Integration in Biology: Philosophical Perspectives on the Dynamics of Interdisciplinarity

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Abstract

This introduction to the special section on integration in biology provides an overview of the different contributions. In addition to motivating the philosophical significance of analyzing integration and interdisciplinary research, I lay out common themes and novel insights found among the special section contributions, and indicate how they exhibit current trends in the philosophical study of integration. One upshot of the contributed papers is that there are different aspects to and kinds of integration, so that rather than attempting to offer a universal construal of what integration is, philosophers have to analyze in concrete cases in what respects particular aspects of scientific theorizing and/or practice are 'integrative' and how this instance of integration works and was achieved.

Keywords: Integration, interdisciplinarity, reduction

Overview

Interdisciplinarity is a major characteristic of contemporary science. Not only do scientists recognize the significance of interdisciplinary research and discuss strategies of how to increase interdisciplinarity in particular research contexts, but interdisciplinarity has also come to be analyzed by science studies scholars as a topic in its own right (Frodeman et al., 2010; Repko, 2008). A related notion is *integration*, which can refer to either the integration of different scientific fields or the formation of an integrative account that combines a variety of different ideas. Integration in the latter sense can in principle include accounts that primarily use ideas from one scientific discipline, e.g., integrating knowledge pertaining to different levels of organization—which is an important issue to be investigated even when such integrative accounts do not involve much interdisciplinarity, given that the development of any kind of integration faces additional challenges. Indeed, integration and interdisciplinarity are to be studied not just because they are a fact of modern science, but also because they are vital to some instances of success in science, and it is relevant to understand how they were achieved in the face of difficulties.

In the philosophy of biology, there is a clear rationale for scrutinizing integration, as it is a replacement for the traditional idea of reduction (Brigandt, 2013; Brigandt & Love, 2012b). The philosophical notion of theory reduction assumed that the knowledge from several fields can be logically deduced from a more fundamental, lower-level theory (Nagel, 1949; Oppenheim & Putnam, 1958; Schaffner, 1976). But the particular tenet that classical genetics can be reduced to molecular biology was immediately criticized (Hull, 1976), and more generally reduction—or any strong notion of unification—came to be seen as an inadequate characterization of biology. An ontological reason for this is that the complexity of many biological phenomena does not permit a reductive account (Mitchell, 2003, 2009). An epistemological and methodological reason is the presence of diverse scientific aims, methods, approaches, standards, and modes of explanation within biology—and often within a single biological field. As a result, a philosophy of biology concerned with understanding actual biology and its practice needs different concepts than reduction. While some replaced the notion of reduction with the idea of the disunity of science (Dupré, 1993; Rosenberg, 1994), this fails to analyze the relations that do exist among different scientific ideas and the collaborative interactions among scientists (Brigandt, 2010;

Love, 2008). Consequently, ‘integration’ is a more appropriate characterization. But beyond arguing that integration takes place in biology, the philosophical task is to understand what it involves, how integrative practices operate, how integrative accounts are formed, and what the challenges and limits to integration are.

These questions are currently subject to many individual studies in the philosophy of biology; and they also motivated my recent research project on integration in biology, which was conducted in collaboration with Alan Love and Todd Grantham, among others, and involved workshops funded by the Social Sciences and Humanities Research Council of Canada. Although initially focussing on the interdisciplinarity needed to account for the evolutionary origin of novelty (Brigandt & Love, 2010, 2012a), the project was subsequently broadened to various instances of integration across biology. Such different cases were presented and discussed at a September 2011 workshop at the Minnesota Center for Philosophy of Science (organized by me and hosted by Alan Love). Most of the papers making up the special section of the present issue of *Studies in History and Philosophy of Biological and Biomedical Sciences* stem from presentations at the workshop.

Taken together, the papers of this special section touch upon a variety of issues and address quite different biological domains. After discussing recent philosophical accounts of integration and unification, Anya Plutynski (this issue) sets out to scrutinize the goals of integration in the context of cancer research. Her focus is on mathematical models of cancer dynamics, and she argues that while such mathematical modeling can trade simplicity for explanatory detail, such models nonetheless have come to incorporate evidence from a variety of domains and become successively more integrative across time. The contribution by Ingo Brigandt (this issue) takes a look at systems biology to discuss a special kind of integration, to wit, the combination of mathematical explanation and mechanistic explanation in this field, a discussion motivated by the fact that philosophical discussions of molecular mechanisms have tended to neglect the explanatory role of mathematical modeling. While he mentions that scientists putting forward mechanistic explanations also have therapeutic interventions in view, this is explored in great detail by Bill Bechtel (this issue), who uses chronobiology as a philosopher’s “model scientific field” for investigating processes of integration. Bechtel argues that the experimental identification of a mechanism’s components has to be followed by the integrative step of accounting for how the component’s organization and interaction generates the mechanism’s behaviour—which often requires the involvement of mathematical modeling—and he discusses how current research in chronobiology relates disruptions in circadian mechanisms to the formation of disease, e.g., various types of cancer.

