Integration in Biology

Ingo Brigandt

Department of Philosophy, University of Alberta, Edmonton, Canada
Email: brigandt@ualberta.ca

Abstract

Although interdisciplinarity is an ubiquitous idea in science, it wasn't until three decades ago that the idea that the relation among fields consists in reduction was replaced with the notion of integration between fields. The thriving literature on integration in biology recognizes a variety of types of integration, including the integration of data, the integration of methods, and the integration of explanations or models. There are also different features that call for integrative research and motivate integration: the complexity of some biological phenomena, as well as the pursuit of scientific problems or aims that can only be achieved by an integrative framework. Beyond motivating integrative efforts, a complex scientific problem can also structure integrative efforts and scaffold the integrative explanatory framework to be developed, because the problem has an internal structure that entails what disciplinary contributions are needed and how they are to be connected up. Although epistemic aims have been recognized as a major motivation for integration, the important role of non-epistemic aims, such as environmental or biomedical aims, has so far been underexplored in discussions of integration in biology. This yields the opportunity for enhancing interactions with the philosophical literature on science and values, which recognizes that scientific aims can legitimize the use of non-epistemic values within science.

1 Historical background

Given the ubiquity of interdisciplinary research and ongoing calls for more interdisciplinarity, integration—including integration across different biological fields—seems to be an obvious and relevant topic for philosophical discussion. However, philosophers of biology have come to explicitly mention integration not much sooner than three decades ago (Bechtel, 1993), and only two decades ago did integration become a serious topic in the philosophy of biology. Beforehand, the relations among scientific fields had often been characterized as an instance of *reduction*. The so-called layer-cake model of Oppenheim and Putnam (1958) envisioned a hierarchical order of disciplines, where one was reducible to the other: sociology reducible to biology, biology to chemistry, and chemistry to microphysics. Later, not only did such a hierarchical, strictly linear model of the relations of fields came to be rejected, but some even endorsed a thoroughgoing *anti-reductionism* that envisioned a *disunity* of scientific fields (Dupré, 1993; Fodor, 1974; Rosenberg, 1994). Although especially philosophers of biology adduced many arguments against reductionism, such negative arguments have the drawback that they do not provide any positive account of the relations between biological fields. If biological fields and biological theories cannot be reduced to each other, is there any other connection? Contemporary discussions on *integration* in biology can be seen as filling this gap left by previous philosophical debates.

A general account of theory reduction was originally put forward by Ernest Nagel (1949). In a nutshell, he conceptualized reduction as a logical relation between two theories, if the reducing theory logically entails the laws and other components of the theory to be reduced. It was Kenneth Schaffner (1969, 1993) who applied such a theory reduction model to biology, more specifically arguing that classical genetics could be reduced to molecular biology or

biochemistry.[1] This occurred in a historical period where the molecularization of biology was conspicuous, so that it was natural for philosophers of biology to engage with the question of whether classical genetics could be reduced to molecular genetics. Soon after Schaffner advocated reductionism, others argued against it, likewise appealing to a combination of philosophical reasoning and empirical considerations from biology (Hull, 1974; Wimsatt, 1979). There have been two main types of anti-reductionist arguments, which, beyond the original question of whether classical genetics can be reduced to molecular genetics, have reappeared in other cases throughout discussions among philosophers and biologists (Brigandt & Love, 2023).[2]

As already mentioned, even if different biological fields do not stand in a relation of reduction, anti-reductionist arguments leave the connections between fields unanalyzed. A major contribution to this problem was the notion of the *unification* of fields. In the 1970s, Nancy

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[1] Apart from theory reduction, another model was explanatory reduction. Instead of logical entailments, explanatory reduction focuses on part-whole relations, addressing the important idea that a reductive explanation explains a whole in terms of its parts (Sarkar, 1998). While such reductive explanations are related to mechanistic explanations (Kaiser, 2015), many contemporary accounts of mechanistic explanation eschew the notion of reduction, as Section 2 will illustrate.

