Reflective Interdisciplinarity in Practice: Integrating Biology and Philosophy in Studies of Individualization

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Abstract

Interdisciplinary research is widely acknowledged as a valuable means of knowledge production and as crucial for addressing complex scientific and societal problems. Interdisciplinary research takes many forms, and this article offers a novel case study of a distinctive form of interdisciplinarity, *reflective interdisciplinarity*. The article analyzes interdisciplinary research undertaken by philosophers of biology and empirically working biologists studying individualization. This kind of interdisciplinarity is reflective because biology is the target domain that philosophers of biology (and philosophically-minded biologists) reflect upon – as opposed to interdisciplinarity that occurs, for example, when insights from multiple distinct research domains are integrated. To analyze our case study, an analytic framework is developed that expands the framework of Katri Huutoniemi and colleagues. The developed framework distinguishes four dimensions of interdisciplinarity: objects of interdisciplinary research, interdisciplinary research activities, communication of interdisciplinary results, and personal, institutional, and other conditions of interdisciplinary research. The case study shows, first, that reflective interdisciplinarity can involve deeply immersive and cooperative interdisciplinary research processes ('*inquiry-embedded integration'*) that include a form of knowledge-producing inquiry through which novel epistemic products emerge from joint commitments and goals, shared research questions, and intensive, collaborative discursive practices. The article adapts Margaret Gilbert's notion of a plural subject in characterizing inquiry-embedded integration. Second, the analysis of the case study demonstrates how communicative choices, together with institutional and normative conditions, are partially constitutive of the interdisciplinary process. They shape the content of interdisciplinary products and play decisive roles in interdisciplinary activities such as knowledge integration. Finally, because the case study comprises the authors' own research processes and publications, the analysis demonstrates that self-reflexive, qualitative analysis of interdisciplinary practice provides a valuable means of theorizing about interdisciplinarity with potential to offer transferable insights.

1. Introduction

This article analyzes how reflective interdisciplinary research works in practice through a case study of collaborations between empirically working biologists and philosophers of biology. The interdisciplinarity involved is *reflective* because the interdisciplinary collaborations brought together biologists and philosophers of biology – the latter representing a discipline that reflects on the former (Kaiser et al. 2014). The focus of that collaborative research is on individual differences (variation among individuals in a species population) and individualization (how individual differences emerge and change) in animals. We show that our case study reveals some underlying processes and mechanisms of how interdisciplinary collaboration functions, and when and why it is successful. Freeth and Caniglia (2020) point out that, oftentimes, interdisciplinary collaborators are figuring out how to collaborate on the spot, whilst collaborating. Given that interdisciplinarity is widely held to be both a valuable means of knowledge production and crucial for addressing complex scientific and societal problems (e.g., Nissani 1997; Repko 2008; Frodeman 2010; Lowe et al. 2013; Waldman 2013; O'Rourke et al. 2016; Serpa et al. 2017; Freeth & Caniglia 2020; Reijula et al. 2023), understanding the 'how' of particular cases of interdisciplinary research is important because it can give rise to insights that may be transferable to other cases, providing useful guidance for future (reflective) interdisciplinary research.

Much of the philosophical and methodological research on interdisciplinarity has centered on developing conceptual typologies (e.g., Kelly 1996; Boden 1999; Choi & Pak 2006; Klein 2010; Mäki 2016) and on discussing the various obstacles and opportunities of interdisciplinarity (e.g., Repko 2008; Weingart & Padberg 2014; Brister 2016; MacLeod & Nagatsu 2016; MacLeod 2018; Nersessian 2019; Freeth & Caniglia 2020; Kuper et al. 2025). These issues are undoubtedly important. At the same time, we have much to gain from examining the practical "nuts and bolts" of how interdisciplinarity operates in specific cases, particularly with a view toward informing future interdisciplinary work (Lau & Pasquini 2004; Prainsack et al. 2010; Collard & Fitzgerald 2015; Bozeman et al. 2016; Fam & O'Rourke 2020). As has been observed, many publications on interdisciplinarity have tended to "hover at the level of theory with little or no attention to what is happening on the ground of practice" (Klein 2005, 7). Fortunately, this pattern has begun to shift (see, e.g., MacLeod & Nersessian 2016; Nersessian 2019). This article contributes to that shift by focusing on that practical dimension of interdisciplinary work.

Our analysis starts from the observation that much interdisciplinary research is *integrative*, that is, involves the constructive combination of knowledge ('epistemic integration') from different disciplines (O'Rourke et al. 2016). Following the literature, we call this 'integrative interdisciplinarity', and it contrasts with proposed forms of non-integrative interdisciplinarity (e.g., Grüne-Yanoff 2016; Thorén and Persson 2023) which remain outside the scope of this paper. We understand 'knowledge' (and 'the epistemic') broadly, as including various *elements* (Repko 2008, 83; O'Rourke et al. 2016, 68), such as concepts, assumptions, methods, theories, data/evidence, and explanations. The observation that interdisciplinarity is often integrative is widely touted (e.g., Boden 1999; Youngblood 2007; Repko 2008; Boix Mansilla 2010; Klein 2010; Hvidtfeldt 2017; Nersessian 2019), with some believing integration to be the hallmark of interdisciplinarity (e.g., Boden 1999; Repko 2008). Huutoniemi et al. (2010) provide a framework for the analysis of the sort of knowledge integration that is typically at play in integrative interdisciplinary research. We revise and extend this framework to analyze four dimensions of integrative interdisciplinarity (henceforth,

'interdisciplinarity'). These are: (1) the elements of knowledge being integrated (*objects* of interdisciplinary research), (2) how the integration is performed (*activities* of interdisciplinary research), (3) to which audience(s) integration results are communicated (*communication* of interdisciplinary results), and (4) why and under which conditions integration takes place (personal, institutional and other *conditions* of interdisciplinary research).

For our case study we analyze interdisciplinary research undertaken in the context of the Joint Institute for Individualisation in a Changing Environment (in short, "JICE"), located at the Universities of Münster and Bielefeld in Germany. The JICE brings together researchers from different disciplines interested in diverse aspects of individualization and hosts several projects, including the Transregio-Collaborative Research Center TRR-CRC 212 (in short, "CRC") "A Novel Synthesis of Individualisation across Behaviour, Ecology and Evolution: Niche Choice, Niche Conformance, Niche Construction", funded by the German Research Foundation (DFG), and a research project "Individualisation in Changing Environments" (in short, "InChangE"), funded within the programme "Profilbildung 2020" of the Ministry of Culture and Science of the State of North-Rhine Westphalia. The CRC brings together empirically working biologists from ecology, behavioral and evolutionary biology, as well as theoretical biologists, statisticians, and philosophers of biology to study individual differences, individualization and its consequences.

The insight that individuals within a species population differ in ecologically and evolutionarily significant ways has driven biological research on individualization for the past two decades (e.g., Bolnick et al. 2003; Réale et al. 2007; Dingemanse et al. 2010; Wolf & Weissing 2012; Edelaar & Bolnick 2019). Biologists study, for example, individual differences in behaviors (e.g., animal personalities; Kaiser & Müller 2021), metabolic and hormonal traits (e.g., Barber et al. 2024; Mutwill et al. 2020, 2021; Rystrom et al. 2024), and interactions with the environment (i.e., individualized niches; Takola & Schielzeth 2022; Krüger et al. 2026). Moreover, biologists investigate how these differences arise and change over time (i.e., processes/mechanisms of individualization; Trappes et al. 2022), how individual differences are mediated, for example, by infochemicals (Müller et al. 2020) or genetic and epigenetic factors (e.g., Grosser et al. 2019; Errbii et al. 2024; Hoffman et al. 2024), and which ecological and evolutionary consequences distinct individual differences have (e.g., Réale et al. 2007; Schwarz et al. 2022; Errbii et al. 2024). InChangE broadens this scope by including researchers from psychology, sociology, economics and management science, geoinformatics, and the medical, psychiatric, and public health sciences (e.g., Baune 2020; Abendroth et al. 2022; Boissonnet et al. 2023; Kandler et al. 2024; Carranza-Pinedo & Diprossimo 2025; Kuper et al. 2025).

