Interdisciplinary Research as a Complicated System

Amaris Dalton1, Karin Wolff2, and Bernard Bekker1

Abstract
Notwithstanding the rapidly growing body of literature on interdisciplinary research, several of the crucial dynamics in interdisciplinary research systems remain poorly understood and undertheorized. To this effect we seek to provide a ‘fundamental’ ontology of interdisciplinary research systems. We principally understand an interdisciplinary research system as a complex system consisting of researchers from different disciplines that have undergone a pseudomorphosis (i.e. a false formation) into a complicated system through the formation of a central organizing principle. The central organizing principle provides a stricter definition of the research problem and subsequently coalesces the intentionality of system agents through a unification of their disparate aims and methodologies. This pseudomorphosis is thereby associated with an exchange of individual freedom for organizational utility resulting in internal tensions which, we argue, most prominently expressed in the interplay of epistemic incompatibilities between disciplines. We explore three frameworks for successfully navigating these incompatibilities: circumvention, which is based on avoidance of areas of disciplinary incompatibility; pragmatism, which is based on ignoring areas of compatibility; and disciplinary synthesis which involves a paradigm shift in researchers’ understanding of their disciplinary propositions resolving perceived incompatibilities. It is anticipated that this paper may be of benefit to researchers and organizers seeking to effectively structure interdisciplinary research projects, specifically in terms of framing the research problem and the modes of inquiry, and in structuring the interdisciplinary research team.

Keywords
critical realism, meta-synthesis, philosophy of science, qualitative evaluation, dialectic critique

Introduction
This paper is the second in a series of three papers on the collaborative research hierarchy. The collaborative research hierarchy is often conceptualized as a pyramid consisting of three tiers: firstly, multidisciplinary research, which is typically understood as the least integrated and least cooperative form of collaborative research; secondly, interdisciplinary research, wherein a larger degree of emphasis is placed on cooperation between researchers along with a level of centralized control or centralized purpose; and thirdly, transdisciplinary research, which is considered as the most integrated form of collaborative research, likely incorporating social/corporate/political actors from outside of the research process (Alvargonzález, 2011; Choi & Pak, 2006; Collin, 2009; Fawcett, 2013; Julie T J. ulie T. Klein, 2008; Stock & Burton, 2011; Uwizeyimana & Basheka, 2017).

In Dalton et al. (2021) the authors sought to redefine multidisciplinary research systems as robust complex systems involved in the process of unconcealment of the metaproblem. Multidisciplinary research systems were framed as complex systems using a framework of features common to complex systems as identified by Ladyman & Lambert (2013). These features are: an ensemble of interacting elements; disorder

1Department of Electrical and Electronic Engineering, Stellenbosch University, Stellenbosch, Western Cape, South Africa
2Faculty of Engineering, Stellenbosch University, Stellenbosch, Western Cape, South Africa

Corresponding Author:
Amaris Dalton, Department of Electrical and Electronic Engineering, Stellenbosch University, Cnr Banghoek Road & Joubert Street, Stellenbosch, 7600, Stellenbosch, Western Cape 7602, South Africa.
Email: amaris_dalton@sun.ac.za
followed by the emergence of robust order; and system memory. In our interpretation of multidisciplinary research systems as complex systems we sought to counter the prevalent narrative that considers a fragmented approach to addressing a large complex problem (what we termed a *metaproblem*) as being necessarily ineffective. Rather, we argued that what may be considered a form of swarm-intelligence emerges within a multidisciplinary research system. Interactions and communication signals within the system, both with other researchers (e.g. through publications, conferences) and with the metaproblem (e.g. through results from one’s own research) serve as *orientation signals* – or stigmergy. At a large scale, such stigmergy creates the impetus for a measure of self-organization within the system, similarly to what is seen in, for example, foraging ants. When considering the functioning of a multidisciplinary research system, we argued that the system’s emergent intelligence expresses itself in the iterative unconcealment of the metaproblem. Unconcealment may be understood as a dialectical explorative process, which though not in conflict with propositional truth, is broad enough to allow for the differing (and at times conflicting) epistemologies encapsulated within a multidisciplinary research system.

In this paper the authors consider the second tier of the collaborative research hierarchy – interdisciplinary research. We develop a conceptual model of the ontology of interdisciplinary research systems, which - despite increased research interest - remains poorly understood and undertheorized (Siedlok & Hibbert, 2014). To this effect, the investigation of disciplinary systems and their operational inter-relations can be enriched through the application of sociological tools. Critical Realism (Bhaskar, 1979; Archer, 2005) offers an overarching approach to this investigation in that it a) facilitates the ontological un-packing of causal mechanisms that can illuminate structures and practices b) allows for epistemic relativism, as is likely to be encountered within interdisciplinary research, but remains underpinned by ontological realism which we deem beneficial to effectively investigating external objects such as the metaproblem.

A second sociologically useful lens is that of Archer’s Structure-Culture-Agency (2005). From a Critical Realist perspective, research activity implies a dialectically iterative process of structural causality and maintenance. In other words, cultures evident in particular structures arise as defining characteristics of particular fields constituted by particular agents. A field might be characterised by its dominant forms of knowledge, techniques and dispositions whereby it may be argued that all research practices are essentially socio-cultural in nature. Accordingly, rather than suggesting structural determinism and conditioning (Archer, 2005), a Critical Realist approach may contribute to unpacking the complexities in interdisciplinary research systems, where *complicatedness* is not conflated with *complexity*. We furthermore seek to introduce and develop several theoretically novel causative mechanisms expressed both in successful and unsuccessful instances of interdisciplinary research – notably the central organizing principle and a phase transition from a complex to a complicated system through a process termed *pseudomorphosis*. We believe this paper would be beneficial to researchers and organizers seeking to effectively structure interdisciplinary research projects, specifically in terms of framing the research problem and the modes of inquiry, and in structuring the interdisciplinary research team.