[2] The first type of argument against reduction points out that the higher-level effect of a lower-level entity (e.g., the phenotypic effect of a DNA sequence) depends on the lower-level entity's context, so that one specific higher-level effect (e.g., one possible phenotype) is not generally entailed by the presence of the lower-level entity (the DNA sequence). The second type of argument points to cases where a higher-level phenomenon is due to different kinds of constellations on a lower level. For instance, classical genetics captures the phenomenon that 'allele *A* is dominant' (relative to allele *a*). Dominance can be due to various underlying molecular features, including within and outside of protein-coding DNA sequence—as long as the molecular constellation generates the phenotype characteristic of allele *A*. If so, one such molecular constellation does not capture all instances of dominance, so that such a lower-level theory as molecular biology fails to account for classical genetics concepts such as dominance, as well as principles from classical genetics, e.g., the law of segregation. (For a more detailed explanation and discussion, see Brigandt & Love, 2023.)

Maull and Lindley Darden argued for unification in biology through the notion of interfield theories (Darden & Maull, 1977; Maull, 1977). One example of theirs is the chromosome theory of inheritance. When established around 1920, the chromosome theory functioned as an interfield theory bridging the hitherto unrelated fields of Mendelian genetics (which studied the inheritance of phenotypes across generations) and cytology (which investigated the material contents of cells and is nowadays called cell biology). This theory asserts that chromosomes are the material basis of inheritance by being the carriers of alleles (genes). Through chromosomal processes taking place within cells, e.g., crossing over, this interfield theory sheds light on phenomena discovered by Mendelian genetics, such as the non-random assortment of alleles called linkage disequilibrium. While this bridging of Mendelian genetics and cytology can be considered a 'unification,' it is not a reduction, as neither was cytology reduced to Mendelian genetics, nor was classical genetics reduced to cytology.

While the term 'unification' is occasionally used in recent philosophy of science (Grantham, 2004a; Nathan, 2017), most philosopher if biology have come to view this notion as inaccurate for capturing actual biology, as it suggests very strong interrelations between fields, possibly the merging of fields, as well as static relations between the fields that do not obtain given the ongoing transformations of individual connections across disciplines. Consequently, the looser term 'integration' has become the most widely favoured notion to describe interrelations across biological fields. An early example of this trend was William Bechtel (1993) describing the creation of modern cell biology (a successor of cytology using new experimental tools) as 'integrating' biological disciplines. Bechtel notes that, at the same time, the creation of cell biology as a discipline also generated a sort of disintegration, because the new discipline institutionally distanced its practitioners from researchers in other disciplines—underscoring why he prefers the notion of integration over the old 'unification.' To be sure, not all instances of integration are across different fields, as findings and models from one field can also be

integrated in scientifically productive ways. But to the extent to which integration involves several fields or disciplines, the notion of *interdisciplinarity* is an allied concept. Correspondingly, many contemporary philosophical accounts discuss integration and interdisciplinarity alongside each other (e.g., Bechtel, 2013; Boon & Van Baalen, 2018; O'Rourke et al., 2016; Plaisance & Elliott, 2021).

2 A variety of types of integration

Many accounts of integration in biology have focused on *explanations* that are integrative. Indeed, Brigandt (2010) and Green et al. (2015) use the notion of 'explanatory integration' in the title of their articles, while Nathan (2017) prefers the label 'unificatory explanation' over integrative explanation. However, a core point of this section will be that there are different types of integration, where one can find at least integration of data, integration of methods, and integration of explanations (Brigandt, 2013b).

Although not all scientific explanations are mechanistic explanations, philosophical accounts of mechanisms were instrumental in championing the notion of explanatory integration as an alternative to the outdated notion of reduction (mentioned in Section 1). A mechanism consists of entities and activities that are organized such that a certain outcome phenomenon (e.g., cell-cell signalling) is produced. Thereby, this phenomenon is explained in terms of the relevant mechanism components, their organization, and interaction. By pointing to concrete examples of *multilevel* mechanistic explanations, philosophers have made the case that these are not reductive explanations, where some of them are also *multifield* explanations (Bechtel, 2013; Craver, 2005; Darden, 2005; Tabery, 2014). In the domain of neuroscience, Carl Craver (2005) analyzes research on memory and learning as uncovering multilevel mechanisms, where different fields contribute. Based on a discussion of how this research has proceeded in practice,