Philosophers contribute to the study of individualization in several ways. This includes clarifying and refining central concepts, such as individualization (Kaiser et al. 2024b; Killin 2025), individuality (Kaiser & Trappes 2021; Trappes 2022), animal personality (Kaiser & Müller 2021), individualized niches (Trappes et al. 2022; Kaiser & Morrow 2025a, 2025b), niche choice, niche conformance, and niche construction (Trappes et al. 2022; Kaiser & Trappes 2023), and the social niche (Kaiser et al. 2024a). Additionally, philosophers contribute by pointing out the empirical relevance of definitions and conceptual distinctions (Kaiser et al. 2024a), scrutinizing methodological assumptions (Kaiser & Müller 2021) and epistemic challenges (Trappes et al. 2025), providing common-ground conceptual syntheses and analyses thereof (Kaiser et al. 2024b; Kaiser & Morrow 2025a), providing qualitative, thematic

analysis of core aspects of the interdisciplinary research (Killin 2025), explicating arguments for certain views (Trappes et al. 2022), and revealing implicit assumptions that give rise to misunderstandings or controversies (Kaiser & Morrow 2025b).

Our case study analysis is *self-reflexive* in orientation. We examine the research processes and outputs (publications) of an interdisciplinary research center and project to which we belong. Analyzing our own interdisciplinary research as a case study provides the advantage of having access to detailed information about how the interdisciplinary collaborations proceeded – the context of the research situation (von Unger 2021). In other words, we have first-hand backstage access to the research processes underwriting the publication projects. Most of this remains hidden when solely approached from an external viewpoint, for example when an analysis is restricted to the outputs of others' collaborations, such as publications. A further, ethical merit of self-reflexive analysis is that it motivates accountability through transparency (and may manifest other ethical virtues too; von Unger 2021; see also Huutoniemi 2016). However, our analysis tells only one part of the story. While some of our insights from our case study may generalize to other interdisciplinary collaborations (in particular, to other cases of reflective interdisciplinarity), others are likely specific to the fields involved – biology and philosophy of biology – or even to the individual researchers themselves. Thus, there are limits to our paper's generalizability. To gain a more complete picture of how interdisciplinarity works in practice, our analysis should be complemented by further studies that, for instance, focus on interdisciplinary collaborations between different disciplines than ours, or that use different methodologies (Lau & Pasquini 2004; Prainsack et al. 2010; Gerson 2013; Collard & Fitzgerald 2015; Bozeman et al. 2016; Fam & O'Rourke 2020). Our article expressly encourages such a research agenda.

This article proceeds as follows. Its main claim is that a detailed analysis of specific cases of productive interdisciplinary research – the nuts and bolts of how interdisciplinarity works in practice – is insightful for its own sake, for its contribution to philosophical theorizing about interdisciplinarity, and for its potential to inform future interdisciplinary research. Section 2 clarifies the sort of interdisciplinarity that we are concerned with and then outlines our framework of analysis. Sections 3 through 6 apply each of the four dimensions of this analytical framework to our case study. The article advances four main conclusions. First, reflective interdisciplinarity – in our view, an underexplored form of interdisciplinarity – warrants sustained analytical attention. Second, two forms of knowledge integration in interdisciplinary collaborations can be distinguished: extant-knowledge integration and inquiry-embedded integration, in which researchers constitute interdisciplinary epistemic plural subjects. Third, applying the four dimensions of our analytic framework to particular cases enables rich qualitative analyses. Such analyses show, for example, that communicative choices are not merely responses to externally imposed constraints but are also partially constitutive of the interdisciplinary research process itself. Finally, our case study shows that a self-reflexive approach to analyzing interdisciplinary research is both theoretically and empirically valuable. These are lessons, we believe, that are transferable beyond our specific case study.

2. Interdisciplinarity as Knowledge Integration

Before proceeding with our case study, some preliminaries are necessary to provide a solid ground for our analysis. First, we need to provide a basic characterization of what we take interdisciplinary research to be, which grounds the framework of analysis that we develop and use in this paper. Second, we need to consider further

the distinctive features of the interdisciplinarity of our case, which involves clarifying the reflective interdisciplinarity at stake. The aim of this section is to address both points (2.1 and 2.2) and then to introduce our framework of analysis (2.3).

2.1 Interdisciplinarity and Knowledge Integration

We follow the literature in distinguishing interdisciplinarity from multidisciplinarity and transdisciplinarity. Multidisciplinarity involves the parallel, side-by-side research pursuits of disciplines on a research topic, or the juxtaposition of insights from multiple disciplines on a research question. By contrast, interdisciplinarity involves disciplinary boundary crossing such as integration (Boden 1999; Repko 2008), problem feeding (Thorén & Persson 2023), or other kinds of exchange (Grüne-Yanoff 2016; Mäki 2016). Transdisciplinarity incorporates actors beyond academics as research partners, such as local communities, policy makers, companies, and other stakeholders (Hoffmann et al. 2013). Interdisciplinarity is what is at stake in this article, and in particular, integrative interdisciplinarity.

Integrative interdisciplinarity involves the constructive combination of elements of knowledge (e.g., Repko 2008, 83; O'Rourke et al. 2016, 68), such as concepts, assumptions, methods, data/evidence, explanations, or theories, from multiple disciplines (see, e.g., Boden 1999; Kelly 1996; Youngblood 2007; Boix Mansilla 2010; Klein 2010; Hvidtfeldt 2017; Nersessian 2019). As Repko formulates it, "interdisciplinary integration is the process of creatively combining ideas and knowledge from disciplinary and other sources to produce a more comprehensive understanding or cognitive advancement" (Repko 2008, 123). The other sources that Repko has in mind are interdisciplines, like cognitive science, and schools of thought with broad application, such as Marxism or feminist theory. Interdisciplinary researchers "*integrate* information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single-disciplinary means" (Boix Mansilla 2010, 289; emphasis in original). Committing to the assumption that interdisciplinarity requires the integration of knowledge (see, e.g., Boden 1999; Youngblood 2007; Repko 2008; Boix Mansilla 2010; Klein 2010; Hvidtfeldt 2017; Nersessian 2019), although not necessary for our purposes, allows one to distinguish genuinely interdisciplinary research from, for instance, a mere exchange of ideas between disciplines or a juxtaposition of research methods.

Knowledge integration, however, can occur in diverse forms (Mäki 2016; O'Rourke et al. 2016). Two are particularly relevant to our case study, which we call 'extant-knowledge' integration and 'inquiry-embedded integration'. The division and character of cognitive labor (see Reijula et al. 2023) takes a different shape across the two forms: Extant-knowledge integration is a more traditional style of integration, in which elements of knowledge, once extracted from distinct research lines, are integrated to produce new understandings. This occurs, however, at a relatively late stage in the research process (Repko 2008). Inquiry-embedded integration is a more immersive and interdependent style of collaboration, in which researchers from different disciplines form a unit together that focuses on shared research questions and aims, developing emergent interdisciplinary knowledge together through extensive collaboration *as a body*, on the basis of individual researchers' complementary expertise. The two forms of knowledge integration are not mutually exclusive and indeed can and do overlap. We return to this in Section 4.