**The Rise of Collaborative Research**

An increasing trend towards collaborative (specifically interdisciplinary) research is clearly observable throughout the second half of the 20th century (Baldwin & Austin, 1995; Katsouyanni, 2008; Sanderson, 1996). Several popular alternative hypotheses describing the impetus towards collaborative research have been presented. One such hypothesis, presented by several authors including (Makarova et al., 2019; Rosenblat & Mobius, 2004), argues that trends in globalization facilitated by improvements in transport, telecommunications and interconnectedness is mechanistic in the creation of a global village, which facilitates greater research collaboration. We agree that globalization is instrumental in the facilitation of collaborative research. We do not however deem globalization to be *fundamental* to the collaborative process. Consider the following example: in the modern hyperconnected world, it remains very unlikely that certain disciplines with a significant degree of epistemic and ontological separation would collaborate on a research project unless a communal metaproblem is identified that transcends the scopes of their respective disciplines. An example of this can be seen when considering journal citation scores that have been used to compile various ‘maps of science’ e.g. (Hassan-Montero et al., 2014; Rosvall & Bergstrom, 2008) that illustrate the separation between disciplines as a function of cross-citations.

We maintain that the initial impetus towards collaborative research is fundamentally based in the metaproblem’s transcendence of individual disciplinary bounds, implying the individual discipline’s inability to adequately investigate the metaproblem. There are two sides to the coin of the metaproblem’s transcendence of disciplinary bounds. The first relates to the metaproblem itself - specifically the frequently discussed increasing scale and complexity of problems being investigated (Bennett & Gadlin, 2012; Sonnenwald, 2007). The argument here is that the societal magnitude of the problems being investigated – e.g. climate change, ecological collapse, or the energy transition – is so vast and complex that it necessarily transcends any discipline’s bounds and as such necessitates collaboration between scientific disciplines. The second relates to what may be the epistemic incompleteness of any given discipline. By epistemic incompleteness, we simply mean that the discipline’s knowledge and understanding of its subject are imperfect or inadequate. This imperfection is implied in, and is also what allows for, the discipline’s
Table 1. Potential benefits from interdisciplinary research.

| Benefit                                      | Selected Studies                                               | Summary                                                                                         |
|----------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Problem-feeding (Grantham, 2004; Thorén & Persson, 2013) | Disciplines may, especially when using shared heuristics, rely on each other for generating hypotheses and solutions. It is often maintained that interdisciplinarity leads to creativity and innovation. From the author’s reading of the literature, it is at this point deemed unclear if this increased creativity is based on a policy assumption as noted by Siedlok & Hibbert (2014), or actually borne out by the facts. |
| Innovation and creativity (Collin, 2009; Jones, 2010; Nissani, 2019; Siedlok & Hibbert, 2014) |                                                                                                           |
| Disciplinary synthesis and integration (Winskel et al., 2015) | Disciplinary synthesis is often described as an ideal outcome of interdisciplinary research. Interdisciplinary research teams may be able to tackle complex societal scale problems that multidisciplinary researchers are unable to. This, as discussed in this section, stems from both increasing specialization and increased complexity for problems being investigated. |
| Enables a holistic approach suitable to societal-scaled problems (Collin, 2009; Nissani, 2019; Siedlok & Hibbert, 2014) |                                                                                                           |
| Social relations, networking and flexibility (Siedlok & Hibbert, 2014) | Researchers may enjoy the social contact and interaction associated with working in teams with colleagues, as opposed to working in relative isolation. Interdisciplinary researchers may also enjoy more flexibility or freedom. |

continued development. Contributing to epistemic incompleteness is the increased specialization of scientific disciplines leading to a narrowing of disciplinary scope. J. T. Klein (1990) for example recognized that the need for integration and specialization contains a paradoxical element that needs to be balanced. It was further noted by Hunter & Leahey (2017) that increased specialization was perhaps the most cited reason for increasing trends in scientific collaboration.

A significant body of literature exists on the potential benefits and synergies that may arise from interdisciplinary research. Based on a purposive selection of the literature from a number of recent articles, these benefits are summarized in Table 1 below.

Methodology

Critical Realism offers an underlying explanatory framework for considering the ontological and epistemological nature of causally active structures in both natural and social domains (Mingers, 2014). Bhaskar (1979) differentiates between three stratified domains of reality: Real, Actual and Empirical, where the Empirical constitutes that which is observed and experienced within the Actual events (and non-events) as a result of Real generative mechanisms. As this paper is focused on the structure and dynamics of social systems, Critical Realism is adopted as a philosophical framework that allows for the exploration of mechanisms and system archetypes (Senge, 1990) so as to understand our observations regarding the successes and failures of interdisciplinary research. Practically, Bhaskar’s Critical Realism is furthermore suitable to interdisciplinary research practice where researchers from the physical and social sciences are increasingly collaborating, as it is philosophically positioned ‘between’ the positivist and constructivist practices that have respectively been dominant in the physical and social sciences.