While botany rarely receives attention from philosophers, Sabina Leonelli (this issue) fortunately fills this lacuna. Focusing on data integration, she distinguishes inter-level integration (in research on one species), cross-species integration, and translational integration (involving knowledge from within and outside academia) to enable interventions that improve human health or the environment. Leonelli argues that since these three modes of integration serve different scientific goals and require different epistemic strategies and organizational infrastructures, achieving one mode of integration need not yield another mode. This touches upon the organization of scientific work and the societal context of science, an issue specifically analyzed by Eli Gerson's (this issue) sociological treatment. Rather than focusing on the content of science and epistemic types of integration (integrating data and explanations), Gerson addresses integration as a phenomenon about the organization of scientific work, which apart from the establishment of what he calls metawork includes various institutional aspects. His focus is how on how a new specialty emerges out of previous specialties, and he breaks this institutional process down into six basic phases.

While also using Gerson's notion of metawork, the paper by Jim Griesemer (this issue) zeros in on the integrative practice of one researcher and his collaborators during a period of more than a decade. The research of the evolutionary morphologists David Wake is used as a case, because Wake's development of a "research platform"—his use of the whole family of lungless salamanders—permitted novel perspectives at the intersection of functional anatomy, evolutionary biology, systematics, and developmental biology. Griesemer discusses how Wake showed that the problems he addressed would receive an incorrect solution if approached from one specialty only. The intersection of different fields germane to evolutionary biology are likewise addressed by Alan Love and Lance Lugar (this issue), though they highlight the presence of conflicting approaches concomitant with integrative practices. Addressing interdisciplinary explanations of the origin of evolutionary novelty during the Cambrian period, they focus on biological explanations involving physical principles. Such explanations have been resisted by those preferring explanations in terms of developmental genetics, and Love and Lugar analyze the philosophical and scientific assumptions behind the objection to physics-based approaches. Maureen O'Malley (this issue) discusses another case where integration has failed—prokaryote and eukaryote phylogeny. Despite attempts to uncover a tree of life encompassing all species, prokaryote phylogeny is often not integrated with overall phylogeny because networks rather than branching tree structures obtain due to horizontal gene transfer. O'Malley breaks down her analysis into limits to data integration, methodological integration, and explanatory integration; and she argues that there may well be advantages to not integrating prokaryote phylogeny with eukaryote phylogeny. As Bill Wimsatt (this issue) explains, cultural evolution is an interdisciplinary domain where an adequate integrative framework is yet to be developed. Accounting for the complex process of cultural evolution includes disciplines beyond biology, including cultural anthropology, archeology, and history of technology. Wimsatt argues that many traditional approaches (e.g., variation and selection based accounts that acknowledge both genetic and cultural inheritance) fail to include the important ways in which culture is sequentially acquired throughout an individual's life cycle, where later steps presuppose prior cognitive, cultural, and institutional developments. Wimsatt discusses the latter under the label of "scaffolding," when laying out his set of elements that any adequate theory of cultural evolution will have to include.

Common themes and trends

It has become clear that integration has many faces, both in terms of what is being integrated and how the integration is achieved. An early philosophical model of integration was put forward by Lindley Darden and Nancy Maull (1977). This paper was a landmark because it articulated the systematic epistemic relations among fields without requiring that fields are reduced to each other. Invoking "interfield theories," this model argued that fields can become related by the establishment of suitable theories. Yet the notion of a theory has become a less central philosophical notion to characterize biological knowledge; and several other concepts are nowadays used. In the philosophical study of molecular biology, most prominently are the notions of a mechanism and mechanistic explanation, given that mechanisms include entities on several levels of organization and different fields can contribute to elucidating different aspects of a complex mechanism (Craver, 2005; Darden, 2005). Some of the contributions to the present special section (Bechtel, Brigandt) continue the ongoing trend of appealing to *mechanistic* *explanations*. One novel perspective is that while past discussions have often proceeded as if they conceived of scientific explanations as representations of reality providing intellectual understanding, the papers by Bill Bechtel and by Ingo Brigandt explicitly indicate that mechanistic explanations are at the same time tools for effectively intervening in nature, and that mechanistic research is often geared toward biomedical and other applied purposes. Generally, while being aware that molecular biology is used for biomedical and agricultural aims, too often philosophers (unlike historians) have restricted their epistemological studies to the curiosity-driven aspects of scientific practice.

