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Intellectual inflation: one way for scientific research to degenerate☆

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ABSTRACT

This paper aims to analyze a specific way in which a scientific programme or area can, in Lakatosian terms, degenerate: namely, through a developmental process of intellectual inflation. Adopting a pluralist approach to the notion of scientific progress, we propose that the historical development of a particular scientific area can be analyzed as being intellectually inflationary during a bounded period of time if it has considerably increased its productive output (thus demonstrating productive progressive) while the overall semantic or epistemic value of those products have not improved in a significant fashion (thus lacking progress in a semantic or epistemic sense). Then, we apply this concept to thoroughly assess whether there have been some intellectually inflationary patterns in the development of (i) information-theoretical evolutionary biology in 1961–2023, and (ii) ensemblist non-equilibrium statistical mechanics in 1938–2023. And finally, we argue that tracking and analyzing intellectually inflationary patterns in the history of sciences might contribute to vindicate a non-productivist picture of current scientific research.

1. Introduction

A field of scientific research can develop in different ways. Drawing on his methodology of research programmes, the philosopher Imre Lakatos (1970) famously distinguished between a progressive historical evolution, in which a programme expands its theoretical content and accumulates predictive successes, and a degenerative development, marked by the absence of such advances. The more degenerate a research program becomes, the more it tends toward para-scientific statuses such as bad science, pseudoscience, or nonscience (Mahner, 2013, Niiniluoto [2024]). While this pluralistic conception of scientific progress and degeneration —combining both semantic and epistemic criteria (see Niiniluoto [2024]Niiniluoto [2024])—has been under-recognized within the Lakatos scholarship, it remains highly valuable for addressing some of the major challenges in contemporary philosophy of science.

The main issue is that the original Lakatosian framework is now often seen as relying on imprecise and overly broad tools, given its focus on series of theories as central scientific objects and prediction as the core epistemic aim of science. This perception is especially prevalent in light of over fifty years of advances in the philosophy of science, particularly by historicist philosophers. From a modern perspective, it could be possible to identify various forms in which a research programme —or a 'scientific area' more broadly— can degenerate in forms that align with Lakatos' general intuitions.

In this paper, we develop an account of one specific form of degenerative scientific development called intellectual inflation. According to our precise definition, intellectual inflation occurs when a research area experiences (i) a substantial increase in productive activity (e.g., in publications, conferences, attraction of researchers and funding): without (ii) corresponding to significant improvements in the overall semantic quality (in the accuracy, informativeness, or soundness) or the epistemic outcomes (such as successful predictions or robust explanations) of its outputs. We argue that philosophers of science today are well-equipped to analyze patterns of intellectual inflation using both classical qualitative methods, such as epistemological analyses of scientific theories and models, and modern quantitative techniques, such as data-based publication or citation analyses.

The plan for this paper is as follows. Firstly, we introduce the Lakatosian ideas of progress and degeneration as they apply to the development of scientific research programmes, highlighting their key limitations as philosophical tools. In Section 3, we define the concept of intellectual inflation by drawing on various notions of scientific progress, arguing that an intellectually inflationary development is characterized by significant productive growth that is not matched by semantic or epistemic advances. Then, we apply this notion to two illustrative case studies: (i) the development of information-theoretical evolutionary biology from 1961 to 2023 (Section 4), and (ii) the evolution of

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ensemblist non-equilibrium statistical mechanics from 1938 to 2023 (Section 5). Finally, we advocate for the analysis of intellectual inflation as a means to address one of the most poorly understood yet dangerous challenges in modern science: the increasing emphasis on productive metrics (such as the number of publications and citations metrics, and the attraction of funding and researchers) as the primary driving force of scientific research.

2. Lakatos on progressive and degenerating science

Imre Lakatos is perhaps best known for his work 'Falsification and the Methodology of Scientific Research Programmes' (Lakatos, 1970), where he introduces and popularized the concepts of progressive and degenerating. These ideas were applied to what he termed 'scientific research programmes,' which he understood as diachronically extended sets of individual scientific theories. These scientific research programmes are characterized by a common 'hardcore' of theoretical hypotheses, surrounded by a protective 'belt' of auxiliary assumptions that shield the core from falsification (see Musgrave and Pidgen [2021] for a more detailed analysis). Within this framework, Lakatos argued that the development of research programme could be deemed progressive if and only if it satisfies the two necessary conditions of being: (i) theoretically progressive and (ii) empirically progress. If either or both conditions are absent, the programme is considered degenerative. But, what did Lakatos properly mean by those conditions?

> "Let us say that such a series of theories is theoretically progressive (or 'constitutes a theoretically progressive [scientific research programme]') if each new theory has some excess empirical content over its predecessor, that is, if it predicts some novel, hitherto unexpected fact. Let us say that a theoretically progressive series of theories is also empirically progressive (or 'constitutes an empirically progressive [programme]') if some of this excess empirical content is also corroborated, that is, if each new theory leads us to the actual discovery of some new fact. Finally, *let us call a* [research programme] *progressive if it is both theoretically and empirically progressive, and degenerating if it is not*" (Lakatos, 1970, 118. Italics added)

In modern terms, the actual development of a research programme can be described as 'theoretically progressive' if its amount of content or information about novel predictable phenomena diachronically increases from t_0 to t_n, and 'empirically progressive', if these predictions became diachronically supported by the empirical evidence collected during the very same period. Thus, for Lakatos, a research programme's progressive evolution depends on satisfying two mayor criteria: it must be progressive both in a semantic or content-related sense (i.e., theoretically) and in an epistemic sense (i.e., empirically).

Interestingly, these two conditions align with the two dominant broad conceptions of scientific progress: the semantic and the epistemic. The semantic approach explains the notion of progress in science as an increase in the semantic values of scientific outputs, such as theories and models, in terms of informativeness, truthlikeness, accuracy, and so on (see Niiniluoto, 2024, S.3.4, 3.5). In contrast, the epistemic approach focuses on the ability of a research program to generate knowledge, whether through solving problems (also called the 'functional view', e.g., Kuhn, 1962; Shan, 2019), accumulating true beliefs (Bird, 2007), or providing a deeper understanding of target phenomena (Dellsén, 2018). In this light, Lakatos' (1970) view can be seen as a methodological pluralist about scientific progress. He relied on the notions of theoretical and empirical progress as tools for semantic and epistemic evaluation in science, respectively, to determine whether the development of a research programme could be deemed scientifically progressive. This approach allows Lakatos' framework to bridge both conceptions of scientific progress, emphasizing the need for both theoretical enrichment and empirical success.

As mentioned in the introduction, our primary focus here is not directly on the Lakatosian notion of scientific progress, but rather his technical concept of 'degeneration'. While Lakatos (1970, p. 118) often the term 'degenerated' interchangeably with 'non-progressive', analyzing how research programmes degenerate is key to understanding why they fail to exhibit what we intuitively regard as essential to scientific inquiry: the generation of research that is semantically and epistemically valuable. This is why the distinction between progressive and degenerative research programs served as a normative criterion for Lakatos, used to differentiate truly 'scientific' programs (i.e., progressive) from those that are 'non-scientific' or even 'pseudo-scientific' (Mahner, 2013, p. 32).[1] This criterion has been widely applied in the philosophy of science literature since then, as seen in Thagard's (1978, pp. 223–234) explanation of astrology's non-scientific status.