Craver argues that it did not just reductively seek the neural correlate of memory and learning. One feature relevant to memory formation is long-term potentiation, which is the strengthening of synaptic connections between neurons as an important aspect of synaptic plasticity. Yet long-term potentiation was not studied as a kind of memory, but as a component of multilevel memory mechanisms. Craver identifies four relevant levels: memory and performing learning tasks, the hippocampus, synapses and their activities, and, at the lowest level, the activities of molecular entities (such as neurotransmitters).[3]

In a similar fashion, Lindley Darden (2005) uses the notion of mechanisms to argue that the relation between classical and molecular genetics is a case of multifield integration. This not only replaces her earlier invocation of 'unification' with the new notion of 'integration' (see Section 1), but also moves her focus away from theories (Darden & Maull, 1977) to mechanisms as effecting integration. While the field of molecular genetics focuses on such entities as nucleotides and DNA segments, the field of classical genetics addresses chromosomes. Even though chromosomes are ultimately made of DNA, against the idea of reduction Darden (2005) argues that not DNA or other molecular-level entities, but the higher-level entities of chromosomes are relevant to how classical genetics explains the inheritance of alleles. For instance, classical genetics appeals to the crossing-over of chromosomes as accounting for the linkage frequency of alleles (where alleles closer together on a chromosome are more strongly linked as they are less likely to be separated by crossing-over). At the same time, the different entities and activities that molecular and classical genetics address are still connected, through

[3] Craver (2005) also points to intralevel integration as a relevant aspect of this research, for example, the integration of neuroanatomical and neurophysiological approaches. He emphasizes that a reductionistic perspective, always looking to a lower level, obscures how progress has been made by integration within one level.

serially integrated mechanisms.

One fruitful aspect of discussions of integration in terms of mechanistic research is that, rather than exclusively focusing on integrative explanations as the product of science, they also address integration as an *ongoing process*. Many mechanistic explanations are not finished. Instead, the discovery of mechanisms involves finding out about more and more of the entities, activities, and organizational aspects of complex, multilevel mechanisms (Craver & Darden, 2013). This focus on integrative research in scientific practice again departs from traditional arguments for reduction, which invoked reductive explanation as something that can, in principle, be established by some finished science (Brigandt & Love, 2023). Related to integration as a process is O'Malley's (2013) suggestion to view integration as a 'meta-heuristic'—just like reduction can be approached as a meta-heuristic. In either the case of aiming at integration or at reduction, it is not guaranteed that this will be accomplished. Indeed, O'Malley discusses an example of failed integration—the relation between traditional tree-of-life phylogeny and modern prokaryote phylogeny, where networks of ancestry defy an exclusively branching tree structure. Still, it can be fruitful to pursue the meta-heuristic: what is learned along the way of attempting to achieve integration (or reduction) is more important than whether it is ultimately achieved.

The next section will cover other examples of integrative and interdisciplinary explanations that don't prioritize mechanistic explanations. But even though many philosophical discussions on integration have focused on explanations, it is important to recognize other types of integration. Maureen O'Malley and Orkun Soyer (2012) have made the useful distinction between explanatory integration, methodological integration, and data integration. While their case study on the integrative nature of molecular systems biology documents all three types of integration (see also Green, 2013), here I focus on their discussion of the *integration of methods*. Molecular systems biology attempts to understand complex molecular and cellular systems.

Based on data about many molecular components and their interactions, systems biology uses representational and modelling tools to understand the activity in complex molecular networks and its and system-wide effects. According to O'Malley and Soyer, the methods that are combined and integrated in systems biology include experimental methods, computational and bioinformatic tools, and visualization methods. Model building and the computational analysis of complex networks and models are just some examples of bioinformatic tools. In the case of robotized experimentation, experimental and computational tools are being combined. A further method is the generation of hypothesis through the computational mining and analysis of published literature and databases. At the intersection of systems biology and synthetic biology, biological methods are integrated with engineering methods.