2.2 Reflective Interdisciplinarity

We now turn to the second issue, clarifying the peculiarities of the interdisciplinarity in our case study. The case study concerns the interdisciplinary collaboration between a philosophical discipline (philosophy of biology) and the discipline that it reflects on (biology) – rather than, say, a collaboration that integrates insights from multiple distinct research lines (perhaps the synthesis of insights from biological and economic data in the service of answering a research question about sustainability). For this reason, the interdisciplinarity in our case study is characterized as *reflective* (Kaiser et al. 2014). Researchers from the two disciplines, biology and philosophy of biology, typically address different types of research questions and have different "modes of thinking" (Repko 2008, 19), but often with respect to the same subject matter. Philosophers of biology typically tend towards the aspects of biology that are more conceptual, abstract, qualitative, and general; empirically working biologists typically tend towards the aspects that are more empirical, concrete, quantitative, and particular; both are generally interested in methodology and theory, as well as evidence synthesis. Even though the characterizing features of the difference in perspective and research interests here are more or less specific to cases of reflective interdisciplinarity (see Kaiser et al. 2014, 60), a difference in the types of research questions and the modes of thinking between different disciplines generally holds in most interdisciplinary research (Repko 2008).

When researchers with complementary skills and expertise pursue a common goal and mutually contribute to each other's research process (combining Boden's co-operative and integrated forms of interdisciplinarity; Boden 1999; Klein 2010), progress is typically made easier when the gap between the disciplines is rather small or has been substantially reduced or otherwise overcome. Indeed, in our case, the productive combination of biology and philosophy of biology was possible and very natural because biologists with strong interest in theoretical-conceptual issues came together with philosophers of biology who employ a practice-based (e.g., Ankeny et al. 2011; Boumans & Leonelli 2013; Waters 2019) and philosophy-*in*-science approach (Pradeu et al. 2024). This philosophical approach demands a careful analysis of biological research in practice, addressing also biological research questions, and seeking to produce philosophical ideas and claims that are biologically relevant. Hence, in our case, the two collaborating disciplines are rather "neighboring fields" (Fagan 2025, 126) or "trading zones" (Galison 1997; Wylie 2000; Collins et al. 2007). This stands in contrast to cases of "broad" or "wide" interdisciplinarity across humanities and the sciences, which deal with a larger gap (Kelly 1996; Klein 2010).

2.3 An Analytic Framework for Integrative Interdisciplinarity

To further analyze the knowledge integration at play in our case study, a framework is needed. Huutoniemi et al. (2010) developed a typology of interdisciplinary research that consists of three dimensions: (1) scope of interdisciplinarity, i.e., what is integrated; (2) type of interdisciplinary interaction, i.e., how it is done; and (3) type of goals, i.e., why interdisciplinarity takes place. Prima facie, this framework seems useful and appropriate because it is in accordance with central philosophical insights. First, the dimension "scope of interdisciplinarity" draws attention to the fact that different elements of knowledge can be integrated, giving rise to different types of epistemic integration (e.g., Mitchell 2003; Andersen & Wagenknecht 2013; O'Malley & Soyer 2012; Craver & Darden 2013; Leonelli 2016). Second, the dimension "type of interdisciplinary interaction" corresponds well with the philosophical thesis that for

understanding how science works we should not only consider scientific outcomes or results but pay special attention to the epistemic activities in which scientists engage (e.g., Chang 2012). Finally, the dimension "type of goals" is in line with the general pragmatist stance that we need to analyze the epistemic (and non-epistemic) goals that scientists pursue (e.g., Andersen & Mitchell 2023).

However, we revise and extend Huutoniemi et al.'s framework to capture additional aspects that are relevant to analyzing interdisciplinary research. We add a fourth dimension that concerns the communication of the results of interdisciplinary research, and we revise a dimension to analyze not only researchers' aims ("type of goals"; Huutoniemi et al. 2010) but more broadly the personal, institutional and other conditions under which interdisciplinary collaborations take place. Our framework thus encompasses four dimensions (see Table 1).

Table 1. Framework for analyzing interdisciplinary research, distinguishing four dimensions of analysis: objects, activities, communication and conditions of interdisciplinary research.

Dimension	**Characterization**
(1) *objects* of interdisciplinarity	what sort of knowledge is integrated, such as research questions, methods, research results (the "scope of interdisciplinarity"; Huutoriemi et al. 2010)
(2) *activities* of interdisciplinarity	how the integration is performed (the "type of interdisciplinary interaction"; Huutoriemi et al. 2010)
(3) *communication* of interdisciplinarity	how the integration process and results are shaped by the need to communicate the results to the targeted readership (including, e.g., decisions over articulation and extra-textual representation)
(4) *conditions* of interdisciplinarity	why and under which conditions – whether general or more particular – integration takes place (e.g., aims of researchers and institutional structures impeding or facilitating interdisciplinarity).

In the following sections, we use this framework to analyze how biological and philosophical knowledge is integrated in studies of individualization. Reflecting on our own interdisciplinary research, which allows for detailed access to 'behind the scenes' processes of the research invisible in final outputs, we focus on four specific interdisciplinary publication projects associated with JICE (see Table 2).

Table 2. Integrating biology and philosophy of biology in studies of individualization: specific publications comprising the interdisciplinary case study, their main topic, summary of content, journal and intended primary readership, and disciplinary composition of co-authors.

Reference	Main Topic	Short summary	Journal / intended primary readership	Disciplinary composition of co-authors
Kaiser & Müller 2021	Animal personality	This article examines what it means for animals to have personalities, clarifying the ontology of animal personality and how personality traits are studied in biology. It argues that personality traits are best understood as behavioral dispositions and proposes three criteria - individual differences, temporal stability, and contextual consistency - for identifying them.	Biology & Philosophy (philosophy)	1 philosopher, 1 biologist
Trappes et al. 2022	Niche choice, niche conformance, and niche construction	This article introduces three mechanisms of organism-environment interactions: niche construction, niche choice, and niche conformance (NC^3). It shows how these processes shape phenotype-environment matches, fitness, and individualized niches, thereby linking individual- and population-level research.	BioScience (biology)	4 philosophers, 8 biologists
Kaiser et al. 2024a	Individualization concepts across disciplines	This article examines how different disciplines approach individualization and distinguishes three forms: generating individual differences (Individualization$_{ONE}$), tailoring applications to individuals (Individualization$_{TWO}$), and social changes shaping autonomy and responsibility (Individualization$_{THREE}$). It clarifies links between individualization and individuality, and it provides a shared conceptual basis to support interdisciplinary research.	European Journal for Philosophy of Science (philosophy)	3 philosophers, 10 biologists, 10 other scientists
Kaiser et al. 2024b	Social niches	This article clarifies the concept of an individualized social niche, distinguishing it from related concepts such as social environments and roles. It outlines three processes - social niche construction, conformance, and choice - that explain how these niches arise and change within ecological and evolutionary contexts.	BioScience (biology)	1 philosopher, 4 biologists

Three publications are within the scope of the CRC (biology and philosophy), while the paper Kaiser et al. 2024b is broader, drawing also on other disciplines represented in InChangE. Focusing on these four publication projects allows us to analyze the dimensions of interdisciplinary research in considerable detail, and given the spread of specific topics and disciplines, also to seek more general insights about how interdisciplinary collaboration works in practice. Figure 1 provides an overview and detailed information about the research processes leading to the four publications.