It is important to note that, for Lakatos, scientific degeneration is not simply a matter of a theory or model within a program being refuted. Unlike naive falsificationists such as Popper, Lakatos did not equate the rejection of theoretical content with the degeneration of a research program. A program can still be considered progressive even if some of its theoretical claims are empirically refuted, as long as the program continues to expand its predictive power and generate successful new predictions (Musgrave and Pidgen 2021). The term 'degenerative' is not meaningfully applied to individual scientific objects—such as theories, models, or hypotheses— but rather to the historical evolution of the research activity centered around these objects. Degeneration, therefore, occurs when a research programme fails to diachronically increase its prediction-oriented semantic content or the number of empirically successful predictions over a defined period of development. In this sense, it signals a stagnation in both the theoretical and empirical dimensions that are crucial to Lakatos' conception of scientific progress.

It is now fair to ask whether the Lakatosian concept of 'degenerated' (and by extension, also 'progressive') still holds relevance for the historical analysis of science more than fifty years after its introduction. At first glance, the answer may appear negative.

Firstly, Lakatos' concepts are tailored specifically for the HPS evaluation of scientific theories—or more precisely, theory-like sequences within research programs—that can be normatively assessed in terms of their predictive capacity and empirical support. In hindsight, this focus on theories, which was characteristic of the historicist philosophy of science in the 1960s and 1970s, now seems unduly restrictive. By confining our analysis to the contributions of narrowly conceived theories, we overlook the potential epistemic contributions of other scientific entities such as hypotheses, models, representations, questions or even individual concepts. These elements may play significant roles in the theoretical or empirical progress—or degeneration—of a field of scientific research, but they are left out of the original Lakatosian framework.

Secondly, Lakatos' emphasis on the generation of novel predictions as the sole epistemic criterion for evaluating the progression or degeneration of a research program seems, from today's perspective, to impose a strong methodological constraint.[2] This focus on prediction

[1] "We 'accept' [research programmes] as 'scientific' only if they are at least theoretically progressive; if they are not, we 'reject' them as 'pseudoscientific'. Progress is measured by the degree to which a [research programme] is progressive, by the degree to which the series of theories leads us to the discovery of novel facts. We regard a theory in the series 'falsified' when it is superseded by a theory with higher corroborated content" (Lakatos, 1970, p. 118).

[2] Although in his 'Falsification and the Methology … ' Lakatos (1970) is mostly focused on the predictive aim of scientific research, he also briefly considered the explanatory dimension of this proposal: "This demarcation between progressive and degenerating [programmes] sheds new light on the appraisal of scientific -or, rather, progressive-explanations. If we put forward a theory to resolve a contradiction between a previous theory and a counterexample in such a way that the new theory, instead of offering a content-increasing (scientific) explanation, only offers a content-decreasing (linguistic) reinterpretation, the contradiction is re solved in a merely semantical, unscientific way." (Lakatos, 1970, pp. 118–119).

dismisses other forms of knowledge acquisition that could also contribute to scientific progress. Contemporary philosophy of science recognizes the importance of non-predictive aims such as explanatory power, heuristic fruitfulness, the improvement of theoretical intelligibility, and the development of more accurate models. All these aspects can influence whether a scientific research programme is genuinely progressing or degenerating, but they are largely neglected in Lakatos' original formulation.

And last but not least, some of the core assumptions underpinning Lakatos' original methodology, such as the clear-cut distinction between internal and external history or the rigid separation between a program's 'hardcore' and its 'protective belt', are increasingly difficult to justify in light of over fifty years of methodological advances in the fields of history and philosophy of science (HPS). This Lakatosian picture, once seen as central to understanding how scientific theories evolve in the early-1970s, is currently seen as oversimplifications that do not fully capture the complexity of scientific practice.

For these reasons, the Lakatosian original theoretical framework would struggle to remain relevant today without significant modifications. In the next section, we propose a revised approach that expands on the Lakatosian ideas by incorporating scientific objects beyond just theories and to include epistemic goals other than prediction. These modifications aim to adapt and enhance Lakatos' proposal into a conceptually richer framework, making it more suitable for the nuanced analyses required in contemporary philosophy of science.

Nevertheless, in this paper, we advocate for a neo-Lakatosian position—not by defending Lakatos' original framework, but by supporting his core insight that we philosophers must rely on multiple and distinct senses of 'progress' to satisfactorily analyze the entangled developmental dynamics of scientific research. Since the late 1960s, most philosophical accounts of scientific progress have been methodologically monistic. These include the already mentioned functional view (e.g., Kuhn, 1962; Shan, 2019), the truthlikeness approach (e.g., Niiniluoto, 2014), the epistemic account (Bird 2007), and the recent noetic framework (Dellsén, 2018). Each of these frameworks tends to prioritize a single dimension of scientific progress, such as problem-solving, truth approximation, or knowledge accumulation. In contrast, we vindicate Lakatos' methodological pluralism on scientific progress, arguing that it offers a powerful theoretical tool to explore the diverse and fine-grained ways in which a research area can evolve—particularly, how it can degenerate. Specifically, we focus on one form of developmental degeneration that we refer to as 'intellectual inflationary science'. But what exactly is intellectual inflation?

3. Intellectual inflation

Firstly, our definition of 'intellectual inflationary science' is based on a methodological pluralism regarding the notion of progress in science. In other words, we recognize that different forms of 'progress' must be considered to account for the several ways in which scientific research can degenerate throughout its historical development. This distinction requires us to differentiate between two categories: (i) a core notion of scientific progress reflecting our widely-accepted intuitive sense of what scientific development consist of, mainly capturing a sense of *semantic* and *epistemic* progress (Niiniluoto, 2024); and (ii) a manifold of notions of progress that would not correspond to (i) but can still be relevant to explain how scientific research develop. Examples of (ii) include *productive* progress (in terms of increased output of publications, and research activity), *instrumental* progress (improvement in techniques, and tools), and *social* progress (impact of scientific research in our society). While these forms of progress can influence the growth and direction of scientific fields, they do not inherently capture the scientific character of research.

It is important to highlight that this foundational conceptual distinction between (i) and (ii) is independent of the Lakatosian division between the internal and external history of a research programme. Unlike Lakatos, we are open to considering sociocultural factors as playing an explanatory role in understanding how scientific development occurs. Sociocultural dynamics, funding pressures, or even institutional trends may illuminate the mechanisms of how science evolves. However, these external factors do not define the core purpose of scientific research itself. The central point is that, unlike technological or enginering research, which aims directly at technical progress, and policy-making or socio-economic research, which often seeks to create social progress, scientific research is primarily concerned with generating semantic and epistemic values.[3] Henceforth, we assume that what fundamentally distinguishes scientific research from other established types of research is its pursuit of *semantic* or *epistemic* advances.

Having outlined our commitment to methodological pluralism regarding the concept of progress, we can now define *intellectual inflation* in the following terms: an area of scientific research can be said to have developed in an intellectually inflated manner if there is a significant increase in the amount of research output over a given period without a corresponding improvement in either *semantic* (content or truth-oriented) or *epistemic* (knowledge-generating) progress. To express this more technically:

Intellectual Inflation: The historical development of a scientific research area during a bounded period *T*: t_0–t_1 exhibits a gradable pattern of intellectual inflation if and only if some of these conditions are simultaneously satisfied.

1. Productively Progressive: There is a significantly increasing amount of novel scientific output (papers, books, etc.) generated from scientific research in *T*.
2. Not Semantically Progressive: There is no overall increase in the semantic values (accuracy, informativeness, consistency, and so on) of the semantic items (theories, models, data-sets, etc.) in the scientific products in *T*.
3. Not Epistemically Progressive: There is no general accumulation of epistemic results (e.g., problem-solving, successful prediction, robust explanation, or unification) derived from developing scientific products in *T*.