An insightful case of *data integration* has been analyzed by Sabina Leonelli (2013) in the context of botanical research. Data produced by various research groups in one context cannot just be amassed in digital databases in an uncoordinated fashion. For data to be usable in the future in a different, often unforeseen research context, data needs to be standardized, where databases have their own rules for how to organize and upload data and are subject to ongoing curation. One aim of data integration is to reduce inconsistencies across different datasets, which may originally come in different formats, may have been produced by different instruments, or may have been generated by methods that differ in their reliability. As an example, Leonelli points to inter-level integration in research on the thale cress *Arabidopsis thaliana*, which is the main model organism in botany. While we have encountered such multilevel integration already in the context of explanatory integration (in terms of mechanisms), apart from inter-level integration, Leonelli (2013) also points to cross-species integration and translational integration. Her example of cross-species integration is using the grass species *Miscanthus giganteus* as part of research on biofuels, given that this grass is less likely to compete with biofuel options also needed as crops, such as corn, for available agricultural land. While this cross-species research

on *Miscanthus* involves comparisons with results on *Arabidopsis*, Leonelli emphasizes that this is not just the transfer of knowledge from one plant to another, but involves an iterative back-and-forth between these two species—hence integration. Finally, translational integration can be found in research of pathogens negatively affecting plants important to humans. The ultimate aim of improving the human well-being requires tools going beyond the other two types of integration. Leonelli emphasizes that sustainability matters to translational integration not only in the sense of financial viability, but also by considering its impact on the environment and human societies.

While the distinction between explanatory integration, methodological integration, and data integration is useful, one needs to bear in mind that there can be connections or overlap between these types of integration, as well as further things that are being integrated in biology. For example, Grantham (2004b) discusses the difficulties with integrating paleontology and the rest of evolutionary biology. One core issue pertains to data: how to integrate paleontology's fossil data with other data, for example, for the purpose of phylogeny reconstruction. At the same time, Grantham notes a connection to methods, in particular, the hurdles for developing methods that permit the merging of the distinctive bodies of data dealt with in paleontology and other evolutionary biology. Beyond explanations (or models), methods, and data as the things subject to integration, Griesemer (2013) points to the integration of 'approaches' in evolutionary research using the salamander as a model taxon. Gerson (2013) focuses on the integration of 'specialties,' which (like disciplines) have institutional and other social underpinnings that may have to be reconfigured to achieve effective integrative research across specialties.

3 What motivates and structures integrative accounts?

Rather than taking integration for granted, one issue to philosophically address is what reasons biologists may have for engaging in integrative research and developing integrative accounts.

One reason is *ontological*: the *complexity* of many biological phenomena. Sandra Mitchell (2003, 2009) has prominently pointed to complexity as calling for integrative accounts. Mitchell dubs her version of integration 'integrative pluralism,' which acknowledges the need for a variety of models and theoretical perspectives that cannot be reduced to each other, while at the same time pointing out that these models can inform each other. Even though the notion of 'levels of analysis' is often used to justify the need for different approaches, each of which models a different level, Mitchell (2003) argues that we should not overlook cases where these levels are not orthogonal but put constraints on each other. One example of hers is accounting for the behaviour of social insects, as an instance of complex social organization and behaviour. There are *evolutionary* models attempting to account for the origin of the behaviours seen in social insect colonies in terms of natural selection. But there are also self-organization models of insect behaviour, which operate at the level of a colony's *ontogeny*. Mitchell's point is that such models are not independent, as the possible range of colony-phenotypes (as modelled by a self-organization approach) constrains what natural selection acts on (as studied by evolutionary change approaches), so that these models inform and contribute to each other.

More recently, in collaboration with the structural biologist Angela Gronenborn—as an example of interdisciplinary research—Mitchell has investigated research on protein folding (Mitchell, 2020; Mitchell & Gronenborn, 2017). There are various approaches to model the folding of proteins and predict their three-dimensional, functional structure: physical, chemical, and biological approaches. Physics perspectives computationally model the thermodynamics of unfolded and folded proteins, chemistry perspectives experimentally manipulate proteins and the conditions in which they fold in vitro, and biology perspectives investigate protein folding in vivo (e.g., the interaction of a folding protein with chaperones and other cellular components). According to Mitchell, each model can only provide a partial representation of the complexity of

protein folding, but these partial representations constrain and thereby can inform each other.[4]

Apart from ontological features, such as complexity, calling for integration, another kind of motivation is *epistemological*. These are scientific *questions* or research *aims* requiring an integrative or interdisciplinary approach. Darden and Maull (1977), who as mentioned in Section 1 still worked with the label 'unification' (through interfield theories), already pointed out that in each field, there are questions that cannot be answered using the concepts or methods of this field alone. This is in line with the literature on interdisciplinary, which indicates that interdisciplinarity can be fostered by starting out with an interdisciplinary question (Szostak, 2002). Love (2008) uses the equivalent idea of a problem (or more precisely, a 'problem agenda') as calling for an integrative framework. His example of such a problem agenda is accounting for the evolutionary origin of novelties, such as the origin of fins in fish.

