SCIENTIFIC PROGRESS AND IDEALISATION*

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Abstract

Intuitively, science progresses from truth to truth. A glance at history quickly reveals that this idea is mistaken. We often learn from scientific theories that turned out to be false. This chapter focuses on a different challenge: Idealisations are deliberately and ubiquitously used in science. Scientists thus work with assumptions that are known to be false. Any account of scientific progress needs to account for this widely accepted scientific practice. It is examined how the four dominant accounts—the problem-solving account, the truthlikeness account, the epistemic account, and the noetic account—can cope with the challenge from idealisation, with an eye on indispensable idealisations. One upshot is that, on all accounts, idealisations can promote progress. Only some accounts allow them to constitute progress.

1. Introduction

Intuitively, science progresses from truth to truth. We learn more facts based on previously learnt facts. A glance at history quickly reveals that this idea is mistaken. We often learn from theories that turned out to be false. Take theories about cancer causes. According to the blastema theory (developed in the 19th century), cancer cells are developed from budding elements (blastema) that are scattered among normal tissue. We now know this to be incorrect, but we learned from this theory that cancer is made up of cells (and not of lymph, as previously believed). This discovery remains unchallenged. Replacing the false lymph theory with the false blastema theory thus looks to be progressive.

We could propose that progress is possible whenever we have good reasons to think that our theories are correct. However, such a view is challenged by *deliberately* used *idealisations* in science. Especially when scientists use models or simulations to analsze phenomena, they work with assumptions that are known to be false, like the stipulations that there is no intergenerational overlap, or that humans are perfectly rational.

Some idealisations are 'crutches' for scientific reasoning. We hope to eventually replace them with more accurate assumptions. Other idealisations are considered to be *indispensable*; we need them for realising scientific achievements. Yet surprisingly, both kinds of idealisations do not seem—in principle—to impede scientific progress. There are numerous examples of *empirically successful* scientific inquiries that involve such idealisations, for example, some idealised models can more or less accurately predict the behaviours of interest. A convincing account of scientific progress must do justice to this fact.

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This chapter analyses the challenge from idealisation for accounts of scientific progress, with an eye on indispensable idealisations. I first describe idealisations in more detail (§2). I do not defend a particular theory of scientific progress. Instead, I proceed by analysing how well the four dominant accounts can cope with the challenge: the problem-solving account (§3.1), the noetic account (§3.2), the epistemic account (§3.3), and the truthlikeness account (§3.4). One upshot is that, on all accounts, idealisations can promote progress. Only some accounts allow them to constitute progress.

2. The challenge from idealisation

Scientific inquiry—perhaps inevitably—involves falsehoods. Theories turn out to be false and mistakes happen—from miscalculations to mislabelled substances in experiments. Mistakes typically impede scientific progress. (But think of examples like the discovery of penicillin.)[1] The case is less obvious for what Strevens (2017, 37) calls 'deliberate falsehoods'. He is not interested in *illegitimate* ones, such as fabricating results to get a grant. He is concerned with deliberate falsehoods that are accepted although they are known to be false, paradigmatically idealisations. These are the falsehoods I focus on.

Some terminology before I characterise idealisations in more detail: I use 'scientific account' as an umbrella term for theories, models, and other forms of theorising, and 'idealisation' for deliberately used *false assumptions*. The word 'idealisation' is also used for the practice of idealising, or for models, theories, or laws that involve such falsehoods. I follow Potochnik (2017) in labelling the latter idealised representations or accounts.

Idealisations can be distinguished from *abstractions* and *approximations*.[2] Following Jones (2005), an abstraction is an *omission* that does not lead to a misrepresentation.[3] Take a description of a falling object that omits its colour. For Jones (2005, 175), an important difference is that an idealisation is a (clearly) *false* assumption, for example the assumption that gas molecules do not exert any long range forces on each other. An abstraction involves the omission of something *true*, such as omitting that the falling object is tangerine.