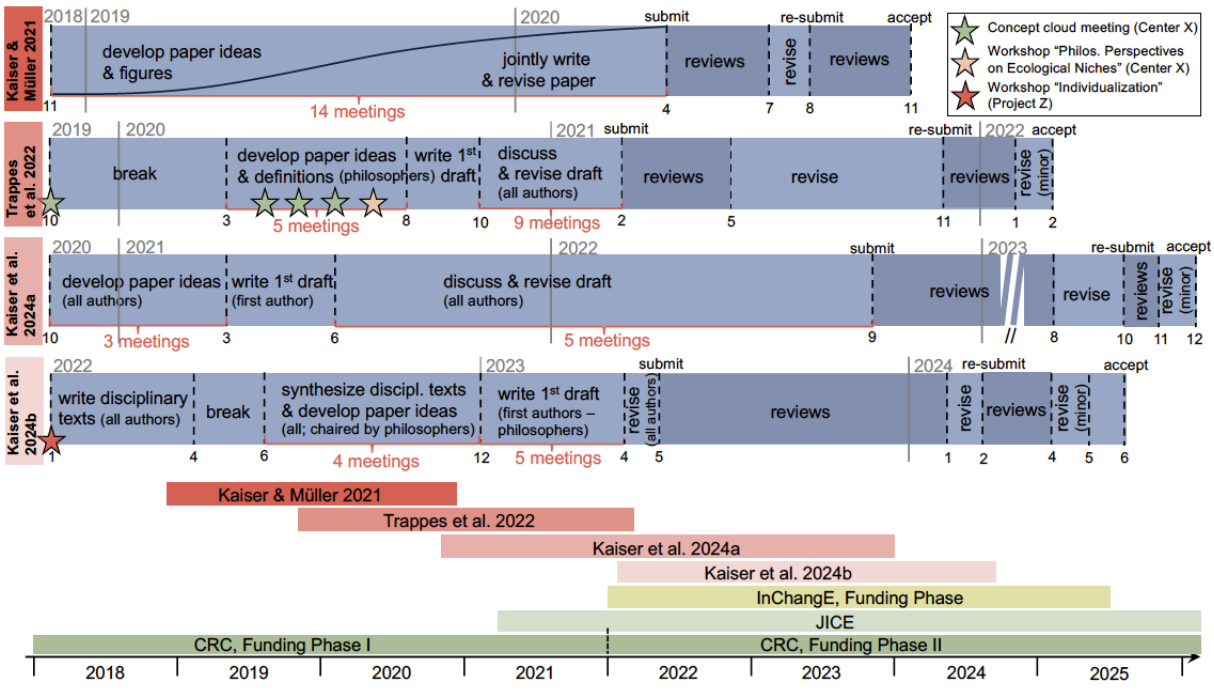

Figure 1. Timeline of collaborative research activities and publications (2018-2025). The lower panel summarizes the funding phases (CRC, Phases I-II; InChangE), the foundation of JICE, and the publication trajectories of the four analyzed papers: Kaiser & Müller (2021), Trappes et al. (2022), Kaiser et al. (2024a), and Kaiser et al. (2024b). The upper panel details the stages of each publication process - from idea development and inputs from collaborative events (e.g., thematic workshops and meetings), through drafting and collective discussion, to submission, peer review, revision, and acceptance -, thereby illustrating the structure and intensity of interdisciplinary exchange.

3. Objects of Interdisciplinarity: What is Integrated?

In the philosophical literature, different types of epistemic integration are discussed, most prominently theoretical integration (Darden & Maull 1977; Mitchell 2003), mechanistic or explanatory integration (Mitchell 2003; Craver 2005; Darden 2005; Bechtel & Richardson 2010; Craver & Darden 2013; Bechtel 2013), and methodological and data integration (O'Malley & Soyer 2012; O'Malley 2013; Love & Lugar 2013; Elliott-Graves 2016; Leonelli 2016).

Interestingly, our case study shows that some types of epistemic integration are more relevant than others to interdisciplinary collaborations between biologists and philosophers. Philosophers of biology typically do not collect new empirical data that could then be integrated with biologists' data (data integration); similarly, in our case, it is not mechanistic knowledge or explanations (from biology and from philosophy) that get integrated. Rather, the interdisciplinary collaborations between philosophers and biologists in our case concern integrating research questions, methods, and the findings of previous research (Mitchell 2009; Brigandt 2010, 2013). Sometimes the collaborative activities are not best described as integrating extant elements of monodisciplinary knowledge, but as focusing on shared research questions and aims, and conducting research together as an epistemic "plural subject" (*sensu* Gilbert 2006; Bacharach & Tollefsen 2010). We will discuss the latter point in Section 4 and focus now on the integration of research questions (3.1), methods (3.2), and previous research results (3.3).

3.1 Integrating Research Questions

One element of knowledge that is integrated in our examples comprises *research questions*. Despite differences in focus, all four publications address research questions that span the biological and the philosophical, and both are treated on *a par*. Indeed, the two are often not clearly separated or flagged out as disciplinary questions, and they are integrated in several ways.

One way to integrate philosophical and biological research questions would be to first identify these questions and deliberately subsume them under a joint, more general question that encompasses the more specific questions from both fields. However, some research questions are already by their nature philosophical-biological questions and can be readily addressed as shared research questions amenable to the joint expertise of the interdisciplinary group. For instance, Kaiser and Müller (2021) address the central, shared question "What is an animal personality?", which encompasses various conceptual, methodological, and ontological issues about animal personality, including research questions that are more biological (e.g., how can we operationally define the biological concept of animal personality?, what are examples of personality traits and types?), or more philosophical (e.g., what is the ontological nature of animal personality?, how is the animal personality concept related to other concepts, such as 'behavioral syndrome'?). Because research questions must be formulated before they can be addressed, we take the liberty of counting such composite, shared research questions as 'integrated' if they can be

productively decomposed in this way and are addressed within the context of an interdisciplinary project. As explained in Section 4, the more specific matters pertaining to Kaiser and Müller's central question are tackled by the authors explicitly via an intensive, collaborative, and discursive style of joint research.

Sometimes the target journal or readership influences the disciplinary balance of research questions. The paper Trappes et al. (2022) originally had a more philosophical framing (i.e., exploring more philosophical research questions about niche construction theory and the conflict between the Modern Synthesis and Extended Evolutionary Synthesis), but was submitted to a biology journal and ultimately revised to focus on its more biological research questions. This was in large part due to comments from biology reviewers regarding the empirical payoff of philosophical questions.

We speak about research questions being 'more philosophical' or 'more biological' because we think that there is no sharp distinction between these two sorts of research questions. However, there are some differences in the questions that philosophers and biologists typically ask, which allow for characterizing certain questions as (more) philosophical, others as (more) biological. When it comes to biological concepts, such as 'animal personality', 'social niche', 'niche choice', 'niche conformance', 'niche construction', 'individual differences', and 'individualization', biologists are typically concerned with defining these concepts with practical implementation in mind, linking them to specific, empirically studied examples, and pointing out the empirical relevance of conceptual considerations. This is why these papers aim at developing clear definitions, and providing examples of these phenomena. Philosophers, by contrast, tend to be interested also in the ontological assumptions implicit in defining and using concepts (e.g., animal personality traits as dispositions, Kaiser & Müller 2021; focal individuals as parts of social niches, Kaiser et al. 2024a), in the structure and epistemic roles of concepts (Kaiser & Morrow 2025a), and in contributing to the development of unified conceptual frameworks for different disciplines (e.g., Kaiser et al. 2024b asks which common conceptual-theoretical basis can be established for various disciplines studying individualization).