Our minimalist definition of intellectual inflation is versatile and can be adapted to align with any plausible theory of scientific progress. For semantic views, intellectual inflation applies if we accept (1) and (2) as necessary conditions; for epistemic views, it applies if we take (2) and (3) as the required conditions; and finally, For hybrid or pluralist views, all the three conditions (1), (2), and (3) would be necessary, combining both semantic and epistemic criteria with the productive dimension. For the purposes of this paper, we do not need to assume or defend any specific philosophical view on scientific progress. The key point here is that intellectual inflation represents a specific form of degenerative development in a research area. This degeneration occurs because the research area fails to evolve in a semantically or epistemically fruitful manner (as reflected in conditions [2] and [3]), while its development is driven by non-constitutive factors such as increased productivity (condition [1]), like the growing number of publications or research outputs.

Why call it 'intellectual inflation'? The term 'intellectual' in this context highlights that the inflationary process is sustained not solely by factors internal to the scientific objects involved (which would merely constitute epistemic inflation) but also by external, sociocultural factors that are relevant to condition (1). These external influences might include institutional pressures, funding incentives, or even the push to publish for career advance, all of which drive productivity without necessarily advancing knowledge.

A key point of departure from orthodox Lakatosian scholarship in

[3] As the reader might have noticed so far, our definition of intellectual inflation is mainly well-suited for the natural sciences, although it could also be applied in social sciences like economy or social studies.

this definition is that we are not focusing on research programmes, understood as sequences of theories, as the target units of analysis. Instead, we draw on something closer to Hasok Chang's (2011, 209–213) technical notion of a 'domain of scientific practice.' This concept refers to a normatively organized group of agents engaged in certain epistemic activities (describing, explaining, hypothesizing, testing, observing, etc.), exploiting both semantic items (like hypotheses, theories, models—what Hacking [1992, 44–50] called 'ideas') and non-semantic items (such as material tools, detectors, experimental setups—Hacking's 'things'), whose primary aim is to generate scientifically valuable outputs (papers, books, data sets, etc.). Additionally, the idea of intellectual inflation is presented as a gradable concept, meaning that some developmental patterns in scientific domains can exhibit varying degrees of intellectual inflation. The development of some research areas may be more intellectually inflated than others, depending on the balance between productivity and meaningful progress. With these clarifications in hand, we can now explore the specific conditions (1, 2, 3) that underpin our definition of intellectual inflation.

The first condition (1) specifies that the scientific research area under consideration must exhibit productive progress during a defined period *T*. Here, productive progress refers to the extent to which research activity in a given domain increases over time. But how do we gather evidence of such an increase in activity? An intriguing method is proposed by Pradeau et al. (2024), who developed a procedure for measuring the impact of philosophy of science on scientific fields, which can be nicely adapted to our task as follows.

- Firstly, we gather bibliometric data on the total number of relevant publications in the scientific area over the period in question (see also Ramsey & De Block, 2022). This includes papers, books, as well as book chapters (but not reviews), each with at least 10 citations to exclude those with no actual impact. The publications must meet a clearly defined area-inclusion (e.g., using concept C in a form F) criterion to ensure they are genuinely part of the target research domain. This step requires qualitative supervision to discard irrelevant publications that don't fit the area-inclusion criteria.
- Then, to statistically assess this data-set, we perform a simple linear regression analysis on the curated bibliometric data, generating a graph that indicates whether the estimated volume of scientific output is increasing or decreasing over time.
- Finally, we assess qualitatively whether production in this research area has been effectively promoted and sustained over time, focusing on whether some highly influencing researchers in the target field—using citation metrics as proxies—perceive the research as 'pursuit-worthy' (a concept drawn from Laudan's [1977]). As such, this last step involves qualitatively evaluating the textual appraisals from leading researchers, particularly whether they prospectively find some area-based lines of research worth investigating (see also Sánchez-Dorado, 2023).

In our case studies in Sections 4.1 and 5.1, we will apply this data collection method to gather evidence on the quantity of research output in specific scientific areas over their historical development. However, it's worth noting that alternative methods could also be used to achieve similar results, depending on the context and available data.

The second condition (2) stipulates that a research area must exhibit no semantic progress during a given period *T*. In contrast to condition (1), which focuses on productive output, this condition relates to the quality and advance of the conceptual and informational content of those scientific products. The notion of semantic progress has been extensively debated, particularly since the 1960s, when philosophers sought to develop quantitative measures of how much information or truth a scientific theory or model contains. These measures include concepts such as the amount of information content (Levi, 1967) or the closeness to truth (or truthlikeness), explored in depth by Niiniluoto (2014). Despite the richness of this literature, applying these formal-quantitative approaches poses several challenges. Firstly, they require that we already know how the world actually is, a standard that can be considered deeply unrealistic at least for our HPS task assessing the evolution of scientific research. Secondly, these measures are not always applicable to all kinds of semantic devices (theories, models, concepts), as argued by Miller (2014), since what works for large-scale theories may not be useful for smaller or more specific scientific products, like individual models or data sets. And thirdly, those quantitative measures of semantic progress tend to overlook how researchers pragmatically and contextually use theories or models in their actual practices (as encoded in condition [1]).

Given these concerns, we propose instead to rely on a qualitative assessment of the semantic values attached to the descriptive practices (à la Wilson, 2006) within a research area. Following this approach, we minimally and pluralistically understand semantic progress as the overall increase in semantic values—such as accuracy, conceptual coherence, informativeness, and soundness—over time, from t_0 to t_1. An example of such progress can be found in the development of electron-related physics between 1890 and 1925. In accuracy terms, J.J. Thomson's 1897 estimation of the electron's mass was approximately 1/1400th that of hydrogen. By 1925, this estimate had become much more precise, with the electron's mass determined to be approximately 9.109×10^{-31} kg. As far as conceptual soundness is concerned, the concept of electron underwent significant refinement, from a rather vague and underdefined notion in the early-1900s to a more theoretically defined entity in the late-1920s context of quantum mechanics (see Arabatzis, 2006). Therefore, the development of electron-based physics in 1890–1930 should count as semantically progressive according to our qualitative and pluralistic methodology.

The third condition (3) entails that a research area should have exhibited no epistemic progress during the time period *T*. As with its semantic counterpart (2), the intuitive idea of epistemic progress has been theoretically refined in several ways over the past decades, from the Kuhnian (1962) problem-solving view (recently revivified by Shan, 2019) to the more recent Bird's (2008) knowledge-accumulation and Dellsén's (2018) understanding-increasing accounts. As with condition (2), here we are going to presuppose a minimalist and also pluralist notion of epistemic progressiveness. Minimalist in the sense that we are simply going to consider the diachronic accumulation of epistemic results in a research area as the main definitory element of this specific kind of scientific progress. Pluralist in the sense of not theoretically privileging a particular epistemic task (as Lakatos [1970] did in the case of prediction), but otherwise assumes that scientific research is driven by a manifold of different epistemic aims and values such as predictive success, explanatory power, heuristic fruitfulness, disciplinary unification, descriptive accuracy, and so on. Having said that, we now propose to evaluate whether the historical development of a particular research domain displays some epistemic progress by carrying out a qualitative meta-analysis of an excerpt of expert judgement of both specialist philosophers of science and scientific practitioners regarding the epistemic achievements of a target area. Again, other epistemic-assessment methodologies could also be compatible with our proposal.