Following Norton (2012), idealisations should also be distinguished from *approximations*. An approximation merely describes a target system inexactly, such as describing roundish objects as round or streamlining collected data, like a smoothed curve of data points gained by ignoring outliers. What counts as an approximation or inexact description is context-sensitive. One has to specify a proximity range for the value of interest (perhaps relative to a given context). A description is no longeran approximation if the value is not within this specified proximity (but it can be an idealisation).[4]

Neither abstractions nor approximations seem to—in principle—impede progress. If a property does not affect a phenomenon—say, an object's color when analysing its speed—abstracting from away it seems harmless. Indeed, such abstractions can *promote* progress by enabling scientists to focus on the (potentially) relevant properties. Approximations

[1] Fleming saw that bacteria on an agar plate had been killed close to where a mould was accidentally growing. The analysis of this mould led to the discovery of penicillin.

[2] They can be also distinguished from *fictions* (for details see Frigg and Hartmann, 2020, §2.2).

[3] Some omissions lead to a misrepresentation, e.g., models can omit so many aspects of their target phenomena that they do not qualify as accurate representations.

[4] Norton focuses on idealised models. Idealisations are (or represent) "[...] a real or fictitious system, distinct from the target system [...]." (2012, 209) This is compatible with Jones' account. A gas model that assumes that gas molecules do not repel each other can be construed as a model of fictitious gases.

can be beneficial because we often must trade off precision against other values like applicability across domains (see, e.g., Levins, 1966). They can also simplify (mathematical) reasoning. The case of idealisations is less clear. Adding falsehoods to scientific reasoning seems to be a form of *regress*. On the other hand, using idealisations can be progressive. As I illustrate in the following, idealisations can be a (perhaps essential) part of empirically successful investigations. I describe this puzzle about idealisations in more detail (Section 2.1), before I focus on two kinds of idealisations (§2.2-2.4).

2.1. A puzzle about idealisations

As Cartwright (1983) demonstrated for the case of physics, idealisations are used in scientific theories or laws. However, they are most prominently discussed in the case of scientific models and simulations. The majority of them involve at least some idealisations. For instance, according to the aorta model developed by Caruso et al. (2015), the walls of the aortas are *rigid* (although they are elastic).

Scientists even use different idealised models for analysing the same target phenomenon *at the same time*. Weisberg (2007) calls this 'multiple-models idealization.' Even more puzzling, these models can be *incompatible*. One example in physics are the *optical* Glauber model and the *Monte Carlo* Glauber model for analysing collisions of atomic nuclei. According to the former, nuclei are perfect spheres of energy. According to latter, nuclei are not such spheres; the protons and neutrons constituting the nucleons are distributed at random. These assumptions are contradictory; the models are not compatible. Another example is that water is construed as a continuous fluid in some models and as being composed of discrete particles in others (Teller, 2001). These examples are not considered to be bad scientific practice (among other things because the models focus on different aspects of the phenomena), and it does seem that our theories about nuclei collisions and water are progressing.[5]

Relatedly, scientists often keep using idealised models even if they have de-idealised or less idealised versions, as Elgin (2017, ch. 12), Potochnik (2017, ch. 2), and Dellsén (2016) highlight. For instance, the ideal gas law is widely used (e.g., for teaching purposes) although we have less idealised options, such as the van der Waals equation.

That scientists frequently use idealisations is puzzling. What is attractive about working with assumptions known to be false? Why is this not considered to be improper scientific practice? The answer leads to another puzzle.

As Potochnik (2017, ch. 2) emphasises, one reason to work with idealisations is to *reduce complexity*. When exploring complex phenomena, it can help to start with a simplified analysis. More accurate models can be built when the phenomena are better understood. Idealised models can support *explorative* purposes, such as the simulation of various climate scenarios (see, e.g., Gelfert, 2016, ch. 4, Rohwer and Rice, 2016). Some models are employed to *formulate causal hypotheses*, which can be empirically tested (see, e.g., Alexandrova, 2008, Pincock, 2014). And models are used to *evaluate competing hypotheses*. For instance, Schmid-Hempel and his team explored why honeybees sometimes leave food sources even if their honey sacks are only partially filled. Their model was not designed to adequately capture this behavior, but to "[...] investigate how much of the bees' behaviour can be accounted for by purely energetic models of nectar collecting." (Schmid-Hempel et al., 1985, 61)[6] That honeybees maximize their energy *efficiency* rather

[5]Multiple-models idealisation is analysed by, e.g., Morrison, 1999, Weisberg, 2007, Potochnik, 2017.
[6]This example is taken from Rice, 2016.

than their energy *intake* turned out to be more plausible.