Some research questions can be assigned to both disciplines, for instance, questions about how a concept relates to other concepts. Examples include how 'social niche' relates to 'social environment' and 'social role' (Kaiser et al. 2024a), how 'animal personality' relates to 'behavioral syndromes' (Kaiser & Müller 2021), which different concepts of individualization can be distinguished, and how they relate to each other (Kaiser et al. 2024b; see also Killin 2025). Other research questions can be formulated in a more philosophical or biological way. For instance, we can ask "What are the criteria for ascribing personality traits?" versus "When does an individual have a certain personality trait?" (Kaiser & Müller 2021). Whether a research question is more philosophical or more biological partly depends on whether it is connected to existing debates or research fields in philosophy or in biology, and whether it conforms to certain disciplinary standards (e.g., philosophers looking for ascription criteria whereas biologists are more engaged in empirical studies).

3.2 Integrating Methods

In our case, knowledge is also integrated by combining philosophical and biological *methods*. The biological methods that are relevant here are mainly methods used in conceptual-theoretical research in biology, such as in writing concept, opinion, or review papers, rather than the empirical methods used in biological laboratory research or fieldwork. Empirical methods are sometimes described in interdisciplinary

publications (e.g., Kaiser & Müller 2021), but biologists tend not to use them directly as means to research collaboratively with philosophers of biology, or in contributing to the writing of joint publications with philosophers. Still, the methods that biologists use when writing concept, opinion, or review papers tend to differ from those of philosophers of biology, and these were integrated in the writing of joint, interdisciplinary publications.

When exploring what an animal personality is, Kaiser & Müller (2021) analyzed exemplary empirical studies of boldness in animals, as one example of a personality trait. The bibliographic search identifying salient empirical studies was initiated and performed by Müller (the biologist of the duo) since this method is much more frequently used in biology. Moreover, figures, tables and boxes are much more frequently used in biological than in philosophical publications. Accordingly, all four publications include several figures, and the two targeted at biology journals also make use of tables and boxes. This point will be picked up in Section 5 since it also concerns how the results of interdisciplinary research are then communicated. However, the creation especially of boxes and tables during the writing process is also a research/writing method that influences the results of the interdisciplinary research/integration. Thinking together in the form of figures (and boxes), in our experience, leads to different outcomes than thinking together just in the form of text. Figures in biology are typically based on concrete empirical examples and aim at generalizing findings in an intuitive way (e.g., niche construction is visualized as a simple two-step process by using geometrical forms and colors: the form and color of the environment icon is changed so that it matches the form and color of the individual icon; Müller et al. 2020). By contrast, the figures of and for philosophers are often more schematic and less concrete, used to visualize conceptual distinctions and definitions. This is due to the different research interests, conventions, and expectations of the two disciplines. The fact that all four publications include figures, but that the two in a biology journal include less schematic and more concrete figures, together with boxes, indicates that biological and philosophical writing/representation methods are integrated in each case but with different degrees of emphasis either on the biological or the philosophical side.

One core philosophical method is providing analytical arguments. Philosophical claims and arguments are supposed to be precise, clear, and comprehensible, as well as strong and convincing. Often, philosophers object to claims and arguments by other philosophers, and they develop new arguments for why other philosophers are mistaken in their views. In interdisciplinary collaborations between philosophers and biologists, the philosophical emphasis on critical and opposing argumentation sometimes clashes with the more moderate style of argumentation common to biology, due in part to the general need in biology to stick to what has been or can be established empirically. When jointly writing papers, philosophers and biologists need to find middle ground and adjust their style of argumentation to the target audience. For example, biologists can temper the tone of philosophers' writing and problematize phrasings typical of philosophers such as "the position by author X is implausible because…" or "we reject the view that…".

Moreover, the epistemic values (or virtues) of conceptual clarity, precision, and formal analytical reasoning (which philosophers are trained to pursue) are often seen as beneficial or enriching in the interdisciplinary discourse from a biological perspective, especially when producing empirically relevant ideas. Philosophers can facilitate joint conceptual work by asking questions, synthesizing data/evidence, summarizing discussions, making explicit and analyzing the argumentative structures

implicit in scientific texts, and drafting definitions, and thereby 'forcing' biologists to be conceptually clear and precise, and to reflect on their own and their discipline's biases regarding various assumptions. Such philosophical contributions are often not directly visible in the output of interdisciplinary projects – the publication – but are crucial 'behind the scenes' aspects of the process of interdisciplinary collaboration. Clarity and precision are also demanded for biological definitions of concepts, even though differences exist regarding how formal a definition must be and what the specific requirements or expectations are. Compared to definitions in philosophy, biological definitions are typically less formal. In line with this, in a more philosophical mode, Kaiser & Müller (2021) provide a comparatively formal definition of the three criteria for assigning personality traits, using variables, and providing individually necessary and jointly sufficient application conditions. By contrast, in a more biological mode, the definitions of the concepts of social niche (Kaiser et al. 2024a) and of niche choice, niche conformance, and niche construction (Trappes et al. 2024) provide less sharp categorical divisions and are expressed less formally.

3.3 Integrating Research Findings

Thirdly, knowledge is integrated in our examples by combining the *previous findings* of philosophical and biological research. These findings are crucial to answering the different research questions addressed in the publications. Since the philosophical and biological research questions are integrated (Section 3.1), answering them also requires integrating prior philosophical and biological research findings.

The extent to which disciplinary research findings are integrated in practice varies. In our case, the spectrum extends from simple, section-by-section juxtapositions of philosophical and biological findings to intricate integrations where disciplinary contributions become nearly invisible, though still traceable through discipline-specific citations. An example of the former is Kaiser et al. (2024a), which uses separate sections to present existing disciplinary research about what individualization is and how it is studied in diverse disciplines. These disciplinary research findings are then successively integrated with philosophical findings in the following sections of the paper, identifying similarities across disciplines and facilitating the development of a conceptual-theoretical basis for interdisciplinary individualization research.

By contrast, Kaiser & Müller (2021) interweave biological and philosophical findings (except in the methods section) to tackle the shared question of what constitutes an animal personality. From the biology side, they draw on previous conceptual-theoretical biological research from review, opinion, and concept papers, as well as previous empirical studies of boldness (as one example of an animal personality trait). From the philosophy side, they use literature on dispositions, operationalization, and virtue ethics. These disciplinary research findings are then brought together, integrated, and used to develop new interdisciplinary ideas, such as that personality traits are dispositions, that the concept of personality traits is operationally defined in terms of behaviors and experimental set-ups, and that personality traits/virtues must be stable across contexts.

4. Activities of Interdisciplinarity: How Does Integration Work?

Our case study reveals that in (reflective) interdisciplinary collaborations knowledge can be integrated in different ways. We think that two forms of knowledge integration are most important in our cases: extant-knowledge integration and inquiry-embedded integration (recall Section 2.2). *Extant-knowledge integration* is a more traditional

style of integration, in which extant disciplinary elements of knowledge are brought together to create a new, insightful, integrated whole (Repko 2008). As pointed out in the previous section, extant-knowledge integration happens when philosophers and biologists collaborate and bring together pre-existing philosophical and biological research questions, methods, and research findings and integrate them into new, interdisciplinary wholes.