Then, according to our definition, the historical evolution of a research area might display a pattern of intellectually inflated development in case there is a correlation between a (1) huge productive progress and (2–3) a clear lack of semantic and/or epistemic progress. One might be tempted to infer a deep (mainly causal) connection between (1) and (2–3) from their diachronic correlation. We will remain silent on this regard. Of course, it could be reasonable to expect them to be closely related, since, for example, the epistemic results assessed in (2) have been obtained by exploiting the semantic devices in (3) and both the semantic devices and the epistemic results are displayed in the scientific products generated in (1). It might be also possible, at least from a pluralist view of scientific progress, that an area can be more semantically progressive in some subperiods and more epistemically progressive in distinct subperiods. In any case, what matters for the purpose of assessing patterns of intellectual inflationary development is the overall progress achieved in the three senses (i.e., productive, semantic, epistemic). Finally, it should be noticed that other plausive senses of progress that are involved in scientific research, such as the popular notions of social or technological progress, would be irrelevant to unfold patterns of intellectual inflations. For instance, the biomedical research on mRNA in 1990–2023 could qualify as non-inflationary science even it would have not led to any direct clinical application (such as some COVID19 vaccines in 2021), and likewise, the research on nanotechnological devices since the 1970s could qualify as non-inflationary even if it would have not led to developing any novel useful technology.

Now, we are going to rely on this proposal to analyze whether two research programmes or 'areas' (to avoid undesired implications about them having a classical Lakatosian hard-core plus auxiliary hypothesis structure),[4] one from biology and another from the physical sciences, could qualify as being intellectually inflationary according to our proposal. To do so, our main task is in the following two section to collect robust evidence to in-detail assess whether these two particular areas have been (a) productively, (b) semantically and (c) epistemically progressive for a bounded period of time. Finally, in order to present both cases in an accessible fashion to non-specialist readers, we will try to reduce the use of technicalities to the minimum required to show the applicability of our proposal.

4. Case study A: informational evolutionary biology (1961–2023)

Our first case study is the historical development since the early-1960s of a subdomain research area of evolutionary biology defined by the use of informational concepts, which has raised much interest in the philosophy of biology in the last decades (e.g., Maynard Smith, 2000; Jablonka, 2002; Artiga, 2024). As the philosophers Peter Godfrey-Smith & Kim Sterelny have claimed: "Information has also become a focus of general discussion of evolutionary processes, especially as they relate to the mechanisms of inheritance." (Godfrey-Smith & Sterelny 2016). Let us give some historical context about this area.

What can be called 'informational evolutionary biology' (IEB) emerges as the result of a vast proliferation in the late-1940s and early-1950s of applications of the famous Claude Shannon's [1948] information theory (i.e., a framework aimed to improve the encoding and transmission of signals) in many different research domains, from quantum statistical mechanics to religious studies. Although the very idea of capitalizing on Shannon's theory in evolutionary biology was actually suggested in the early-1950s by Henri Quastler, Hubert Yockey and George Gamow,[5] it was precisely Motoo Kimura who in his 1961 paper 'Natural selection as the process of accumulating genetic information in adaptive evolution' firstly described biological evolution as a natural process generating Shannon information (i.e., bits) in organisms.[6] Using Shannon's statistical tools, Kimura aimed to quantify the total amount of 'genetic information' (roughly, the infrequency of genetic units) in Cambrian organisms and its rate of accumulation in adaptive processes:

> "We know that the organisms have evolved and through that process complicated organisms have descended from much simpler ones. This means that *new genetic information was accumulated* in the process of adaptive evolution, determined by natural selection acting on random mutations. Consequently, natural selection is a mechanism by which *new genetic information can be created*." (Kimura, 1961, 127. Italics added)

4.1. Productive progress in IEB

Firstly, to assess whether IEB has been productively progressive in the past decades we need to collect data on how many scientific products have been generated between 1961 (publication year of Kimura's foundational paper) and 2023 that significantly belong to this research area.[7] We performed an advanced research on Scopus database requesting the total number of relevant publication (restricted to articles, books and book chapters in the field of biological and biomedical sciences with at least 10< citations) that explicitly include information-theoretical descriptions or tools to modelling evolutionary processes as the IEB-inclusion criterion as an unified but also heterogenous scientific research area. This Scopus request output was a total of 848 publications diachronically distributed as depicted in the spiky curve in Fig. 1 (see below). Then, in order to statistically analyze these results we performed a simple linear regression on the Scopus data,[8] also depicted (but in this case as a smooth curve) in Fig. 1, showing a nearly exponentially increasing tendency until 2016 and then a decrease in the 2016–2023 period.[9]

Apart from this quantitative evidence on the productive progressiveness of IEB in 1961–2016, one could also find pieces of textual evidence on how representative biologists (in terms of Highly Cited Researchers, such as Daniel Brooks [5.915 citations] or Christoph Adami [8.243 citations][10]) have vindicated to substantially increase the research activity carried out in this particular research area, even before Kimura's 1961 paper:

> "This notion of the role of order, which is basic to information theory, is worth pursuing in biology (…) from applying the theory to specific problems, we may obtain an experimental check on the validity of these ideas." (Yockey in Quastler, 1958, 51).

[4] Of course, as suggested by an anonymous reviewer, we can still use the expression 'research programme' in an ordinary sense, once it has been made sufficiently clear that it is not given the particular technical sense accorded to it by Lakatos (1970).

[5] Henri Quastler spread the idea in the 1955–1964 period that the evolution of living organisms could be reformulated as a natural process in which information is somehow involved: "For individual components of biological systems the problem of organization is one of specification, or information content (…) With pairs of components different problems arise relating to function, information transmission, action and interaction of information, and the like" (Quastler, 1958; ix).

[6] Of course, in addition and independently of Kimura, other evolutionary biologists in the early-1960s such as John Maynard Smith also considered relying on Shannon's theory to statistically model evolutionary processes: "Around 1960, I conceived the idea that, using information theory, one could quantify evolution simultaneously at three levels genetic, selective, and morphological." (Maynard Smith, 2000, p. 186).

[7] Note that the upper and bottom limits of this period have not been arbitrarily settled: 1961 is the publication year of Nakamura's article as the first scientific-academic product of IEB, and 2023 is the last year in which there are stable data about the scientific production in this field.

[8] The formula we used for computing a linear regression on the Scopus data of Figs. 1 and 2 in Section 5.1 was $Y = mX + b$, where Y was the total number of publications per year (dependent variable), X is the publication year (independent variable), m is the estimated slope, and b is the estimated intercept.

[9] The Scopus data collected in this Fig. 1 has been obtained by performing an advanced query on Scopus search tool assisted by the Boolean formula TITLE-ABS-KEY (biological OR biology AND evolution OR evolutionary AND information AND theory). The research has been limited to articles, books chapters and books in the Scopus database. Data collection date: 16/04/2024.

[10] All citation data have been collected using Scopus Author searches. Data collection date: 30/09/2024.

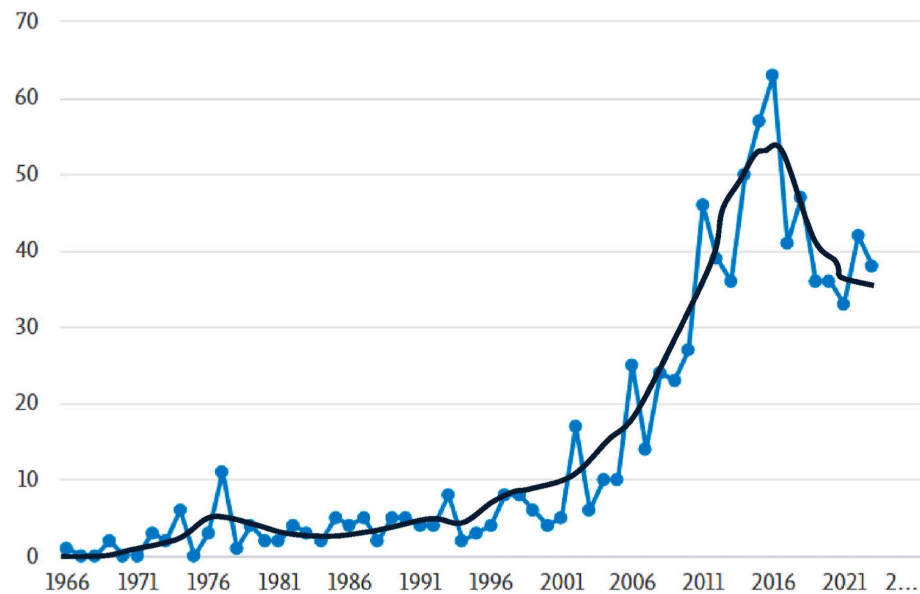

Fig. 1. Scopus data about the distribution of 848 scientific products (with 10< citations) per year that explicitly rely on informational descriptions of some biological evolutionary processes in 1961–2023. A simple linear regression is performed on the data set, showing an upward (pre-2016) and downward (post-2016) tendency in the productive rate of IEB.