These reasons are not exhaustive but suffice for our purposes (for more suggestions see Potochnik, 2017, 48). There is another aspect that justifies the use of idealisations, and often governs it, namely their *empirical success*: Working with idealisations often leads to the desired results. For example, many idealised models can more or less accurately reproduce or predict the behaviors of interest, or match observed data. For instance, the behaviors predicted by the aforementioned honeybee model match the data surprisingly well. Some simulated possible climate scenarios turn out to be realistic. And so forth. This success is important. Scientists typically employ an idealisation based on educated guesses about which aspects of a phenomenon they can idealise. When the scientific account involving it is *not* empirically successful, the idealisation is often revised or removed. Take the Glauber models mentioned earlier. The 'perfect sphere' idealisation used in the optical Glauber model led to false predictions. According to it, the collision of two nuclei should result in the formation of an *ellipsoid*. Measurement showed that other shapes can result. The Monte Carlo Glauber model (which was subsequently invented) does not use this idealisation and fares better with the shape predictions. (The optical Glauber model is still used for cases where the shapes are not crucial, such as explaining how much energy there is in the intersection of two colliding nuclei.)

The frequent success of idealisations is challenging for accounts of scientific progress. Arguably, empirically successful scientific accounts are progressive. But how we can progress by working with clearly false assumptions? In what follows, I introduce two kinds of idealisations: *Galilean* idealisations (§2.2) and *indispensable* idealisations (§2.3). This is not an exhaustive distinction, but these kinds constitute two extremes for the challenge from idealisation for scientific progress. Galilean idealisations can often be replaced with empirically accurate counterparts. While we clearly progress with such replacements, we still need to account for empirically successful intermediate stages. Indispensable idealisations are considered to be *irreplaceable*, and are thus the most puzzling.

2.2. Galilean idealisations

Galilean idealisation is the use of idealisations to mathematically simplify a scientific account of a phenomenon to render it (more) computationally *tractable*. This idealisation strategy is named *Galilean* because Galileo used it in his scientific investigations (see McMullin, 1985, Weisberg, 2007). Whereas Galilean *idealisation* is a strategy, I dub the falsehoods it employs Galilean *idealisations*.

As Weisberg (2007) emphasizes, this idealisation practice is *pragmatically* justified: We want to gain tractability. When the phenomenon is better understood and the mathematical methods are more advanced, we can de-idealise the model and replace it with increasingly accurate ones. He illustrates this with an example of models used in computational chemistry to compute wavefunctions for molecules of interest. The early very simplified models were gradually replaced with more accurate models. Galilean idealisations are thus not meant to be permanent. We hope to replace them with what Strevens (2008, 300) calls a *veridical counterpart*, which correctly captures the respective properties. A veridical counterpart of the idealisation that, say, gas molecules exert no long range forces on each other would accurately capture how these forces interact.

Empirical success is important. A simplified model that does not produce empirically adequate results (such as successful predictions) is often not further used. On the other hand, a successful de-idealisation of an empirically successful model shows that "[...] the [idealized] model does give a relatively good fit to the real structure of the explanandum object." (McMullin, 1985, 264) The idea is that the model approximately captures the target phenomenon because its idealisations turn out not to be essential.

2.3. Indispensable idealisations

Whereas Galilean idealisations can often eventually be replaced with veridical counterparts, *indispensable* idealisations are considered to be not replaceable.