Ontologically, research systems (whether multi-, inter- or transdisciplinary) are social structures in which agents engage with concepts, processes and outcomes in service of knowledge generation (epistemology). The research processes are causally interdependent epistemological and social structures achieved through consensus. In other words, communities of agents in particular fields - who have agreed to the conventions of naming and interrogating phenomena - conduct their research following accepted methodological processes and communicate their findings so as to be intelligible to their field (or beyond).

Within this research act, one may observe practices informed by ‘deep principles’ that “impose a coherent symbolic order” on the culture of the particular field (Nash, 2003). To a certain extent, this is what Archer describes as ‘conditioning’ (2005). However, this ‘conditioning’ does not necessarily suggest a form of inescapable determinism - structures and systems change on the basis of fundamental paradigm shifts (Kuhn, 1962) or ‘falsification’ (Popper, 2005) brought about by agents engaged in sociocultural scientific practice.

Researchers are inducted into research systems by way of acquiring the Discourses (ways of thinking, doing, believing, valuing) (Gee, 1989) and, subsequently, appropriately recognizing and realizing (Bernstein, 2000) the associated practices. The appropriate realization of these practices identifies a particular agent as belonging to a particular culture. The cultural system is sustained through agents enacting its associated ‘legitimate’ practices. The more complex the internal structure of a particular culture, “the more difficult it is to assimilate new items” (Archer, 2005). However, it is precisely the concomitant sociality of research practice that...
allows for ‘recontextualization’ (Bernstein, 2000) to take place, for context-specific interpretation dictated, for example, by pragmatism or politics or agency.

The Structure-Culture-Agency relations (Archer, 2005) within any research system are complex, comprising a myriad of causal mechanisms governing practices. These causal mechanisms may operate in invisible ways when groups of researchers collaborate in order to address an overarching metaproblem, presenting ‘constraining contradictions’ and ‘logical tensions’ (Archer, 2005) as a result of conflictual relationships within conceptual, cultural and socio-cultural systems. Understanding the variations between these three system dimensions is crucial to the explanation of stability or change (Archer, 2005).

The purpose of this paper is to interrogate the structural features of interdisciplinary research systems from a disciplinary perspective.

**Interdisciplinary Research: A Complicated System?**

A central assertion of this paper is that interdisciplinary systems primarily function as complicated systems, unlike multidisciplinary research systems which, as discussed in Dalton et al. (2021), may be considered as complex systems. Indeed, as noted by Poli (2013), distinctions between complex and complicated systems are gradually becoming more uncertain (somewhat ironically) because of the increasing literature on complex systems. A possible reason for this confusion is the overemphasis on what Critical Realism views as the empirical domain (that which appears visible), often at the cost of working within a well-established ontological structure. We seek to elucidate several such distinctions, as this allows us to gain a clearer understanding of the structure of the archetypical complicated object within which we introduce active agents in the next sections.

An important distinction between complex and complicated systems, as highlighted by several authors e.g. (Glouberman & Zimmerman, 2016; Poli, 2013; Rogers, 2008), is the underlying assumption that hard causality and predictability govern a complicated system, as opposed to the softer, more chaotic and less (clearly) causal principles governing complex systems. Understanding this distinction is key when considering how to manage or influence these respective systems, particularly with reference to the less causally-definable complex system where the predictability of certain actions and initiatives is unclear. Poli (2013) likened this to ‘learning to dance’ with a complex system. Conversely, complicated systems may be conceived more mechanistically where inputs result in appropriate and proportionate outputs, making such a system easier to model.

Another feature of complicated systems is their composition of multiple parts or components interacting with each other. As noted by Poli (2013) complicated systems tend to be analyzed in terms of structural decomposition. When these components are combined through a mechanical process, such as the assembling of a car, or sending a rocket to outer space, we observe a complicated system at the Empirical domain, underpinned by multiple, separable Real causal mechanisms.

**The Central Organizing Principle**

A level of centralized control or intelligence is a common feature of complicated systems (Kurtz & Snowden, 2003). In the case of interdisciplinary research systems, we shall refer to this centralized control as the central organizing principle (CrOP), which we consider as a system archetype. The CrOP can be thought of as an active agent that establishes the interdisciplinary research system by defining the metaproblem, guiding the modes of investigation and selecting the system’s researchers. As such the CrOP is similar to what (Archer, 1995) has called ‘corporate agency’ in that the aims strived for have been self-actualized and articulated, and are expressed through organization towards a strategic pursuit. In keeping with Archer, the CrOP is furthermore understood to be already embedded within and conditioned to certain social structures, though this does not deny its agency. Unlike Archer’s corporate agency, we do not deem it necessary for the CrOP to be an emergent property consisting of multiple agents (though this can also be the case), but can also be autonomous individuals in positions of power.

The level of centralized control is an important distinction between inter- and multidisciplinary research systems, whereby in a multidisciplinary research system, neither the metaproblem, nor the modes of inquiry, is transcribed at a systems level owing to the lack of central organization and weak communication between researchers (Dalton et al., 2021). The CrOP is therefore a catalytic mechanism that coalesces the intentionality of system agents through a unification of their disparate aims and methodologies, thereby directing multiple monodisciplinary agents towards a point of convergence. As noted by Bion (1952) in a highly influential early paper on group dynamics – at its inception point, every group is formed for a purpose, to ‘do’ something, and interdisciplinary research systems are no different.