There is a second integration activity, *inquiry-embedded integration*, also happening in our cases. It involves representatives of different disciplines focusing together directly on shared research questions that are amenable to the different disciplines involved, and proceeding (via shared epistemic aims and other shared commitments) to produce new interdisciplinary knowledge by way of extensive joint discussions and joint thinking, merging the represented expertise. Whereas extant-knowledge integration involves the production of new, interdisciplinary knowledge via the synthesis of existing disciplinary knowledge, inquiry-embedded integration bakes interdisciplinarity into the investigative approach itself, and does so earlier in the process. In cases of inquiry-embedded integration, we thus see that interdisciplinary integration does not (or need not) primarily occur at the level of synthesizing results produced independently by distinct disciplinary investigations. Rather, it unfolds in the course of the research process itself, producing an interdependent investigative dynamic, shaping research questions, methods, modes of communication, and related aspects.

For example, Kaiser & Müller (2021) address the philosophical-biological research question “What is an animal personality?” by explicating how (animal) personality in general is related to personality traits and behaviors, and by specifying three conditions for ascribing personality traits to individual animals. Through intensive collaboration and discussion with one another, each critically responding to the other’s ideas through a back-and-forth discursive process, the two authors developed all ideas in the paper together and jointly wrote the paper (see Figure 1). Their cooperative research led to a mutual transformation (Plutynski 2013; Pence 2025) of their conceptions of animal personality as well as what counts as an adequate explication of it. One could say that through their joint commitments and via their shared research questions and goals, the two authors produced novel interdisciplinary knowledge as a body, as if they were a “plural subject” (*sensu* Gilbert 2006, 145).

Bacharach and Tollefsen (2010) adapt Gilbert’s notion of a plural subject to the case of co-authorship of (as opposed to “mere contribution” to) artworks. Although our aims are slightly different to theirs, we follow their example and extend their line of reasoning by considering the case of *epistemic* plural subjects in interdisciplinary scientific research. At the heart of Gilbert’s notion of a plural subject is the idea of a joint commitment: “A and B […] constitute a *plural subject* (by definition) if and only if they are jointly committed to doing something as a body” (Gilbert 2006, 144-145, emphasis in original; see also Gilbert 1989). The notion of a joint commitment is content neutral, defined in terms of individuals committing to a shared goal (or goals) as a body, where “committing to” is understood as a decision of the will – pledging oneself to the shared project – signifying an acceptance of responsibility for collaborating on the project, along with other members of the collaboration, working together as a single unit or voice. Acting together “as a body” means that participants are jointly committed to shared goals, are mutually responsive and synchronize tasks, and take an interdependent approach to achieving the result, understood as a collective accomplishment. In cases of artwork

co-authorship, the salient collective accomplishment is presumably the collaborative production of an artwork. The analogous accomplishment for an epistemic plural subject will typically be the production and dissemination of new knowledge, such as through a collective publication.

Research collaborations that constitute an interdisciplinary epistemic plural subject typically will still perform extant-knowledge integration. After all, extant-knowledge integration produces new understandings by productively combining insights based on knowledge from multiple disciplines (Repko 2008). For instance, Kaiser and Müller integrate insights from previous biological literature on boldness in animals with insights from philosophical literature on dispositions, operationalization, and virtue ethics. Nevertheless, our point is that this analysis of constituting an interdisciplinary epistemic plural subject describes exemplarily the nature of Kaiser and Müller's collaborative integrative interdisciplinary research dynamic. Moreover, it partially explains the transformative nature of their interdisciplinarity (Plutynski 2013; Pence 2025), and it usefully distinguishes their case (and cases like theirs) from cases exclusively involving the extant-knowledge integrative style of interdisciplinarity (Repko 2008), as well as cases of interdisciplinarity without integration such as problem-feeding (Thorén & Persson 2023). Although no doubt a fruitful scientific methodology, the passing of problems and solutions across disciplinary boundaries *per se* would appear, in typical cases at least, to lack the formation of such a body that constitutes an interdisciplinary epistemic plural subject.

In their interdisciplinary collaboration, Kaiser and Müller often made different contributions, based on their disciplinary expertise (e.g., different methodological expertise, different knowledge about past research findings, etc.). In this way, the two collaborators worked out how to meet their obligations as individuals that are party to a joint commitment to produce knowledge together and write a paper together on this basis. The biologist Müller contributed knowledge about empirical studies, examples of animal personality traits, knowledge about the animal personality research field (e.g., which research questions have been addressed, which empirical studies exist, what literature is important, what the relevant related topics and research fields are), and methodological expertise (e.g., bibliometric skills, knowledge about which research methods are used). The philosopher Kaiser contributed philosophical ideas about dispositions, operationalization, and virtue ethics, as well as methodological expertise (e.g., developing formal definitions, clarifying concepts). However, they did so together, acting as a body, by contributing together via their joint commitments to achieve shared goals, their mutual responsiveness and synchronization of tasks, and their interdependent approach to collective collaboration.

In two publications – Trappes et al. (2022) and Kaiser et al. (2024b) – the philosopher(s) involved took a leading role in writing the papers by structuring joint discussions, asking clarificatory questions, writing discussion summaries, suggesting definitions, writing first drafts of the papers, and contributing philosophical research findings about niche construction theory, mechanisms and activities, and causal relations. However, the main ideas in the papers were collaboratively developed together by philosophers and biologists in numerous joint discussion meetings. The biologists also contributed knowledge about the biological research field and about their own empirical research by adding relevant examples throughout the paper at hand. Indeed, the papers Trappes et al. (2022) and Kaiser et al. (2024b) involve both extant-knowledge and inquiry-embedded integration to more moderate extents, in contrast to the Kaiser & Müller (2021) paper. In Kaiser et al. (2024b), for instance, the shared central question "What is a social niche?" was addressed by biologists and a

philosopher of biology working closely together, in the manner of an epistemic plural subject, while biological and philosophical methods and previous research findings were also integrated in the more traditional, extent-knowledge manner. These two papers thus were also produced by interdisciplinary epistemic plural subjects, though it could be argued that in comparison to the Kaiser & Müller paper, the collaborators in these two cases constitute epistemic plural subjects to a lesser degree, or constitute an epistemic plural subject less rich in its characteristic qualities.

Finally, the paper Kaiser et al. (2024a) is primarily an example of extant-knowledge integration since disciplinary knowledge is presented separately – initially juxtaposed in the vein of multidisciplinary communication – but this knowledge is then used by the philosophers for conceptual-theoretic integration and analysis throughout the subsequent sections of the paper. The authors constitute a plural subject in Gilbert's sense, but due to their methodological approach requiring only minimal activities of interdisciplinarity, they constitute an interdisciplinary epistemic plural subject only to a baseline or more minimal degree. Thus, while the constitution of a plural subject is typically conceived as being either present or absent (e.g., Gilbert 2006), our analysis also makes sense of the idea that there is a continuum for fruitfully comparing various examples in which it is present.