One important upshot of the special section discussions is that there is much more to integration than putting forward integrative explanations (or integrative theories), on which recent accounts have focused (Brigandt, 2010; Kitcher, 1999; Love, 2008; Mitchell & Dietrich, 2006; but see Bechtel, 1993; Grantham, 2004). Maureen O'Malley explicitly distinguishes between integrating *explanations,* integrating *methods* (inference and modeling methods as well as experimental methods), and integrating *data*. Each kind of integration can take place without the others and may take place in different ways (see also O'Malley & Soyer, 2012). Anya Plutynski likewise analyzes her case by discussing data integration and explanatory integration separately, while Alan Love and Lance Lugar argue for the need to distinguish integration of data and integration of standards (within overall explanatory endeavours). Sabina Leonelli's discussion is exclusively devoted to data integration; and it is false to assume that data integration is much more trivial than explanatory integration, as she makes plain that the integrated data are not raw data, but to be useable across researchers and for many future purposes, data have to be thoroughly curated and prior standards for representing data in databases and organizational infrastructures have to be set up. Jim Griesemer argues that the integration of *approaches* is the best characterization for the case he discusses, while Eli Gerson focuses on the integration of *specialties*. All of the above types of integration differ in the kinds of units that are being integrated, but other distinctions can be made, enriching the various aspects and types of integration. For example, Leonelli's taxonomy distinguishes inter-level integration, cross-species integration, and translational integration, all of which are modes of data integration and thus her taxonomy is orthogonal to the units that are integrated.

An advantage of focussing on the integration of ideas (e.g., data, methods, and explanations) rather than speaking about the integration of fields is that the latter can evoke the connotation that integration consists in several fields merging so as to result in one remaining field (the label disciplinary "synthesis" is similarly misleading, Brigandt & Love, 2010). But integration hardly ever consists in several fields fully merging (Brigandt, 2010), and even in the case of a merger the resulting field would have some internal structure and heterogeneity, which should not be disregarded. What is more common is that integrative endeavours lead to the formation of a new field—or a new specialty, as analyzed in detail by Gerson's paper. The formation of a field qualifies as integration if the new field grew out of and uses the intellectual resources of several previously existing fields. It is a new field once it has gained some independence from its originating fields (typically an independence marked by institutional factors), but even then it maintains interdisciplinary relations to the latter. In the case of the formation of cell biology as a new discipline, which came to bridge gaps between previous disciplines, Bechtel (1993) observed that "one surprising feature of such integration is that it generated further disintegration as the new institutions [of the novel discipline] separated the practitioners of the new discipline from other, closely related biological disciplines" (p. 277). There is nothing paradoxical about maintaining that integration across fields is concomitant with new disintegration, once one is clear about the fact that the integration pertains to some intellectual connections while the disintegration is about other potential connections. And bear in mind that some contributions to this special section also address problems with integration or integration yet to be achieved (Love and Lugar, Wimsatt), or point to instances where additional integration may well be undesirable (O'Malley). Overall, fields being integrated more precisely means that these fields become *more* integrated than they used to be (Plutynski, this issue), so that integration of fields is a matter of degree[1] and relative to what intellectual connections across the fields initially existed and what particular novel relations have been established.

Given that integration is a *process*, the most relevant epistemological task is not solely to analyze the outcome of integration (i.e., the characteristics of an integrative account), but to study the steps that permitted this increasing integration. Beyond scrutinizing the theoretical changes in a particular biological domain, this importantly includes the scientific *practice* involved (Brigandt, 2013). Indeed, integration nearly always involves the coordination among

[1] "… chronobiology is more like cognitive science than biochemistry or cell biology in that it remains an interdisciplinary field." (Bechtel, this issue)

the various practices of different biologists, possibly biologists from different disciplines. As a result, the philosophical investigation of integration is the study of how scientific interactions lead to enhanced integration or maintain integrative practice—the philosophical study of the 'dynamics of interdisciplinarity,' as the title of this essay puts it.[2] Several of the contributions to the special section study concrete scientific practice or at least analyze in detail how biological knowledge and methodologies have changed across time (Bechtel, Griesemer, O'Malley, Plutynski, among others). Tied to scientific practice are the organization and institutional aspects of science, which nowadays are also seen as in need of investigation by philosophers (Bechtel, 1993, 2006). In addition to the explicitly sociological discussion by Gerson of new specialty formation as an institutional process, several of the special issue contributors touch upon the organization of scientific work and its institutional underpinnings, most notably Leonelli, who investigates the creation of databases as aspects of scientific infrastructure (see also the papers by Bechtel and Griesemer).