Drawing from the well-established and theorized field of organizational dynamics, whereby organizations are also frequently conceptualized as mechanistic complicated systems, we propose two mechanisms for the formation of the CrOP: bottom-up and top-down. We consider these mechanisms as heuristics which it is therefore understood cannot encapsulate all the real-world complexity associated with the organization of an interdisciplinary research system. Rather, these heuristics serve as useful tools in elucidating certain dynamics at work in the formation of such systems, which are useful in improving our understanding thereof.

The top-down imposition of central organization is aligned to the traditional understanding of interdisciplinary research formulated by Jantsch (1972) as “…coordination from a
higher level...”. In organizational theory, a top-down approach is typically considered to be deductive - i.e. based on logic, rather than observation or experience (Shepherd & Sutcliffe, 2011; Easterly, 2008). Examples of interdisciplinary research systems with a top-down imposed CrOP include systems with an overarching objective which excludes the often idealized value-free science (Betz, 2013; Proctor, 1991) where decisions are made from positions of power by managers, committees, etc. Examples include commercial R&D e.g. (Loiter & Norberg-Bohm, 1999; Sackett, 1990); military research where a particularly prolific example is the RAND Corporation’s embrace of an interdisciplinary research culture (Augier & March, 2020; Bessner, 2015); expert councils to policymakers and think tanks (Doukas et al., 2010; Hess et al., 2016; Thunert, 2004); funding organizations making available research grants (Islam et al., 2018), etc.

We propose that the bottom-up formation of the CrOP is facilitated through individual agents already operating within a multidisciplinary research system, who perceive the necessity of formalized collaboration with others towards the fulfillment of their research aims. This dovetails well with the broader commonly held conceptualization of bottom-up strategies as being experience-based, or inductive (Shepherd & Sutcliffe, 2011) and is not aligned to the traditional more hierarchical view of interdisciplinary research systems. The bottom-up formation of the CrOP may rather be seen as a progression in the evolution of what had previously been a non-integrated multidisciplinary system. Because bottom-up interdisciplinary collaboration feeds into a research process that had previously been ongoing, such collaboration may be considered as being primarily aimed towards the fulfillment of the preestablished research aims of a principal researcher (i.e. the researcher/entity that posed the research question), largely through the acquisition of certain requisite specialized skills. It was for example noted by several authors e.g. (Hagstrom, 1964; Shrum et al., 2007), that the cost and unavailability of certain specialized equipment along with the lack of certain expertise were important drivers of interdisciplinary collaboration.

**Pseudomorphosis from Complex to Complicated**

We suggest that the central organizing principle, by virtue of a stricter definition of the metaproblem, seeks to impose the dynamics of a complicated system, notably in terms of increased centralized control, onto what is in fact intrinsically a complex system. With the establishment of a form of centralized control, a system becomes more mechanistic and formalized – as is characteristic of a complicated system - especially compared to the dynamism of a multidisciplinary system as discussed in Dalton et al. (2021).

To describe this transformation, we borrow a term from geology - pseudomorphosis - literally meaning false (pseudo) formation/shaping (morphe). Relating to philosophy, the term pseudomorphosis was adopted by Spengler (1918) to provide an allegory for how a developing culture may be shaped by prominent preceding historic cultures within a geographic area. We do not however mean pseudomorphosis exactly in this sense, but rather in closer keeping to its literal etymology, to describe the imposed ‘false’ form of a complicated system, onto what is a more naturally complex system. During pseudomorphosis, a measure of functional coherence is necessitated for the system to function effectively towards an objective. This is associated with increased accountability and managerialism within the system. During the interdisciplinary research process, an internal process of negotiation and compromise ultimately results in an exchange of individual freedom for perceived organizational utility as proposed by De Wet (2022). Such systemization is also likely to cultivate cultural reproduction, as noted by Archer (2005). Indeed, when enough individual autonomy is ceded by researchers, it becomes useful to start thinking of an interdisciplinary research system holistically as a complicated organization, as opposed to a decentralized collection of individual agents. In the process of ceding freedom for utility, agents are, at least within the Empirical domain, ‘aware’ of the tension between individualism and contextualism that is playing out. In Dialectical Critical Realism, an agent’s awareness and compromise may be described as an agent’s reflectivity (Archer, 2003) which has the causal power to modify structures. Despite reflectivity being a mediating factor between structure and agency, we propose that tensions brought about by the pseudomorphosis often remain unresolved due to certain epistemic incompatibilities between agents (discussed in more detail in sections below) which is expressed in the failure of interdisciplinary research.

The stricter conceptualization of the metaproblem is, we argue, a feature of the interdisciplinary approach that can be construed both as a strength or as a weakness, depending on the context. What should be clear is that this mode of interaction between an interdisciplinary research system and the metaproblem can no longer be considered as unconcealment, as was the case for a multidisciplinary system. The system rather, we argue, becomes involved in a process of attainment, a voyage of utility rather than discovery. Central organization thereby becomes a drawback when the slower, comprehensive, and systematically robust iterative unconcealment process, as found in a multidisciplinary system, is sought.

