to talk about abduction with investigators who often prefer to remain data-driven rather than reflexively aware.[9] Second, the data bring additional, material

[9] Indeed, in a Polanyian (Polanyi, 1962) or Meekian (Meek, 2011) theory of knowing, it is not possible to know something by constantly focusing on the means by which one knows it; one must eventually make the means of knowing subsidiary to the focal objects of knowing.

constraints to the interdisciplinary synthesis process that are not captured when focusing on the subjects alone. That is, the material forms of the data circumscribe the number of possible explanations and how long it might take to integrate them (Malley 2013). Example constraints include merging spreadsheets with different columns and rows and interfacing qualitative and quantitative data. Third, by phrasing abduction in terms of data, we can bring to bear findings from cognitive science about the various cognitive processes involved – recognition, imagination, and matching – since these findings are also framed in terms of data. Fourth, the materiality of data invites material tools that could help address the unique challenges of interdisciplinary inquiry. These tools should address differences in data formats as well as meanings to maintain the stereoscopic focus on objects and subjects of interdisciplinary process. Such tools might include the Toolbox Dialogue Initiative (O'Rourke & Crowley, 2013), group concept mapping (Kane & Trochim, 2007), VisPorter (Chung, North, Self, Chu, & Quek, 2014), and even simple tools like rubrics (Better Evaluation, 2013). Given argumentation's under-emphasis on data-driven difficulties, these insights from interdisciplinarity can contribute to future work in this other field.

In the other direction, from argumentation to interdisciplinarity, interdisciplinary abduction via the Walton-PEPR stereoscope reveals interesting things about integration. First, when integration is used to produce an explanation, it seems to proceed through four phases of disciplinary dialogue. In each phase, the participants are exchanging claims, reasons, and evaluations of those claims and reasons. That is, integration is constructed through a social, fallible, embodied process of reasoning or argumentation (Laursen, in press). Second, integrative explanations develop through a series of reasoning filters determined by the epistemic, cognitive, and pragmatic values of the participants. These filters show there are appropriate roles for values in interdisciplinary abduction. Third, since integrative, interdisciplinary explanations develop through the social exchange of reasons, interdisciplinary abduction – and likely all interdisciplinary inquiry – should be studied through discourse analysis (Choi & Richards, 2017). Discourse analysis can reveal conversational moves, discourse frames, rhetorical strategies, and other argumentative features inherent in human communication (Jaworski & Coupland, 2014).

In summary, Walton's model is extremely important for identifying the interpersonal necessities of interdisciplinary abduction, such as shared understanding, exchange of explanations, and conversational moves across disciplinary perspectives. But the model lacks clarity about the necessary

features of an integrated, shared, agreed-upon dataset – specifically, what it takes to recognize and match data patterns. Therefore, it will not do to adopt only Walton's model or only the PEPR model. We need both to understand the unique challenges of interdisciplinary abduction.

Here is an example of how we might fruitfully use the two models together. Say we want to understand how the Intergovernmental Panel on Climate Change (IPCC) concluded that humans are the primary cause of today's climate change (Intergovernmental Panel on Climate Change, 1990). Walton's model first asks us to identify who is asking what question based on what dataset. To do that, we need the PEPR model to remind us to look for a dataset made of patterns, not points, and to ask how different types of data were combined in that dataset. Walton's model next asks us to describe the candidate explanations; the PEPR model forces us to look closely at the imagination process that generated them. When Walton's model next prompts us to wonder how the IPCC chose the "humans are to blame" explanation among all the others, the PEPR model specifically asks how the IPCC came up with that pattern match. Finally, when we wonder how the IPCC decided they were ready to publish, Walton's model asks us to audit their concern for defeasibility and comprehensiveness, and the PEPR model focuses our attention on the framing and scope of their conclusions. The two models form a sort of stereoscope that allows us to see more dimensions to abduction. Walton points us to the who, why, and when features of an interdisciplinary abductive argument based on who is doing the explaining, but the PEPR model points us to the what, where, and how features based on the data to be explained.

This sort of stereoscope is exactly the kind of double integrative perspective desired by Angus McMurtry in his 2010 article, "Knowers and Phenomena: Two Different Approaches to Interdisciplinarity and Interprofessionalism." McMurtry describes such integrative perspectives as sociomaterial perspectives of knowing (Fenwick, 2010). Existing sociomaterial theories include communities of practice (Wenger, 1998), cultural-historical activity theory (Cole & Engeström, 1993), complexity theories (Mitchell, 2009), and actor-network theory (Crawford, 2004). The PEPR-Walton stereoscope could indicate another sociomaterial theory of knowing based upon argumentative inferences. Such a theory would focus on the material and social reasons used to epistemically justify interdisciplinary conclusions.

Conclusion

In this article, I have taken us on a journey from the perspectives of

both disciplinary and interdisciplinary inquiries that are trying to generate rigorous answers to causal questions. We saw that a key reasoning task in both kinds of inquiry is abductive inference to the best explanation, a process I first presented in terms of Douglas Walton's (2004) dialogic model of abduction. While both disciplinary and interdisciplinary inquiries can be understood through this model, sharing, as they do, some inquiry challenges, they also manifest different challenges based on the number and diversity of perspectives being integrated in the inquiry. The complex phenomena and diverse tools and perspectives in an interdisciplinary dialogue generate particularly diverse data formats and meanings. As explained above, such data diversity creates unique challenges for interdisciplinary abduction, including disagreement on the type of abduction and particular question under consideration, disagreement on what count as legitimate points and then patterns in the dataset, an ill-structured and enormous range of possible explanations, and difficulty in reporting the strength and scope of a pattern match from each of the viable explanations. These unique difficulties require considerations and vocabulary that complement Walton's, adopted in a model I named the PEPR model of abduction, abbreviating four phases of Pattern Recognition, Explanation Imagination, Pattern Matching, and Report Publication.

Given the unique challenges facing interdisciplinary investigators, future research can proceed on various fronts. First, is there a clear threshold for maximum disagreement before disciplinary perspectives and data become incommensurable? Second, how and how much must perspectives and data be integrated in order to count as an interdisciplinary inference to the best explanation? Third, how do different socio-institutional settings change the difficulties of interdisciplinary abduction, if at all? Fourth, which tools aid interdisciplinary abduction in which settings? Fifth, what is the role of abductive versus other kinds of arguments in interdisciplinary inquiries? And are these other kinds of arguments also different from their disciplinary versions? Lastly, how does the Walton-PEPR combination compare to existing models of interdisciplinary integration, even if the latter do not address abduction specifically?

This deep dive into interdisciplinary abductive reasoning illustrates the potential fruitfulness of intersecting the scholarship of interdisciplinarity and that of the field of argumentation studies. On the one hand, interdisciplinarity reminds argumentation scholars to remain attentive to constraints imposed by interdisciplinary data, which are particularly diverse in formats and meanings due to the range of phenomena, tools, and participants generating them. On the other hand, argumentation reminds interdisciplinarity theorists

that integration is a social reasoning process governed by participant values. I don't think either field has completely lost sight of data or socially-driven inferences, respectively, but they have emphasized one or the other so much that their accounts of interdisciplinary abduction would be quite lopsided on their own. Together, they provide language that maintains the necessary balance (or tension) between objective and subjective constraints (McMurtry, 2010), another example of a sociomaterial approach to integration (McMurtry, 2013).

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