I emphasize the role of epistemological features such as scientific problems and explanatory aims, because only once such an aim is actively pursued by scientists is there a motivation to develop the integrative account (Brigandt, 2010, 2013a). Something comes to be seen as a relevant scientific problem in a certain historical and disciplinary context, motivating integrative efforts. At a later point, a new problem arises and is recognized as such, calling for a solution specific to this new issue. The nature and the depth of integration required depend on the problem at hand (Brigandt, 2010). One scientific problem may require an integrative explanatory framework that uses contributions from several biological disciplines, whereas another problem may call for data integration within one field. This again underscores the diversity of integrative

[4] If one relies on the rough distinction between data integration, methodological integration, and explanatory integration made in the previous section, Mitchell's integrative pluralism would be most closely aligned with explanatory integration, as are the philosophical accounts mentioned in the remainder of this section.

accounts, which are modulated by the nature of the scientific problem addressed. Because of this, in Brigandt (2010), I argued against the idea that integration is an aim in itself. This differs from Philip Kitcher (1999) and Todd Grantham (2004a) considering unification to be a *regulative ideal*, where biologists should attempt to achieve as much unification as possible (in a complex world that sets limits on how much unification can be achieved). In contrast, I maintain that even integration is not a regulative ideal or an aim in itself (always to be pursued and for the sheer sake of integration).[5] Instead, an instance of integration (of a specific nature and depth) may be needed for the purpose of solving a certain scientific problem.

We have encountered two kinds of features that *motivate* integrative research: the complexity of some biological phenomenon and the pursuit of a scientific problem that can only be solved by an integrative or interdisciplinary account. A further relevant issue is what *structures* integrative accounts and their formation. One suggestion stems from explanations in terms of mechanisms, which were introduced in the previous section. A mechanism has some structure, due to its multilevel nature and the spatial and temporal organization of its component entities and activities. This organization guides how the integrative account looks like. A more general philosophical account of what structures integration (without being restricted to mechanistic explanations) has been put forward by Alan Love (2008) using the notion of a

[5] Pence (2025, p. 38) specifically objects to this tenet of mine: "scientists *do* often pursue integration as 'an aim in itself'—or, at the very least, they cite integration as one of the reasons that the explanations that they offer should be valued and accepted by the scientific community." However, this misconstrues what an aim in itself is. Adducing integration as *the reason for some scientific activity* (e.g., accepting explanations) does not address the question of why integration is valued or what *the reason for integration* is. And only an answer to the latter question would tell whether integration is always cited as the reason for integration (integration as an aim in itself) or whether some other reason is given for the importance of some instance of integration (integration as a means to some other end, e.g., solving a specific scientific problem).

problem agenda (see also Love, 2013; Love & Lugar, 2013). A problem agenda is not just one scientific question that could be given a simple answer, but a complex assemblage of related questions. As his core example of a problem agenda, Love discusses in detail the evolutionary origin of novelty, such as the origin of paired fins in fish and their substantial transformation into limbs in amphibians. Accounting for any evolutionary novelty is a major task, as this involves explaining the very origin of a novel morphological structure which did not exist in ancestral taxa (i.e., is not homologous to any ancestral structure), where its evolutionary origination involves substantial changes in development on several levels of morphological organization. Other examples of evolutionary novelties are the vertebrate jaw, feathers (which substantially differ from reptilian scales), and the turtle carapace (since there the shoulder blade is inside the rib cage).