Conversely, in an interdisciplinary system, a more sharply focused and holistic approach is adopted allowing for a stricter degree of control and coordination that is not possible within a multidisciplinary system. Interdisciplinary research thereby lends itself well to situations wherein concise and prompt outcomes are expedient. Consequently, a heterogeneous group of researchers requires a stricter problem definition to facilitate a measure of mutual directionality between system members and to allow for the achievement of the task at hand. Our assertion on the positive utility of goal orientation in research systems is in keeping with aspects of organizational
management theory as discussed by e.g. Mehta et al. (2009) or Porath & Bateman (2006). This further supports our understanding of interdisciplinary systems to be subject to a Real causal mechanism associated with utility and managerialism as opposed to that of unconcealment in relation to multidisciplinary research.

**System Boundaries**

When considering interactions between a research system and its external environment, our primary concern is the environmental impact on system agency. In describing interactions with the environment outside of the system, we borrow the terms externalities and internalities from the field of economics. In Cilliers (2011) boundaries of complex systems are described as being highly porous. Conversely, we propose that a complicated interdisciplinary research system’s boundary is substantially denser than that of the multidisciplinary complex system in terms of the impact of informational exchange. This boundary density is partially a function of the system’s strong structures and centralized control that embeds individual agents in a process with organizational inertia. As noted by Archer (2005), systemization cultivates cultural reproduction which further strengthens the system’s boundaries, especially in specialist groupings such as research systems. Therefore an externality has less of an impact on a group of closely associated researchers working under a quasi-organizational directive than on an individual researcher when working in a loosely associative multidisciplinary system. However, for the same reasons, externalities that do penetrate an interdisciplinary system have an impact that reverberates across the entire system.

Interactions between research systems and the ‘external’ environments have been referred to as transdisciplinary research (Brandt et al., 2013). However, as nothing truly happens in isolation, we deem it more appropriate to consider interactions with the external environment as forming an inherent part of both multi- and interdisciplinary research systems, as opposed to a distinct system in its own right. Thereby, it is deemed incorrect to draw distinctions between research systems that receive inputs from their external environments and those that do not – it rather becomes a question.

![Diagram](image-url)

*Figure 1.* Interdisciplinary research consisting of individual researchers/actors (A), following the dictation of the organizing principle towards the prevised metaproblem superstructure, whilst being stratified within a collaborative feedback loop.
Successful Interdisciplinary Research: Reflection and Structure-Agency Synthesis

What do we mean by successful? It is noted by Siedlok & Hibbert (2014) that a consensus position has not, as yet, been reached in the literature regarding the long-term viability of interdisciplinary research. Certain authors adopt an optimistic perspective to this effect, based in large part on various successful examples of interdisciplinary research and the (supposed) necessity of interdisciplinary research stemming from the aforementioned societal scale of challenges being investigated (Hackett & Rhoten, 2009; Nissani, 2019), along with increased disciplinary specialization. Other authors however maintain that interdisciplinary research is primarily short term and project based (Ferlie et al., 2005; Lindkvist, 2005) due to frequently observed failures of interdisciplinary research. Table 2 provides a summary of certain oft cited barriers to successful interdisciplinary research.

To establish what is meant by successful interdisciplinary research, consider several interdisciplinary researchers, brought together by a CrOP to fulfill a perceived disciplinary epistemological incompleteness, investigating a (predefined) metaproblem. In generating a research outcome that is representative of the system’s constituent disciplinary elements, Structure-Agency tensions imposed by the CrOP through the pseudomorphosis are played out in a dialectical (inter-agent and agent-structure) and reflective (intra-agent) process.

The frequently cited reasons for failures of interdisciplinary research (as noted in Table 2) suggests that failure may well result from the artificial, mechanistic process of pseudomorphosis from inherent complexity into complicatedness, ignoring perceived epistemological incompatibilities. This amalgamation of heterodoxy is inherent to the structure of interdisciplinary research systems and therefore, as will be expounded on below, necessitates the unfolding of a reflective process to be ‘successful’. The next sections explore the interplay between epistemic incompatibilities within the structure of an interdisciplinary research system and describe three frameworks in terms of which successful interdisciplinary research may be conducted.

Disciplinary Incompatibilities

A significant body of literature can be found on epistemological incompatibilities between disciplines – especially at the case-study level of analysis. Verbruggen (1998) for example, describes disciplinary differences encountered between economists and natural scientists in conducting environmental research. Verbruggen (1998) notes that the point of departure for natural scientists is strongly deterministic, where an environmental problem is considered as an effect in a causal chain of events and a new technological application is favored as the required solution. Economists

| Barrier to Success                        | Studies                                                                 | Summary                                                                 |
|-------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Not beneficial to career progress         | (Jones, 2010; Siedlok & Hibbert, 2014; Winskel et al., 2015)            | It has been noted by several authors that interdisciplinary research tends not to be regarded with the same level of seriousness or respect as certain traditional disciplines within the academic establishment, perhaps resulting in slower career growth and fewer funding opportunities. It was noted that this may be related to their lack of specialization which may take interdisciplinary research away from the ‘cutting-edge’ and may also be related to the lack of pre-existing structures within the establishment to accommodate such research |
| Language barriers                         | (Kurz, 1995)                                                            | Researchers from different backgrounds do not necessarily share a common language, which hampers efficient communication |
| Disciplinary traditions and cultures      | (Siedlok & Hibbert, 2014)                                               | The way in which a discipline conducts itself, its practices, habits, traditions, symbols and cultural elements may act as a barrier to interdisciplinary research |
| Epistemological incompatibilities         | (Alberti et al., 2011; Verbruggen, 1998)                               | Epistemological incompatibilities refer to a seemingly irreconcilable difference between disciplines regarding what is and what is not true |
| Ego, competition and personal unwillingness to change | (Kurz, 1995; Nissani, 2019)                                           | The problem of the ego of the researcher has been shown to hamper interdisciplinary research in various ways. There may be a feeling of superiority or inferiority between disciplines as noted in Kurz (1995) leading certain disciplines to feel unappreciated. Researchers may also fail to accept certain study outcomes if it contradicts disciplinary orthodoxy and may be unwilling to change certain preexisting structures (Nissani, 2019) |
may conversely consider societal processes as a starting point, to which the same strong determinism may not be applicable at the macro level of analysis, hence allowing for a certain leeway. Another example of epistemological incompatibilities between the disciplines of archeology and anthropology, is discussed by Alberti et al. (2011). A notable difference elucidated by Alberti et al. (2011) is between the classic Archeological ontology based upon the Aristotelean notion of substance, versus a more relational ontology where historic objects may be considered as part of an interactive web of related entities forming a complex composite identity.