"We would like nothing better than for this book to aid in taking a step toward real unification. (…) the most general outcome of these efforts will be an expansion of the research agenda in evolutionary biology." (Brooks & Wiley, 1988, xiv).

"In this age of bioinformatics and genomics (…) the idea that Shannon information quantitatively describes how much information is stored within genomes (and how to measure it) is still not widely accepted." (Adami, 2024, 499).

As such, all these representative appraisals of pursuit regarding IEB strongly support our hypothesis that the productive progress derived from our previous quantitative analysis is not merely the result of the overall increase in the publications of in any field in the last decades (especially since there is no overall increase since 2016, see Fig. 1). Otherwise, the huge productive progress in IEB has been historically grounded on an intentional and socially-articulated agenda promoted by a network of influential biologists highly capable of attracting research resources (Ph.D. students, institutions funding, etc.) to this area.

4.2. Semantic progress in IEB

Secondly, according to our definition in Section 3, for IEB as a productively progressive research area (at least in 1961–2016) being qualifiable as intellectually inflationary it must also satisfy the condition of being semantically non-progressive in this period. Following our minimalist criterion, we can qualitatively assess IEB's semantic progressiveness by analyzing at what extent the descriptive and modelling practices in evolutionary biology relying on information-theoretical concepts were accumulated in later stages of historical development. The earliest case of informational description is the following.

(A) "the genetic constitution has become correspondingly more complex in evolution. (…) we may say that genetic information is increased in the course of progressive evolution, guided by natural selection of random mutations." (Kimura, 1961, p. 138)

In this quote (A), Kimura (1961) is using the expression 'genetic information' in the Shannon's technical sense of number of bits, so that random mutations are re-described as the bits-generating process driving the biological evolution of organisms. To assess how informational descriptive practices evolved in IEB's historical unfolding since Kimura's, let us analyze a representative sample (B-E) selected from some of the most cited publications (Scopus: 161, 355, 265, 314, respectively) in this research area.

(B) "Evolution may be described as a nonequilibrium process involving the conversion of information from one form to another and the maintenance of old or forging of new reproductive networks. (…) Thus new and potential information may be converted into stored information only to the extent that this new and potential information is compatible with the ancestral information system." (Wiley & Brooks, 1982, 1)

(C) "An accomplishment of this monograph is to shoot down (…) that evolution is incompatible with the Second Law of Thermodynamics because evolution creates 'order', whereas the Second Law demands that 'disorder' increase with time (…) The correct explanation shows that an increase in Kolmogorov–Chaitin algorithmic entropy is required for evolution to proceed" (Yockey, 1992, p. 185)

(D) "the evolutionary process is driven by an enormous flow of thermodynamic information passing through the earth's biosphere. (…) This second form of information, which is associated with the sending and receiving of signals, with communication, with codes or languages, and with biological or cultural complexity." (Avery 2003, 103)

(E) "Information is a key concept in evolutionary biology. Information stored in a biological organism's genome is used to generate the organism and to maintain and control it. Information is also that which evolves. When a population adapts to a local environment, information about this environment is fixed in a representative genome. However, when an environment changes, information can be lost." (Adami, 2012, 49)

In (B), Daniel Wiley and E. O Brooks (1982, 1988) developed an informational theory of evolution wherein biological evolution was redescribed as a thermodynamic process in which 'potential genetic information' is transformed into information stored in organisms. (C) is extracted from Hubert Yockey's 1992 book *Information Theory, Evolution, and the Origin of Like*, wherein he rejected the biological use of entropy, and proposed instead to describe biological evolution in terms of algorithmic complexity (a notion incompatible with both Kimura's and Wiley-Brooks' statistical information concepts). In (D), John Avery in his 2003 book *Information Theory and Evolution* described evolution by relying on both a different (non-reductive) concept of thermodynamic information and cybernetic information. And finally (E), Christoph Adami (2012, 2024) has argued in the last decades that environmental information is indispensable to modelling evolutionary processes.

The sample of descriptive practices (A-E) is not meant to support the hypothesis that there were conceptual shifts, divergences and controversies. This would be almost trivial for any scientific research area spanning more than seven decades. Otherwise, the selected excerpts taken from the most representative works in IEB can be considered as pieces of evidence favoring the hypothesis that in the 1961–2016 period there were no diachronic increase in the accuracy (e.g., Kimuras descriptive use of Shannon's concept in 1961 was as quantitatively precise as Adami's in 2012), or conceptual soundness of informational descriptions. Each one of the main programmatic frameworks in the history of IEB (A-E) was aimed to start from scratch while disavowing any particular descriptive proposal made in the past. In terms of their conceptual soundness, Adami describes evolutionary processes in the 2010s in nearly the same information-theoretical fashion (i.e., talking about genetic changes as sources of bit-encoded information) as Kimura's in the early-1960s (A), after six decades of productive progress within IEB. Similarly, there has been no increase whatsoever in the degree of verisimilitude from Wiley and Brooks' (1982, 1) to Avery's (2003) description of evolution as a non-equilibrium process: they both suffer from the very same reductive assumptions and have identical ontological commitments. Therefore, since there has been no significant increase in the plausible semantic virtues of informational descriptions and models since the early-1960s, one might conclude that the development of IEB in the last six decades has not been semantically progressive.

4.3. Epistemic progress in IEB

Finally, we need to also assess whether the historical development of IEB in 1961–2023 has been epistemically progressive, generating knowledge and robust understanding in the domain of evolutionary biology. Firstly, we have plenty of evidence showing that IEB has been unable to generate successful and empirically tested predictions (either about novel or already-known phenomena) by directly exploiting their informational models after almost seven decades of development. And this is not because evolutionary biology (like others large time-scale disciples like geology) cannot be predictive science, which as Donaldson et al. (2017) defend is a common prejudice not supported by evidence-based practices in this field. Otherwise, IEB has been a predictively fruitless area because of its extremely computationally costly capability to generate any gene-based prediction on the evolution of organisms. As the historian Lili Kay (2000) cleverly analyzed, this predictive powerlessness of IEB comes back as far as Quastler's programme in the early-1950s: "[Quastler's] pioneering investigations were not necessarily wrong, but they were devoid of predictive capability, means of theory-testing, and experimental agenda" (Kay, 2000, p. 123). Nearly seven decades after Quastler, the main promoters of IEB such as Chris Adami in 2024 similarly attribute the persistent lack of predictive results to the practical inability to compute the vast amounts of genetic data required by informational models:

> "We have seen that automata theory and information theory allow us to quantify the complexity of a sequence in terms of its information content about the environment (…) Yet, an information-theoretic treatment of complexity will not allow us to determine whether any particular trait contributes to complexity or not, *because it is not practically feasible* to test whether or not a trait is informative about any of the potential environments the organism is adapted to" (Adami, 2024, 318. Italics added)

But, although the computational resources required for IEB to generate predictions have been exponentially increasing since late-2000s (simultaneously to the acceleration in its productive rate, see Fig. 1), this area has accumulated a lot of predictive failures in the last decades,[11] such as those reported by Adami himself (2024, 164, 318, 375). Besides, as Sarkar (1996) argued, any plausible predictive success that can be derived from this area (e.g., such as the work on phylogenetic techniques by Brooks and Wiley [1988, ix]) would be independent of the informational component of the model that demarcates IEB from non-information evolutionary biology. Thus, so far IEB has not been epistemically progressive in the strong predictive sense defended, for instance, by Lakatos (1970). But what about in a less demanding explanatory, understanding or heuristic sense?