On Love's (2008) account, a problem agenda is associated with criteria of explanatory adequacy, which circumscribe what a satisfactory account needs to include. For instance, Love argues that a gene-centric account in terms of gene regulation is inadequate to explain the evolution of novelty. Instead, the problem agenda demands an integrative explanation using contributions from several biological fields (see also Brigandt, 2010; Brigandt & Love, 2012). Regarding what structures such an integrative account, so as to guide its establishment, Love's central point is that a problem agenda, consisting of component questions, has an internal structure and that this structure coordinates how the relevant explanatory ingredients are to be combined. To illustrate just some of this structure for the complex issue of accounting for evolutionary novelty, there are questions regarding pattern as well as process. One pattern issue is to establish that the putative novelty is in fact non-homologous to ancestral structures. Here, paleontology, comparative morphology, and in many cases comparative developmental biology are needed. A further pattern issue is to assign the origin of the novelty, as well as changes in other relevant structures, to phylogenetic junctures. The phylogenetic trees provided by

phylogenetics and systematics matter for addressing this component question. Issues pertaining to process crucially include developmental processes and their changes, entailing the involvement of developmental biology. Basically, we need an account of the evolutionary changes in developmental processes that lead to the morphological structure that is the novelty at hand. Traits in several levels of morphological organization are involved in this, from gene regulation, cell-cell interaction and tissue formation, up to the fully formed morphological structure—where the connections between traits and processes at these levels matter for the explanatory account. This implicates the fields of developmental genetics, cellular biology, developmental biology, and morphology. If the novelty is not only a structure (such as feathers) but an anatomical function (such as avian flight), the articulation and interaction among several structures underlying the anatomical function need to be addressed. The problem agenda of evolutionary novelty, as well as the explanatory account, is more complex than what I have mentioned, but this discussion already illustrates what biological fields are needed and how some component questions are related, for instance, that pattern questions have to be answered before process questions or that changes in tissue interactions are to be explained by changes in gene regulation.

4 Outlook: normative reasons for integration

The previous section pointed to the pursuit of scientific aims that can only be achieved through integrative research as a major motivation for engaging in integration. At the same time, discussions have focused on *epistemic aims*, such as the aim of explaining the evolution of novelties (e.g., Brigandt, 2010; Love, 2008). But what about *non-epistemic aims*, such as environmental aims, biomedical aims, or the aim of improving human health and well-being? Are there such normative reasons for integration?

Although non-epistemic aims and values are the cornerstone of the thriving philosophical

literature on science and values (or science, values, and society; Brigandt, 2022), the important role of non-epistemic aims and values is still underexplored in discussions specifically dedicated to integration in biology.[6] A notable exception to this is the recent account of explanatory integration by Charles Pence (2025). Pence introduces the notion of 'integrative promise' as something that motivates scientists to pursue a research program, and also as a means of evaluating research programs. Importantly for the present context, he argues that integrative promise often includes the ethical or social benefits resulting from the pursuit of integrative research. Pence articulates the idea of integrative promise through the notions of stringency and opportunism. Stringency means that a research program is chosen because it stands to produce the non-obvious evidence that would support an integrative explanation. An additional advantage of a possible research program is opportunism, when the program can rely on existing resources, such as tools or a model organism. While Pence's (2025) many examples of integrative promise also illustrate the stringency-opportunism dialectic, our focus is on non-epistemic benefits as a motivation for pursuing integration. Charles Darwin's research on orchids used an integrative framework when attempting to account for the idiosyncratic traits of orchids resulting from flower-pollinator co-evolution. As Pence points out, the orchid work was also meant to further the *social* agenda of increasing support for Darwin's controversial evolutionary theory among the botany community. Another example is how natural history upholds the need for an integrative and organism-centred approach because of the non-epistemic aim of achieving species conservation and enhancing biodiversity. Similarly, Pence points to the European Molecular Biology Laboratory favouring integrative research for its promise to counter threats to ecosystems and biodiversity. He also discusses the use of the ferret as a model organism to

[6] The discussion on interdisciplinarity and integration by Laursen et al. (2021) addresses non-epistemic values. However, their focus is on fostering interdisciplinarity through detecting and resolving problematic value differences, rather than on (non-epistemic) values as a driver of integration.

investigate the transmission of influenza-like viruses in humans. In light of the recent coronavirus pandemic, such a concern for human health and human societies is a glaringly obvious non-epistemic aim motivating integrative research.