When considering how such incompatibilities lead to difficulties – or even failures – in an interdisciplinary research project, the UK Energy Research Centre (UKERC) (Winskel et al., 2015) offers a concrete example of where an interdisciplinary research project devolves towards multidisciplinary compartmentalization of research. The UKERC was founded based on the recommendations by the UK’s Energy Research Review Group and was intended to act as a central contact point for university-based interdisciplinary energy research within the UK. In a broad survey by Winskel et al. (2015) of the researchers involved in the UKERC, a tension between cohesiveness and openness was highlighted where it is noted that the project’s emphasis on disciplinary diversity and openness may have undermined its ambitions towards deep levels of interdisciplinary collaboration which requires significant mutual understanding.

From the examples above it is quite evident how perceived epistemological incompatibilities between disciplines may pose challenges to the collaborative process. Critical realism does accommodate and accept epistemic relativism without discarding ontological absolutism. Therefore, within a Critical Realist framework, epistemic incompatibility will not result in a fatal failure of interdisciplinary research. In the sections below we propose three frameworks that may facilitate successful interdisciplinary research. Each of these takes a different approach to surmounting incompatibility. The first mechanism involves research where the definition of the metaproblem and the composition of the interdisciplinary team is such that areas of disciplinary incompatibility are circumvented. The second mechanism, which one may term epistemic pragmatism, requires a compromise between researchers from different disciplines regarding the strictness of their truth conditions in favor of practical utility. The third mechanism entails a paradigm shift in the collective understanding of researchers within an interdisciplinary research system, which brings about synthesis between (what may at first be perceived as) incompatible disciplinary epistemologies.

Circumvention

In the first proposed framework for successful interdisciplinary research, conflict is essentially avoided, as the scope of the metaproblem does not encroach on disciplinary incompatibilities. Thereby, disciplinary epistemic convergence and compromise, or disciplinary synthesis, is not necessary, and the potential for conflict is significantly reduced. In the circumvention framework, the structure of the interdisciplinary research system is the dominant success factor. With this we mean that the top-down formulation of the metaproblem, agent-selection, and the establishment of the modes of inquiry are set up so as to ensure that conflict is avoided. There is an element of this circumventive process similar to the puzzle building analogy that Kuhn (1962) made in relation to ‘normal science’. Furthermore, unlike epistemic pragmatism and disciplinary synthesis as discussed below, conflict circumvention requires a degree of epistemic similarity between disciplines regarding their understanding of the metaproblem.

As the CrOP establishes the structure of the interdisciplinary research system at its outset, keen insight into the subject area of investigation along with managerial practical acumen is required to circumvent epistemic incompatibilities. It may be assumed that the CrOP is task orientated, rather than prioritizing creative outcomes that might result from the interplay of tensions between disciplines. The bottom-up case is, as we saw, often characterized by the recruitment of required disciplinary skills into an ongoing research process. An example of such a case would be, when a natural scientist working with large data sets requires certain specialized information technology skills to build and maintain the data-storage infrastructure e.g. (De Cauwer et al., 2006), or the use of machine learning expertise to build predictive models based on such data e.g. (Sadowski & Baldi, 2018). Though there are differences in the epistemologies of the respective disciplines mentioned in these examples, these don’t collide in the process of their epistemic augmentation in the pursuit of the research goal. In a pedagogic context another perhaps less positive example is where incompatibilities may be downplayed (Stewart & Perry, 2005), or even actively avoided to prevent confusion, as discussed by Winn & Messenbeimer-Young (1995).

Epistemic Pragmatism

Epistemic pragmatism is the second proposed framework for successful interdisciplinary. In this framework, agency is the dominant force, as opposed to structure as was the case in the circumvention framework. When certain disciplinary incompatibilities arise in an interdisciplinary research team’s collaboration, a level of epistemic convergence on the part of system agents may be necessitated. We consider convergence to be brought about by the system’s pseudomorphosis into a complicated system. Such convergence is associated with a process of mutual disciplinary discovery, especially when researchers are unfamiliar with each other’s disciplines, followed by a dialectical process of internal reflection and negotiation between agents as their positions begin to encroach into areas of perceived incompatibility. In the epistemic
pragmatism framework, disciplinary convergence facilitates a compromise between individual agents regarding what was initially thought to be an incompatibility. Such a compromise may look like a certain softening of the restrictive disciplinary language codes as discussed by Bernstein (2003), and their underlying epistemological understandings by the negotiating parties. Therefore, a pragmatist approach to interdisciplinary research involves apparent disciplinary incompatibilities simply being ignored or discounted rather than avoided or synthesized.