For an information description in IEB being explanatory or even illuminating in a minimal sense, it must be able to specify which are the (causal, mechanistic, statistical, etc.) factors underlying an evolutionary process. As is argued in Section 4.2, any IEB's model or description would ultimately rely either (i) on some version of Shannon's information measure (being quantitative, statistical and asemantic.) or (ii) on the everyday notion of information (being vague, intuitively useable and semantic). On the former case, the model will be able to encode no semantic properties, which are required to give an account of how molecules are directed (or 'are about' or 'have instruction on') toward some specific processes and not others (Maynard Smith, 2000, p. 181), but properly statistical patterns between genetic structures at the cost of neglecting pivotal epigenetic and environmental factors (Jablonka, 2002). On the latter case, the IEB plausible explanations based on the everyday notion of information (or its main teleosemantics variants, see Maynard Smith [2000]) may be relevant to metaphorically grasp (Levy, 2011) the causal mechanisms involved in evolutionary processes. However, the epistemic value of these explanations lies on the capability of those metaphors to grasp the actual causal or mechanistic factors underlying evolutionary process, not properly on the informational descriptions as non-literal representational vehicles. Therefore, following Godfrey-Smith and Sterelny: "The appeal to information has an inferential use that is no way explanatory. A large proportion of the informational descriptions found in biology have this character." (Godfrey-Smith & Sterelny 2016). Thus, so far IEB has not been epistemically progressive in a robust explanatory or understanding sense either, wherein its only actual contribution to generate knowledge in evolutionary biology has been as a provider of suggestive metaphors.

4.4. IEB as intellectually inflationary

According to our definition in Section 3 and to the arguments and data collected in Section 4.1-4.3, informational evolutionary biology qualifies as an intellectually inflationary area of scientific research in the 1961–2016 period because: (a) IEB has displayed an explosive productive progress, although the production tendency changes from 2016 onwards (see Fig. 1); (b) IEB has not generated actual semantic progress because its descriptive and modelling practices have not substantially improved since the early-1960s; and (c) IEB has generated no

[11] "If we take the latter estimate, Equation (3.55) predicts that there are about $\nu = \mathrm{Ne}{-}\mathrm{I} \ln 4 \approx 700$ CRP binding sites in the Escherichia coli genome, far more than are known experimentally (…) we can conclude that perhaps some of the 700 or so predicted sites are functional, but to resolve this question we need more specific position weight matrices that are built from more sites than the ones in this analysis." (Adami, 2024, pp. 156–157) or "When comparing to computational models of evolution in artificial fitness landscapes whose ruggedness can be tuned (the NK model), we found that many of the characteristics of adaptation can be reproduced in these models, but their predictions must fall short because the number of genes is so small in these models that features such as the "endless peak" of the LTEE cannot be observed" (Adami, 2024, p. 164).

successfully predictive or robustly explanatory knowledge in its almost seven decades of development. Some comments in this regard. Firstly, according to our definition, the historical development of IEB could be assessed as recently entering in a non-inflationary stage for the 2016–2023 period, as far as it displays a clearly decreasing tendency in its production rate (Fig. 1). Secondly, it could be prima facie possible for IEB to become semantically progressive in the following years of research activities by, for instance, beginning to accumulate valuable conceptual uses and therefore improving its descriptive-modelling practices. Thirdly, it could be possible for IEB to eventually become epistemically progressive in the future by, for instance, allowing us to generate effective predictions by accessing an increasing pool of computational resources (e.g., quantum computing or AI) or developing cause-tracking explanations. Thus, IEB in 1961–2016 being an intellectually inflationary research area is a contingent matter of fact: could have been otherwise (Hesketh, 2016) and could easily change in the future.

Although the development of IEB has being intellectually inflationary, this does not mean that it has not contributed at all to evolutionary biology. By assessing this research domain one would realize that this contribution has not been semantic nor epistemic, but properly technical or instrumental. Particularly, IEB has been an 'instrumentally progressive area' by transferring statistical modeling techniques from Shannon's information theory and related areas (algorithmic complexity, automata theory, etc.) into the biological sciences. A recent example is the use of information-theoretical methods such as FFP (frequency features profiles) (e.g., Sims et al., 2009) and kWIP (k-mer weighted inner product) (e.g., Murray 2017) as tools in the domain of phylogenetic branches reconstruction.[12]

5. Case study B: ensemble non-equilibrium statistical mechanics (1938–2023)

Our second case study, this time extracted from physics, is the historical development of a branch of classical statistical mechanics devoted to modeling non-equilibrium processes using the notion of ensemble in the period 1938–2023. This research programme, that might be called 'ensemble-based non-equilibrium statistical mechanics' (or 'ENS'), was initially developed by J. W. Gibbs in 1902 to statistically model thermal behaviors such as the approach of an ideal gas to its equilibrium state (Uffink, 2007; Frigg, 2008, p. 3.2.3). What defines ENS against other alternative programmes (such as the Boltzmannian) is its descriptive reliance on the so-called 'ensembles', defined by Gibbs as follows:

> "We may imagine a great number of systems of the same nature, but differing in the configurations and velocities which they have at a given instant, and differing not only infinitesimally, but it may be so as to embrace every conceivable combination of configuration and velocities. And here we may set the problem, not to follow a particular system through its succession of configurations, but to determine how the whole number of systems will be distributed among the various conceivable configurations and velocities at any required time" (Gibbs, 1902, v)

For several reasons, ENS was not seriously considered by the physicist community until it was systematically presented by Richard Tolman (1938) framework in his book *The Principles of Statistical Mechanics*. Because this publication was the first clear scientific product in the research area of ENS, its publication year 1938 could be considered as the beginning of the historical period that we aim to analyze below, as well as the year 2023 as its last year. Having said that, let us now assess in which senses (productive, semantic, and epistemic) the development of ENS in 1938–2023 has been progressive.

5.1. Productive progress in ENS

As we did in Section 4.1, to assess ENS's productive progressiveness in the 1938–2023 period we have requested on the Scopus database the number of publications (restricted to articles, books and book chapters in physical and chemical sciences with 10< citations) that explicitly include ensemble descriptions to modelling non-equilibrium processes as the defining feature of ENS as a unified research domain. The request output was 755 documents diachronically distributed as displayed in the point-segment graph in Fig. 2 (see below).[13] As in the previous case study, we also performed a simple linear regression on the collected Scopus data (see fn.7), thus generating the smooth curve in Fig. 2. Unlike Fig. 1, this graph shows the middle-left part of what seems to be a normal distribution with a maximum somewhere in between the interval 2015–2020. This means that since 1985–1995 there has been a significant quasi-exponential acceleration in the number of publications, thus making ENS a productively progressive area of research.

But, again, ENS's significant productive progress should not be interpreted as caused by a general increasing in the number of publications in any scientific area in the last decades. Otherwise, and as in the previous case study, one could collect textual data on how some influential physicists (i.e., Highly Cited Researchers, such as Edwin Jaynes [21.016 citations]) have vindicated in the past eight decades to either decrease or increase the research activity carried out in this research area, even before Tolman's 1938 book:

> "Accordingly we had to emphasize that in [ENS] a large number of loosely formulated and perhaps inconsistent statements occupy a central position (…) This incompleteness, however, does not seem to have influenced the physicists in their evaluation of the statistic-mechanical investigation" (Ehrenfest & Ehrenfest, 1911 [1959], 67–68).