O'Malley (this issue) makes the insightful suggestion that integration is a meta-heuristic. This is inspired by Wimsatt's (2006, 2007) work on reductionism and its heuristics, according to which while reductionistic heuristics may well fail, the failure of a reductionistic strategy still yields scientific understanding, as it provides increased knowledge about when a particular reductionistic heuristic is likely to fail and especially how the heuristic can be improved. In a similar vein, on O'Malley's notion of integration as a (meta-)heuristic, what matters less is whether integration works out but what is learnt along the way of attempting it. Apart from shifting the focus away from the outcome of integration toward the process of integration, in my view this idea is preferable to the previous philosophical suggestion that integration (or unification) is a regulative ideal, as endorsed by Kitcher (1999) and Grantham (2004). Kitcher is well aware of the fact that given the complexity of nature no fully integrated or unified knowledge is possible, but he still advocates that scientists should strive toward as much unification as possible. My opinion is that while the notion of integration as a regulative ideal assumes a fixed aim, i.e., a predetermined and possibly universal construal of the kind of

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[2] "…the interplay between integration and other norms in the life sciences (e.g., reduction, innovation, generality, precision) needs more attention in order to *understand better the dynamics of scientific practice*." (O'Malley, this issue; emphasis added)

integration to be achieved, O'Malley's suggestion that integration is a heuristic can be seen to allow that scientists' construal about the kind of integration that should currently be attempted can change across time. In other words, *integration is not a fixed aim, but its meaning can be reconfigured* as integrative efforts proceed.

This point about what exact scientific aim is pursued in an integrative endeavour brings us to the general philosophical relevance of investigating *epistemic goals*, both larger agendas shared by many scientists within a field and more local aims pursued as the next individual step in a research project. Note that while epistemic goals are theoretical features, they operate on a different level than data, mechanism descriptions, models, explanations, and theories. For while the latter are various representations of nature, epistemic goals are about the aims of scientific practice. Though distinct from representations of the natural world, epistemic goals are of philosophical relevance precisely because as scientists' values they motivate and justify certain scientific practices (Brigandt, 2013). The special section contributions illustrate this. Love and Lugar discuss how the problem agenda of evolutionary novelty guides the formation of an integrative account, based on associated standards of explanatory adequacy. On their account, physics-based explanations of morphological evolution are often resisted because they allegedly fail to conform to certain standards, which also points to scientific disagreements about the adequacy of standards. Plutynski's discussion of mathematical models of cancer mentions the well-known fact that all models make abstractions and idealizations. While the complexity of nature makes fully complete and veridical scientific representations impossible, she specifically argues that the real issue is that scientists do not aim at complete representations, but that they pursue more local scientific goals. As a result, the adequacy of any model (including the use of idealizations, see also Brigandt, this issue) and the success of any integrative account is contingent upon the particular scientific aim. When addressing data integration, Leonelli focuses not the intrinsic properties of data but on the use of data in relation to specific goals. She stresses "the diversity of epistemic goals and priorities driving integration," when arguing that the different aims of inter-level integration, cross-species integration, and translational integration entail different challenges, so that achieving one mode of integration does not yield the other. Her account of translational integration foregrounds the particular requirements brought about by a scientific aim based on environmental and societal needs. In summary, scientific aims (and the change in scientific aims) importantly guide the dynamics of interdisciplinary and integrative research, and more generally the dynamics of scientific practice. In addition to studying how scientific representations and outcomes meet given scientific aims, philosophers needs to devote more scrutiny to how scientific aims and agendas are set up and reconfigured, and to which extent those aims are adequate (including the social and environmental impact of scientific agendas; Kourany, 2010).

A few decades ago, the model of theory reduction failed for two related reasons (Brigandt & Love, 2012b). First, its philosophical defenders had to argue for the in principle possibility of theory reduction (given the presence of some logical relations among scientific ideas), while conceding that it may not occur in practice. This was deemed to be a misguided approach by those philosophers aiming at an understanding of actual science and its practice. Second, those endorsing theory reduction or alternative models of reduction often strived for putting forward a single and general construal of what reduction is. But biologists mean different things by the term "reductionism," and when issuing pronouncements about the success or failure of "reduction" they make a different ontological, epistemological, or methodological claim, depending on the context. Each such notion of reduction is legitimate and substantial, so that any philosophical project attempting to recover a universal construal of reduction was bound to be flawed. Current philosophical studies of integration must not make the same mistake of attempting to put forward a monolithic account of what integration is. The authors contributing to the present special section of *Studies in History and Philosophy of Biological and Biomedical Sciences* are clearly on the right track. For they provide intellectual insights by scrutinizing concrete instances of biological theorizing and practice and by analytically distinguishing different aspects of and types of integration when laying out how integration works (or why it does not work) in a particular case.

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