Our case study confirms the general wisdom that successful interdisciplinary collaborations require identifying or establishing commonalities as well as acknowledging and valuing differences. Researchers need to create or discover a "common ground" (Repko 2008, 271ff) for their interdisciplinary collaboration, such as shared questions, assumptions, theories, or goals, besides a mutually comprehensible vocabulary for tackling these questions and goals (Bracken and Oughton 2006). A practice-based, philosophy-*in*-science approach (Ankeny et al. 2011; Boumans & Leonelli 2013; Waters 2019; Pradeu et al. 2024) fosters interdisciplinary collaboration because it increases the chance of finding such a common ground. This is because such philosophers typically address questions that are more scientific in character, as well as philosophical questions, and they aim at producing scientifically relevant results. Furthermore, in our experience a personal and professional interest in conceptual-theoretical questions among biologists makes it more likely that they will contribute to identifying or establishing shared interdisciplinary research questions with the philosophers. Other important ingredients – for acknowledging and valuing differences yet finding commonalities – include cognitive openness, flexibility, and epistemic humility (see Repko 2008; Valles 2018, ch 8; Nersessian 2019). That is, the willingness to view a research question from different angles and to appreciate the epistemic limits of one's own disciplinary approach. These latter points are linked to the conditions for interdisciplinary collaboration (see Section 6).

5. Communication of Interdisciplinarity: To which Audience(s) are Integration Results Tailored?

When investigating how knowledge integration in interdisciplinary research occurs in practice, we need to reflect also on the target audience to which the results of interdisciplinary research are communicated (Pohl et al. 2015). We need to analyze how the target audience gives rise to specific communication requirements, which in turn affect how knowledge gets integrated. Our analysis shows that the intended audience of a paper not only affects how integration results, once achieved, are presented, framed, and communicated, but also the processes and results of knowledge integration itself (Section 3.2; see also Lattuca 2001). Our case study

affords especially diverse and informative insights because two of the specific publications were published in philosophy journals, targeting mainly philosophers (Kaiser & Müller 2021; Kaiser et al. 2024b), the other two in a biology journal, targeting mainly biologists (Trappes et al. 2022; Kaiser et al. 2024a).

In our case, the choice of target audience strongly influences the balance between philosophical and biological content: naturally, in a philosophy-oriented article, philosophical ideas, research findings, and links to existing philosophical debates will become more prominent and play a more central role in the paper's structure and argumentation. For example, as mentioned in Section 3.1, the paper Trappes et al. (2022) was originally framed much more explicitly as a philosophical contribution aiming to resolve conflicts between proponents of the Extended Evolutionary Synthesis and the Modern Synthesis in biology. This philosophical framing was ultimately removed because it was perceived critically during review. In contrast, Kaiser & Müller (2021) and Kaiser et al. (2024a) target a more philosophical readership and thus highlight connections to existing philosophical debates (e.g., about dispositions, operationalization, virtue ethics, biological individuality, the concept of environment, methodological individualism). From the perspective of philosophical readers these connections are important because they demonstrate the research's broader philosophical relevance. Article form and length matter, too. In philosophy, long argumentative essay-style texts are the norm, which facilitate such philosophical desiderata. Biology journals typically impose shorter word-lengths and often prefer a succinct communication style (e.g., short sentences, short (sub-) sections, systematic structure).

Another way the target audience shapes the integration of disciplinary knowledge is through its influence on a manuscript's writing style. This refers, for instance, to how argumentative the paper is, the extent of critical and opposing wording used, how explicit and precise the argumentation is, and how formal the definitions of concepts are (e.g., by distinguishing the antecedent concept from its application conditions, providing individually necessary and jointly sufficient conditions, using symbols (variables) in the expression of the definition). On top of related points made in Section 3.2 we here claim that the degree to which different disciplinary writing methods are used depends also on the target audience. In practice, this tailoring happens both during and after the integrative research process. Publications written for a philosophical readership/journal allow for and partly require more argumentative text, stronger and more explicitly formulated arguments (which typically includes clearly criticizing other authors and opposing existing views), and more precise, formal definitions of concepts. For instance, the definitions of the three criteria for ascribing animal personality traits in Kaiser & Müller (2021), published in a philosophy of biology journal, are more formal than the definitions of niche choice, niche conformance, and niche construction in Trappes et al. (2022) and the definition of the social niche concept in Kaiser et al. (2024b), both published in a biology journal. Another example is the ontological claim about which social interactions belong to an individualized social niche in Kaiser et al. (2024b). Originally, this claim was very strong and categorically sharp, entailing that only direct social interactions with the focal individual belong to the social niche of this focal individual. In the review process for a biology journal this claim was somewhat weakened by acknowledging the importance of indirect social interactions to the social niche and focal individual. The result is a more inclusive, though less precisely defined concept. Finally, the tailoring of the results to the intended audience also has its limitations. For instance, arguments formulated very strongly, which are relatively common in

philosophical publications, do not occur in any of these four publications. From a biological perspective, they may seem exaggerated and overly blunt and abstract, not necessarily backed up by empirical results; from a practiced-based, philosophy-*in*-science perspective, they are dispensable and can be weakened without de-emphasizing the novelty of the crucial, core ideas. Thus, they were intentionally removed during the interdisciplinary writing process. So far, none of this may appear surprising to interdisciplinary experts, but our point is that decisions about readership can also drive the integrative process (see Section 3.2), not just post-research writing choices.

Indeed, in our cases, the selection of a target audience had an influence on which visualization tools were used during both the research and writing process, which in turn influenced these processes and the results of the interdisciplinary knowledge integration/production (see Section 3.2). This holds for the figures in all four publications, which were drafted early in the writing process, were continuously revised (often triggering or triggered by revisions to the text or by collaborative discussion of key ideas), and played a crucial role in the collaborators' development of interdisciplinary knowledge. Only the boxes and animal pictures in the figures in Kaiser et al. (2024b) were introduced late enough in the writing process that one could argue that this was merely for communicating and tailoring already existing interdisciplinary research results to the biological audience (and not shaping the integration process itself). Interestingly, many highly cited journals in biology, in particular online journals, now require a graphical abstract (Oliverio & Wright 2025), emphasizing figures as an important way to communicate core messages across disciplinary borders.

6. Conditions of Interdisciplinarity: Why and Under Which Conditions Does Integration Take Place?

Huutoniemi et al. (2010) identify the goals of interdisciplinary research as another main aspect of their framework. We believe that it is best to take a fine-grained, localized approach to analyzing the aims of interdisciplinary research, and to consider also the institutional, group-level, and individual-level conditions under which interdisciplinary research takes place. Our category 'conditions of interdisciplinarity' is broader than their 'goals of interdisciplinarity'; it includes global and local aims as well as motivations for and constraints of interdisciplinary research, ranging from the institutional to the individual researcher.

On the institutional level, several grant agencies offer funding schemes that explicitly value and thus welcome interdisciplinary applications, striving to facilitate a range of interdisciplinary research collaborations. The institutional encouragement of interdisciplinary research is well-documented (see, e.g., Lyall et al. 2013; for a brief overview, see Fagan 2025, 125). Of course, there are also funding initiatives with internal disciplinary structures that impose barriers on interdisciplinary proposals (Bromham et al. 2016). Taking the available funding structures into account is crucial for interdisciplinary research: "Interdisciplinary integration is often shaped as much by institutional structures and funding mechanisms as by epistemic or methodological considerations" (Bruce et al. 2004, 468).

The general narrative in favor of interdisciplinarity is that solving complex problems – among them worldwide practical challenges such as climate change, global health, and sustainable energy – requires researchers to team up and bring together their specialized expertise and knowledge (e.g., Lowe et al. 2013). Although Schmidt (2011) problematizes the use of the term "problem" in the interdisciplinary

discourse, the general point here is a familiar one. We concur with Schmidt that interdisciplinarity takes many forms, some not primarily problem-orientated. In our case study, the existence of interdisciplinary research projects on individualization, funded by specific grants for research consortia (rather than individual projects) addressing major themes (rather than specific problems), were important enabling and motivating conditions for the interdisciplinary collaborations and publications. As members of the same research group, biologists, philosophers of biology, and others are expected to collaborate, to produce joint output, and thereby to reveal the merits of the interdisciplinary composition of the research group. This creates important extra incentives for interdisciplinary collaborations and for producing joint publications.