> "(…) it takes very little to see that objections to the Gibbs II [ensemble approach] are immediately refuted by the fact that the Gibbs canonical ensemble yields the correct thermodynamical predictions (…) while all textbooks give extensive discussions of Boltzmann's [approach], some recent ones fail to mention event the existence of the Gibbs [ENS] (…) much works need to be done in this field" (Jaynes, 1965, 391, 395, 398).

> "For statistical mechanics, the [best tools at their disposal] are ensemblist tools, pioneered by Gibbs (…) It is of little practical value—for their research and for their professional advancement—for physicists to worry about why their tools work as well as they do and what those tools actually have to do with the reality that lies beneath observation." (Goldstein, 2019, 19)

These negative and positive appraisals of pursuit about ENS support the hypothesis that ENS's productive progress since the late-1950s (Fig. 2) has been based on a strongly competitive agenda between pro-ensemble and the against-ensemble leading physicists, which shaped how the available research resources (post-docs researchers, funding, etc.) were distributed in this branch of statistical physics in the 1938–2023 period.

[12] As early as the 1950s, the use of information theory was perceived by biologists as an opportunity to incorporate sophisticated quantitative tools (see Kay [2000] for an historically-informed assessment of this idea). Three decades later, Brooks and Wiley (1988, ix) fulfilled Kimura's 1961 claims by showing the practical usefulness of informational tools for the task of statistically modeling phylogenetic phenomena.

[13] The Scopus data collected in this Fig. 2 has been obtained by performing an advanced query on Scopus search tool assisted by the Boolean formula TITLE-ABS-KEY (ensemble AND non-equilibrium OR equilibration AND statistical AND mechanics). Again, the research has been limited to articles, books chapters and books in the Scopus database. Data collection date: 25/04/2024.

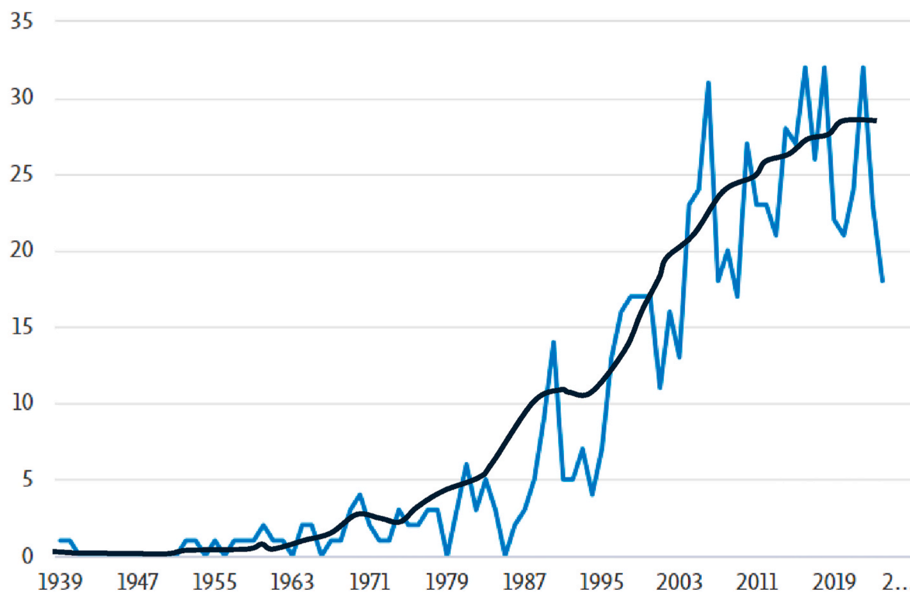

Fig. 2. Scopus data about the distribution of 755 scientific publications (with 10< citations) per year that are derived from ensemble-based non-equilibrium statistical mechanics in 1938–2023. A simple linear regression is performed on the data set, showing a logarithmic-like increasing tendency in the productive rate of ENS.

5.2. Semantic progress in ENS

Secondly, and since there is evidence of ENS's being productively progressive in the last decades, now we need to assess whether ensemblist modelling practices have also been non-progressive in a semantic sense to qualify this area as intellectually inflationary. By following our minimalist criterion settled in Section 3, we would qualitatively assess 'semantic progressiveness' by evaluating if there were actually a diachronic accumulation of past ensemblist descriptive practices that resulted in an overall improvement in terms of accuracy, conceptual soundness and/or other semantic virtues. To that purpose we have selected a collection of representative excerpts selected from some of the most relevant (in terms of total citations, discussion generated, etc.) ensemblist descriptions generated in different decades and active subdomains, e.g., quantum ENS or the philosophy of ENS.

(A) "The general nature of the statistical mechanical procedure for the treatment of complicated systems consists in abandoning the attempt to follow the precise changes in state that would take place in a particular system, and in studying instead the behavior of a collection or ensemble of systems of similar structure to the system of actual interest, distributed over a, range of different precise states" (Tolman, 1938, p. 2)

(B) "A unified and comprehensive presentation is given (…) One introduces the concept of an 'Ensemble', namely, the concept of the totality of all experimental systems prepared according to the thermodynamics specification." (Bauer et al., 1965, pp. 96, 100)

(C) "we deal with a density operator which describes the distribution of the ensemble of a system under consideration. Within the terminology of classical statistical mechanics, we treat the assembly of points in the Γ-phase space, each point of which describes a dynamical state of an element system of the ensemble" (Arimitsu, 1991, p. 207)

(D) "within the Gibbs framework the object of study is a so-called ensemble, an uncountably infinite collection of independent systems that are all governed by the same Hamiltonian but distributed over different states." (Frigg, 2008, p. 56)

(E) "Thermodynamic systems are represented by probability distributions over phase space: mathematically, that is, by positive measures on phase space assigning measure 1 to the whole space." (Wallace, 2020, p. 587)

As one could see from the above sample of ensemblist descriptions, there is an increasing in technical accuracy and conceptual refinement in how ENS-physicist have historically relied on the very notion of 'ensemble' to model non-equilibrium processes. Recall from the beginning of this section that for Gibbs in 1902 as well as for Tolman (A) in 1938, the idea of ensemble allows us to simultaneously describe the microscopic configuration of a collection of systems. The same notion was enhanced in the 1950–1960s by physicists like Jaynes (1965) or Bauer et al. (1965) (B) by specifying that ensemble-based statistical models should be always constrained (or even determined) by the agent's knowledge of the macroscopic properties of the system. Later on, descriptive practices such as the one displayed in Arimitsu's claim (c) show that ensemble models were made mathematically precise by relying on well-defined symplectic geometrical or measure-theoretical terms (as in [E]). Much work is also done in the philosophy of physics, wherein philosophers like Frigg (2008) (D) or Wallace (2020) (E) have argued that ensemblist descriptions in ENS might have different meaning (e.g., virtual copies of a system or our knowledge of the system's microstructure) depending on how we interpret the probabilities involved. Another illustrative example in this sense is Robertson (2020), who has recently defended pivotal ENS's modelling procedures such as coarse-graining, traditionally considered as simply computational devices (Denbigh & Denbigh, 1985; Malament & Zabell, 1980; Redhead, 1996),[14] can be reconceptualized as meaningful abstraction-driven descriptive practices. Therefore, this seems to suggest that ensemblist descriptive practices in non-equilibrium thermal physics have historically evolved (by somehow preserving one little improvement after another) in an overall semantically virtuous fashion, at least in terms of the mathematical accuracy of the ensemblist models and their conceptual soundness.

[14] Illustratively: "As a black box technique, Gibbs phase averaging works just fine. The question is why it works" (Malament & Zabell, 1980, p. 340).