An obvious motivating factor with such a softening is to allow the research to move forward towards the communal goal. Epistemic pragmatism is thereby task- and agency orientated in its research outlook and its willingness to ignore certain inconsistencies in favor of getting something done. Therefore, as per William James’ conceptualization of the pragmatic theory of truth, truth is in this instance defined in terms of its utility (Capps, 2019). For epistemically pragmatic outputs from an interdisciplinary research system to be accepted by its internal regulation - the CrOP - or by the broader public, a level of pragmatism is similarly required on their parts. The audience, in particular the expert audience, needs to go along with the compromise – ostensibly for similar reasons to those held by the researchers.

An example of a fairly high-level pragmatic compromise that is very common between the fields of natural sciences and ethics, is that of Hume’s Guillotine (also known as the Naturalistic Fallacy) – i.e. deriving an ought from an is (Hume, 1882). A quantitative study that offers a (moral) recommendation or imposes a value judgment along the lines of what should be done in response to evidence presented, makes the (often unconscious) practical compromise across the line of incompatibility with the discipline of ethics. To make this example more concrete – if a climate scientist, who, it might be argued, is working within a strictly materialistic epistemology, concludes that observed rising temperatures are bad and that the causative factors should be mitigated, then a pragmatic compromise has been made. It is however clear that such a compromise does not facilitate a synthesis of climate science and climate ethics into a new discipline, but rather signifies an instance of epistemic pragmatism.

Disciplinary Coherence & Synthesis

The question, then, is the degree to which above discussed outcome-orientated circumventive and pragmatic frameworks contribute to a sustainable solution from a disciplinary perspective. In essence, any opportunity to enrich, develop or transform a discipline will contribute to its sustainability and potential to generate collaborative solutions. Furthermore, of concern is the extent to which solutions offered by such outcome orientated modes of research are truly representative of the system’s constituent disciplines (i.e. truly interdiscipli- nary) and whether the solution offered is coherent with each discipline’s underlying epistemic understanding.

To this effect, a disciplinary synthesis (from the Greek σύνθεση meaning composition or putting together (Merriam-Webster, 2021)) has been observed or postulated by several authors investigating interdisciplinary research e.g. (Aboelela et al., 2007; Collin, 2009; Hackett & Rhoten, 2009; J. ulie T. Klein, 2008), and is typically considered to be an ideal outcome. The degree to which disciplines have been synthesized (often described in relation to the standard multi-, inter- and transdisciplinary distinction), and what such a level of synthesis might look like in practice, has been extensively discussed. We deem however that much of this discussion operates within a presupposed implicit perception of the ontological properties of such a synthesis (a term which is at times used interchangeably with integration or harmonization). This section seeks to make this ontology explicit.

The proposed mechanism of disciplinary synthesis functions along the principles of Hegelian logic. A point of departure is our previously mentioned understanding that all disciplines subject to inquiry are epistemically incomplete. A synthesis between two disciplines, we propose, fulfills an aspect of this incompleteness at the point of perceived incompatibility, thereby negating the contradiction. This negation is done by establishing a supervening discipline through the unification of the previously deemed incompatibilities. Therefore, unlike with epistemic pragmatism, disciplinary synthesis involves a multivalent paradigm shift at the point of perceived incompatibility – i.e. a reflective change of multiple disciplines’ understanding of themselves and their subject matter (their epistemology) such that the perceived incompatibility between disciplines, i.e. the incoherence in their epistemologies, is resolved. A level of disciplinary development is thereby initiated which is missing from the more pragmatic approaches to interdisciplinary research, as proposed in the previous sections.

Though there is an element of negation in disciplinary synthesis, the participant disciplines are also preserved within the new discipline whereby the reductio ad absurdum argument, calling for the complete abdication of the initial disciplinary epistemic propositions, is rejected. However, in instances where the preceding disciplinary propositions are outrightly proven false and certain phenomenon can no longer be explained at the hand these propositions, this may lead to an abdication of earlier propositions leading to what has been described as a ‘Kuhn-loss’ (Bird, 2018). Disciplinary synthesis is understood as being temporally constrained and at times even transitory, thereby ending with the research system being dissolved rather than propagating deeper into disciplinary silos. Indeed, it has frequently been noted that science may be very slow to adopt paradigm shifts – evidence to the falsity of certain dearly held propositions notwithstanding. As discussed by Kuhn (1962), in practice science tends not to function on Karl Popper’s ideal of theory falsification (Thornton, 2021), but may rather find itself dogmatically be attached to a paradigm until its most prominent proponents retire or pass away.
Based on the required realignment of the disciplinary propositions, a pragmatic truth condition is deemed unsuitable to disciplinary synthesis. Rather a research outcome resulting from a disciplinary synthesis must be *coherent* in terms of its internal dynamics. Coherence as understood here is a truth condition that needs to be satisfied in terms of the rational consistency of its propositions (Rescher, 1973) – i.e. whether truth forms part of a coherent system of beliefs. In this instance, coherence as truth condition is not seen as being a competitor to the correspondence theory of truth, as often considered to be the case (Young, 2018), but rather as supplementary thereto. Thereby, for a disciplinary synthesis to be enacted, a shift in the underlying disciplinary propositions need to be (re)instantiated in such a way, so as to make them coherent with each other.