Generally, an important basis for successful interdisciplinarity is shared financial support for the researchers of the various participating disciplines, because this allows the participants to focus on the interdisciplinary work, it generates the necessary commitments from both sides and incentivizes interdisciplinarity. Working collaboratively across disciplines is generally more time consuming and difficult than staying within one's familiar disciplinary limits. In our case study, biologists and philosophers both received funds from the very beginning through the same funding programs and were equally involved in the applications for these funds. This generated a strong mutual respect, interest, and involvement in the interdisciplinary research, and consequently the grant writing process itself led to some important preliminary conceptual clarifications. Interdisciplinarity did not simply happen but was planned and facilitated by funding.

Next, we consider the research group level. Due to their expertise, philosophers can, inter alia, contribute to clarifying scientific concepts and developing conceptual frameworks, facilitating interdisciplinary research. Biologists, due to their empirical knowledge, can contribute to this and empirically validate the philosophical work. Having a clear and solid theoretical-conceptual foundation for empirical research is seen as beneficial and necessary in many empirical research areas and is thus valued by many working biologists. For example, the concepts of the individualized niche and of niche choice, niche conformance, and niche construction are central to the research agenda of the CRC. The task of clarifying these concepts and elaborating their definitions was clearly stated in the grant proposal. Hence, publications presenting these definitions were perceived as research priorities. The paper Trappes et al. (2022) was needed also as a joint point of reference for biological research papers published by biologists in the group. The same holds for the conceptual work on 'animal personality' (Kaiser & Müller 2021) and 'social niche' (Kaiser et al. 2024a), even though these concepts are less central to the entire CRC because they are more specific. The same type of motivating condition, though on the research group level, applies to Kaiser et al. (2024a), which is a response to the clearly articulated need of the InChangE group to have a shared conceptual framework that facilitates interdisciplinary research by explicating similarities and differences between disparate disciplinary studies of individualization.

Moreover, there can be conditions for interdisciplinary research at the level of the research field, especially when there is an acknowledged gap in research or a need for something specific in the research field. One example is the paper Kaiser et al. 2024a, which was motivated by the observation that 'social niche' is used in the biological sciences with a variety of different meanings and the clear need in the field to provide an explicit definition of 'social niche' that aims at unifying the different ideas present in current social niche research (e.g., Saltz et al. 2016).

The structure and organization of a research group impose additional motivating and constraining conditions on the interdisciplinary collaboration between researchers from biology and philosophy of biology. For instance, above the individual project level, the CRC is structured into 'research clouds' aiming at promoting the exchange and collaboration between researchers on specific cross-cutting topics (e.g., life history and sensitive phases, interactions and coexistence, concepts and synthesis, molecular and behavioral facilitators). The existence of a 'concept and synthesis cloud' composed of biologists and philosophers, the regular meetings and inspiring discussions, and the clear task of providing some deliverable output of the cloud was another major, structural driver of the paper Trappes et al. (2022).

Finally, at the level of individual researchers we find additional conditions that motivate, constrain, or guide interdisciplinary collaborations. First, in our case study the involved biologists and philosophers have an epistemic interest and curiosity in the other discipline and in the interdisciplinary collaboration itself. Those involved were intrinsically motivated to seek integrative collaboration across biology and philosophy of biology, which for some individuals was strengthened by past successful interdisciplinary collaborations. Moreover, in our case, personal conditions, such as similar or complementary working styles, academic extroversion, or a keenness for novel, exploratory, empirically facing conceptual-theoretical research, were important motivating conditions on the individual level. The same is true of cognitive openness and flexibility (Section 4): individual researchers' willingness to view a research question from different angles and to appreciate the limits of monodisciplinary approaches motivates and facilitates productive interdisciplinary research. Interdisciplinary research is most productive when its participants take a modest stance towards their own field's potential, not claiming priority or entitlement for a particular discipline's contributions, that is, "epistemic humility" (Valles 2018, 182; see also Repko 2008, 44). Researchers' epistemic interest in interdisciplinary collaborations also depends on the professional and personal benefits perceived or anticipated. All this indicates that successful interdisciplinary collaboration requires identifying commonalities and valuing differences. Certain types of commonalities and differences are also important drivers of interdisciplinary research. Having shared or similar research interests (e.g., in the form of shared research questions and goals) motivates interdisciplinary collaborations in practice. In addition, the differences between the disciplines must give rise to disciplinary skills and expertise that is valued from the other disciplinary perspective, for instance because the expertise is complementary: we believe this is especially salient in cases of reflective interdisciplinarity, such as our case comprising biologists and philosophers of biology (recall Section 2). In sum, a major motivating condition for interdisciplinary research on the individual level is that researchers together produce knowledge (by integrating extant disciplinary knowledge or addressing together the same or similar research questions) and that this knowledge is valued by members of the collaboration, unlikely to have been achieved as adequately, efficiently, or effectively within monodisciplinary silos.

7. Conclusions

Our case study demonstrates that analysis of interdisciplinary research in practice – the nuts and bolts of how specific collaborations operate – yields insights of both conceptual-theoretical and practical significance. Such analyses contribute not only to theorizing about interdisciplinarity but also to shaping future interdisciplinary

endeavors by providing concrete lessons on how interdisciplinary collaboration can succeed. This can also be used to improve existing funding structures of interdisciplinary research. By applying our analytic framework, which explicates the objects, activities, communication, and conditions of interdisciplinary research, we have shown its utility for analyzing complex interdisciplinary projects in a systematic and philosophically informed manner.

A central finding is that reflective interdisciplinarity is a special and theoretically interesting type of interdisciplinarity that warrants sustained analytical attention. One aspect that makes it interesting is that reflective interdisciplinarity, particularly between biology and philosophy of biology, does not always proceed through the straightforward conception of integration of extant elements of disciplinary knowledge. Rather, it can involve a more deeply integrated form of collaboration, inquiry-embedded integration, in which researchers jointly develop new epistemic products through shared questions and discursive practices. Through our case study, we showed how this form of integration can result in productive transformation of a phenomenon's conception and what might count as an adequate explanation (Plutynski 2013, 468). Moreover, we showed that interdisciplinary researchers working together can constitute a distinctive form of plural subject, which we labelled 'interdisciplinary epistemic plural subject'. These findings suggest that interdisciplinarity is not merely a matter of synthesis but at times a mode of inquiry in its own right. Next, our case study analysis demonstrates the utility of our analytic framework. For example, it underscores that communication is not external to integration but at times, partially constitutive of it. Decisions about framing, writing style, and audience shape the very content of interdisciplinary products. Likewise, the conditions under which collaboration occurs – from institutional funding structures to researchers' aims and epistemic values/virtues such as humility and openness – play decisive roles in determining success, a task incidentally also requiring multidimensional approaches (Wagner et al. 2011). Finally, reflecting analytically on interdisciplinary research 'from the inside' proves especially fruitful. Self-reflexive engagement enables collaborators to uncover tacit assumptions, to recognize the epistemic and normative conditions that underlie their joint work and provides a setting that might suggest particular lessons, which are transferable beyond the specific case at hand. In this respect, to do philosophy is not merely to be an observer and critic, but an active participant in interdisciplinary knowledge production.

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