5.3. Epistemic progress in ENS

Finally, we also need to assess whether, apart from displaying productive and semantic progress, ENS has also generated significant epistemic results in the last decades. First, there is a solid consensus among physicists on procedures such as phase averaging and coarse-graining being highly efficient in generating empirically testable predictions about the thermal-like behavior of molecular systems. In other words[15]: "the calculational ease of the Gibbs approach is the primary reason why it dominates other approaches" (Callender, 1999, pp. 349, 354–355) or "[ENS descriptions] are shortcuts that enable practical predictions, which are actually carried out in statistical mechanics" (Shenker, 2020, 11). Despite this consensus, it is a well-known fact that ENS has been accumulating lots of evidentially supported predictive successes since the late-1990s. Illustratively, ensemblist descriptions relying on two-time correlation functions have successfully predicted non-equilibrium phenomena, such as diffusion coefficients or thermal conductivity ratios for macroscopic systems (Zwanzig, 2001; Altland & Simons, 2010). Further leading ENS's main experimentally supported predictive successes (e.g., Collin et al., 2005) were derived from the so-called fluctuations theorems', mainly the Jarzynsky equality (after Jarzynski, 1997) and Crooks' theorem (Crooks, 1998), allowing to predict several thermodynamical properties in unstable microscopic regimes. In short, there is lot of evidence supporting ENS being a highly predictively successful (and then, epistemically progressive) research programme, at least since the three decades and against alternative theoretical approaches such as the Boltzmannian or 'individualist' one: "the wider applicability of the Gibbsian approach is indispensable from a naturalistic perspective, in as much as a wide range of empirically successful applications of statistical mechanics cannot be understood within the Boltzmannian approach" (Wallace, 2020, 585).

But, has ENS's historical development being epistemically progressive in, for example, a explanatory sense? Ensemblist descriptions of non-equilibrium phenomena have been widely considered as explanatorily deficient due to their reliance on non-transparent statistical techniques like phase averaging or coarse-graining, often labeled as 'subjective' (Denbigh & Denbigh, 1985, p. 53) or even 'deceitful' (Redhead, 1996, p. 31).[16] In Wallace's words: "Gibbsian statistical mechanics is criticised for trying to explain thermodynamic behaviour as a feature of our information about the world rather than as a feature of the world, for failing to identify entropy as a property of individual physical systems" (Wallace, 2020, p. 584). But, following Robertson (2020, pp. 570–573), simply assuming that ensemblist descriptions are non-explanatory presupposes a strongly biased view of what an explanation is. In fact, accounting for non-equilibrium phenomena by coarse-graining procedures only implies changing the level of description, discarding microscopic details of the molecular system that are explanatorily irrelevant to satisfactorily account for such macroscopic behavior. Thus characterized, ensemble explanations of non-equilibrium processes in nature are not more anthropocentric or illusory distortions than any other statistical explanations of natural phenomena; otherwise, these are nothing but powerful abstractions that allow us to select the explanatorily relevant factors. Therefore, we have good pieces of evidence supporting the claim that the exploitation of these semantic products generated from ENS in 1938–2023 have provided us with predictive as well as explanatory knowledge of a variety of non-equilibrium phenomena, knowledge that has also been supported by experimental data obtained in the past decades.

5.4. ENS as intellectually non-inflationary

According to our definition in Section 3 and to the arguments and data collected in Section 5.1-5.3, ensemblist non-equilibrium statistical mechanics cannot be characterized as an intellectually inflationary science in the 1938–2023 because of this reason: although ENS has displayed (a) a significant productive progress, ENS has nevertheless generated both (b) some semantic progress, by improving the accuracy and soundness of its modelling practices, and (c) substantial epistemic progress by generating experimentally confirmed predictions and some statistical explanations about non-equilibrium physical phenomena. As with our previous case study in Section 4, the historically contingent non-inflationary status of ENS could have been otherwise and it can eventually change in the future in the case of this area no longer being semantically (e.g., there will be no further improvements in the accuracy or soundness of ensemble models since 2023) or epistemically progressive (e.g., ENS's predictions will become refuted by novel experimental data collected in the 2030s). But as far as the ENS's actual historical evolution in 1938–2023 is concerned, its semantically and epistemically-virtuous productive progress constitutes, according to our proposal, an illustrative example of non-inflationary development of a research area.

6. Conclusion

In this paper we have defended that it is a pressing (if not urgent) task for us philosophers of science to assess in which specific sense and why the actual historical development of a scientific area constitutes a case of what Lakatos called 'degenerated science' (Lakatos, 1970). For both Lakatos and our own analysis, degeneration generally occurs when the historical evolution of scientific research fails to meet the minimal conditions underlying our notion of scientific progress. One specific form of developmental degeneration is what we have defined as intellectual inflation, wherein a research area appears to grow productively—through an increase in publications, conferences, founding, and so on—without advancing in terms of semantic or epistemic goods. As illustrated in the case of IEB (Section 4), the development of intellectually inflated areas is driven primarily by productive factors like the sheer output of papers or the expansion of academic activity, rather than by generating new relevant information or knowledge about the world. This stands in contrast to non-inflationary fields, like ENS (Section 5), which show genuine progress by contributing semantic (content or truth-oriented) and epistemic (knowledge-generating) advances. So defined, one of the main virtues of our approach to the idea of intellectual inflationary science is its prima facie compatibility with various prominent theories of scientific progress (see Niiniluoto, 2024). By adopting a pluralistic stance, we argue that the idea of progress in scientific research should not be understood from a single parameter, but instead captured by multiple factors: semantic, epistemic, socio-cultural, etc. As such, this pluralistic account of the nature of scientific progress, that will be elaborated in future work, allows us to detect intellectually inflationary patterns, thus offering a powerful analytical tool for examining the historical dynamics of science.

In conclusion, why should we philosophers of science be concerned with intellectual inflation at all? The most compelling reason is because this increasingly generalized pattern of developmental degeneracy within scientific research is becoming a high risk due to the social impact that scientific research has in our lives, perhaps just as dangerous in the long-run and far less understood than other related problematic

[15] Another way of reporting this general consensus is the following: "in conceptual discussions of statistical mechanics (particularly, though not exclusively, in philosophy) something close to a consensus has emerged: while Gibbsian statistical mechanics, and the Gibbsian definition of entropy (it is conceded) is a standard tool in practical applications of statistical mechanics" (Wallace, 2020, p. 584).

[16] This idea is clearly reflected in the following claim by Malament and Zabell: "As a black box technique, Gibbs phase averaging works just fine. The question is why it works" (Malament & Zabell, 1980, p. 340).

phenomena like pseudoscience,[17] or misconducted science (Mahner, 2013; Ladyman, 2013, pp. 48–52). There is growing evidence of a trend among large-scale scientific institutions and publication markets in recent years to prioritize the volume of research publication (e.g., Radzvilas et al., 2023), over their substantive contribution to gain information and knowledge about the world. Then, this pressure incentivizes a form of massive productivity that does not necessarily advance understanding, creating a system that rewards research output over quality. As philosophers of science, we can play a crucial role in addressing this issue by analyzing and tracking the patterns of intellectual inflation in the historical development of scientific fields. By doing so, and working in collaboration with scientists (Chang, 2004; Pradeau et al., 2024), we can offer insights that may help mitigate this problem. But of course, a lot of work still needs to be done in this direction for us philosophers being able to contribute to a plausible solution to this problem in future. Time will tell.

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[17] Of course, to realistically equate the social dangerousness of inflationary science to that of pseudoscience (e.g., anti-vaccine movement, climate denialists) we should consider a worst-case scenario in which there will come a time in the future when all scientific research is done inflationarily.

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