A highly prolific and still frequently discussed (e.g. (Vanzo, 2016; Watkins, 2002)) example of a disciplinary synthesis is Immanuel Kant’s synthesis of Empiricism, which maintained that knowledge is primarily derived from the senses, with Rationalism, which maintained that knowledge was primarily derived a priori from logic independent of the senses. In his most influential work, the Critique of Pure Reason, Kant sets out to show that certain synthetic judgments derived from experience, notably those related to geometry or arithmetic, can be known a priori. The paradigm shift that Kant enacted was in, rather than considering the mind as a neutral receptor as was typically held by both empiricists and rationalists, by giving it a complex internal structure – an apparatus of perception. It should be noted that certain philosophers e.g. (Russell, 2013; Sperber, 2015) do not hold Kant’s synthesis as valid, but the influence thereof on philosophy is undeniable. Another poignant example of disciplinary synthesis is Bhaskar’s synthesis of epistemic relativism, which gained primacy post-Kant, and ontological realism, in the philosophical more than the scientific sense, resulting in Critical Realism (Steinmetz, 1998).

Our description of disciplinary synthesis is, as per the aims of the paper, focused on the Real generative mechanisms which may likely be expressed as a rigorous and complex process of interactions, learnings and negotiations on the parts of the individual researchers. As such disciplinary synthesis is highly reflective on the part of system agents as it requires an active reformulation of what was perhaps dearly held propositions thereby being critical of self and context. Unlike the former proposed frameworks for successful interdisciplinary research, disciplinary synthesis cannot be coordinated by the CrOP, but must *emerge* organically and bottom-up from the collaborative process between researchers and the reflective process within a researcher. Should disciplinary development and syntheses thereby be a desirable outcome of interdisciplinary research, a loosening of the centralized control imposed by the CrOP may be warranted allowing agents a greater level of freedom. The pseudomorphosis from a complex to a complicated system would accordingly be reversed to a certain degree and a level of complexity – along with the dynamism associated with complex systems which is suggestive of multidisciplinary research - would be reintroduced into the system.

**Conclusion**

Considering the critical realist position that social science should be built from explicit ontologies, this paper seeks to elucidate the dialectical interplay between structure and reflexive agent in interdisciplinary researcher systems. The paper goes on to explore certain frameworks within which successful interdisciplinary research may be actualized. We introduce several archetypical processes- and objects that function as ‘real’ mechanistic structures within interdisciplinary research systems. The first of these archetypal objects is the CrOP which may be considered as an active agent in its own right and is responsible for defining the metaprocess, selecting the system researchers, and dictating applicable modes of inquiry.

We went on to describe the interaction of reflective agents with these archetypical structures and processes, and this interaction is expressed in the empirical domain. As the CrOP is a managerial structure within the research system, its exercising of central organization stratifies researchers and the system such that individual freedom is exchanged for a measure of (perceived) organizational utility. To describe this stratification process, we introduce the term pseudomorphosis, wherein what is intrinsically a multidisciplinary complex system gets morphed into a more mechanical complicated system. For the agents, the pseudomorphosis is associated with a compromise between individualism and contextualism. Tensions resulting from the pseudomorphosis may, we argue, express themselves in the failures of interdisciplinary research.

To explore the expression of these tensions, we conducted a preliminary literature survey wherein the most oft-cited reasons for failures of interdisciplinary research projects were captured. Of these reasons, we perceive *epistemic incompatibilities* to be perhaps the most fundamental – or Real – reason for such failures. In response to epistemic incompatibilities, we propose three frameworks that may facilitate successful interdisciplinary research. The first of these frameworks is that of circumvention, which requires that an interdisciplinary research project and team be structured such that areas of epistemic incompatibility are avoided. Therefore, in the circumvention framework, structure (as opposed to agency) is dominant. The second proposed mechanism is that of epistemic pragmatism, which involves a compromise between researchers with regards to the area of perceived incompatibility. Epistemic pragmatism is undergirded by a pragmatic conceptualization of truth whereby researchers are willing to ignore certain epistemic inconsistencies in favor of a perceived higher goal. In this framework, agency is dominant.

The final proposed mechanism is that of disciplinary synthesis which involves a realignment of the disciplinary
propositions – indeed a paradigm shift – to facilitate a resolution (or synthesis) of what had been perceived as epistemic incompatibilities. In the synthesis framework, neither structure nor agency is dominant, but rather the dialectic between them. It is argued that such a synthesis may be considered as an emergent property of interdisciplinary research that cannot be planned top-down by the CrOP, but rather emerges bottom-up and accordingly requires a loosening of centralized control and organization, but still requires a challenge in researcher’s disciplinary orientation. Disciplinary synthesis is undergirded by a coherence-based conceptualization of truth that does not allow for internal inconsistencies.

Practically it is anticipated that this paper would be beneficial to researchers and organizations seeking to effectively structure interdisciplinary research projects specifically in terms of framing the research problem and the modes of inquiry, and in structuring the interdisciplinary research team. Theoretically, this paper adopts a critical realist perspective which seeks to improve our understanding of the causative mechanisms at work within interdisciplinary research systems.

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ORCID iD

Amaris Dalton https://orcid.org/0000-0002-2893-1961
Karin Wolff https://orcid.org/0000-0002-6150-8364
Bernard Bekker https://orcid.org/0000-0002-5574-0482

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