The relevance of such non-epistemic aims has been extensively discussed in the literature on *science and values* (for an accessible overview, see Elliott, 2017), which also connects up with *socially relevant philosophy of science* (Plaisance & Elliott, 2021). Traditional accounts still upholding the ideal that science should be value-free did acknowledge some role for values, while strictly distinguishing between epistemic and non-epistemic values as well as different stages of the scientific process. Non-epistemic values (e.g., one's environmentalist agenda) can be used in the first stage of choosing a research project as well as the final stage of applying validated scientific knowledge. However, the value-free ideal claimed that only epistemic values may be used in the core of science, the acceptance of scientific models based on evidence. By now, the value-free ideal has been abandoned by most philosophers of science (Brigandt, 2022). While the science and values literature adduced several ways in which non-epistemic values can make a legitimate contribution even in the core of science, of particular interest in the present context is the *aims approach*, as this connects up with scientific aims that call for integration in biology.

The very label 'aims approach' was coined by Kristen Intemann (2015) and then caught on, but the idea was also proposed by others at the time (Brigandt, 2015; Elliott & McKaughan, 2014; see also Elliott, 2017, Ch. 4, and Lusk & Elliott, 2022). On this approach, non-epistemic values and value judgements may be used insofar as they further the particular aims of an instance of research. One example is the choice and use of models in climate change science (Intemann, 2015). There are global circulation models that successfully predict the average temperature increase of the Earth. But there are also more fine-grained regional climate models that are more suitable for understanding climate trends in a region and how countries in this

region can adapt to the effects of climate change. Which kind of model is used depends on the aims of the study, which may well hinge on the social aim of mitigating or adapting to climate change. A model representing the impact of climate change mitigation options in terms of 'average global wealth' fails to capture inequities around the globe (and how climate change may exacerbate inequities), so that a model instead representing the geographical distribution of wealth or well-being is preferable (Tuana, 2010).[7] A further example is the risk assessment for potentially toxic chemicals (Elliott & McKaughan, 2014). In principle, one can assess in a precise fashion the harmfulness of one of the hundreds of new chemicals used in some product through long-term animal studies. In scientific practice, expedited risk assessment methods are used, which among other things use computational modelling to yield a toxicity estimate. This less precise method is justified by the social aim of detecting toxic substances in time, before substantial harm to humans could have resulted.[8]

I do not want to suggest that non-epistemic aims are inherently furthered by integrative

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[7] This shows that the aims approach aligns with the idea that some scientific concepts and categories embody non-epistemic values, at least the use of such a category (e.g., 'average global wealth') can be criticized on such non-epistemic grounds as reducing inequities (Brigandt, 2015; Elliott, 2017, Ch. 6; Intemann, 2015). Value-laden concepts are another way in which non-epistemic values matter even in the core of science. Another advantage of the aims approach is that it need not take any stance on the relation between epistemic and non-epistemic values. It neither needs the clear epistemic-nonepistemic separation that the value-free ideal had to presuppose, nor a thorough continuum that some have proposed as a direct argument against the value-free ideal. On the aims approach, a scientific aim can become relevant due to (more) epistemic considerations as well as (more) non-epistemic considerations,

[8] While such non-epistemic values may be used within science, the science and values literature recognizes that these values need not be the personal whim of a scientist, but that the values used have to be legitimate. One way to articulate this is by requiring that the values underlying the aims of a research study have been democratically legitimized (Intemann, 2015; Schroeder, 2021). Another important idea is that the values used align with the interests of the stakeholders that will be affected by the outcome of the research (Brigandt, 2022; Intemann, 2015).

research. As mentioned in Section 3, I do not consider integration as an aim in itself. Instead, the particular scientific aim—be it epistemic or non-epistemic—entails whether an integrative framework is needed and the shape of integration (what biological fields are involved, whether data, methods, and/or explanations are integrated, and the depth of the integration). That said, there are certainly many scientific aims also answering to non-epistemic considerations that do call for integration in biology. While scientists have argued for more integration based on such non-epistemic aims as maintaining or promoting ecosystem health (e.g., Robinson et al., 2012) and in spite of Pence (2025) as an exception among philosophers of science, philosophers still have to explore in more detail how integration in biology can also advance non-epistemic aims. Since philosophers have recognized epistemic aims as an important motivation for integration (see Section 3) and the work on science and values has emphasized the role of non-epistemic aims within science, this provides the opportunity for future philosophical work, with fruitful interactions among both bodies of literature.

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