Following Rohwer and Rice (2016, 1134), idealisations are indispensable in the case of idealised models "[...] when removing the idealizations has the effect of 'destroying' or 'dismantling' the model [...]." A model is dismantled when it stops working, e.g., when it does not compute meaningful results. An idealisation can be essential to the model's mathematical representation of the target phenomenon. A model is also dismantled when it is no longer empirically successful once the idealisations are removed or replaced. For instance, while the idealised model gives us predictions that match the empirical data, no de-idealised model delivers such a match. An example is given by Rice (2018): Idealisations can be *entrenched* with the accurate assumptions such that once they are removed or replaced, the models are no longer empirically successful. His examples are optimality models in biology. Such models are highly idealised and used to explain behaviors or phenotypic traits (such as the honeybees' foraging behavior) by determining evolutionary optimal strategies for them. In other cases, we can no longer obtain the desired *scientific explanations* if we remove the idealisations. As Rice (2018, 2809) puts it:

> [...] these modeling techniques are often essential and ineliminable because they allow scientific modelers to extract the desired explanatory information that would otherwise be inaccessible.

Several scholars gave examples of indispensable idealisations (e.g., Wayne, 2011, Bokulich, 2011, Kennedy, 2012, Batterman, 2002, Batterman and Rice, 2014, Rice, 2018, 2019). Batterman (2002) suggested *asymptotic* idealisations as one key example. Such idealisations take some sort of limit, such as the *infinite population idealisation* according to which the population of interest is *infinitely large*. It is used in population genetics to create deterministic models of changes in a population's gene frequency (for an analysis, see, e.g., Strevens, 2019). Another example is the *thermodynamic limit*, which states, roughly speaking, that a system's number of particles and its volume are arbitrary large. It is used, for instance, by phase-transition models. Phase transitions are abrupt changes of a system's or substance's qualitative macroscopic properties, such as water's freezing into ice or the magnetization of iron. According to some scholars, this limit is an indispensable idealisation because such transitions cannot be reproduced with a model that assumes finite particles (rather than infinite ones). By employing finite systems, say, systems based on statistical mechanics, we cannot model phase transitions (see, e.g., Batterman, 2002, Batterman and Rice, 2014, Rice, 2018). Others (e.g., Butterfield, 2011, Norton, 2012) dispute this claim and consider the thermodynamic limit and other asymptotic idealisations to be dispensable. I do not take a stance here (for discussion see, e.g., Shech, 2018), but I take for granted that there are some indispensable idealisations.

2.4. Two approaches to idealisations

A key issue debated is whether the understanding, explanations, or scientific accounts that can be obtained from working with indispensable idealisations are non-factive (i.e., contain falsehoods). Many general idealisation accounts have been proposed. I focus on two opposing approaches. According to what I call the *rationalisation approach*, scientific explanations or accounts can involve (indispensable) idealisations and thus be non-factive as long as the idealisations are *justified*, e.g., they fulfill a certain purpose. For Bokulich (2011), an idealised model can explain a phenomenon if the latter falls in its *application domain* (among other things). Rice (2018) proposes that being in the same *universality class* can justify exploring a phenomenon with an idealised model. Elgin (2017, ch. 11-12) argues that we can be justified in using idealisations when they *exemplify* properties of interest, especially when those are difficult to detect. Potochnik (2017) makes the case for accepting idealisations if they help us to *identify causal patterns*. And so forth.

In this paper, I cannot go into any details. Instead, I contrast this approach with an approach according to which the explanations or accounts in question are *factive* despite being obtained using (indispensable) idealisations. Lawler (2021) describes an *extraction approach* to idealisation that serves to capture insights from Alexandrova (2008), Pincock (2014), Bokulich (2016), and Rice (2016, 2018, 2019). According to this approach, idealisations merely *enable* explanations or accounts (and the understanding they can generate), but are not an element of their content. When working with such idealisations only the truths we extract are elements of the content of our explanations, accounts, or our understanding. For instance, the empirical success of the honeybee model suggests that it is true that bees prioritize energy efficiency over energy intake. This information is part of our explanation of their behavior and not the idealised model's content. Pincock (2021) advocates a similar view according to which idealised models can be explanatory when truths are underlying each falsehood relevant for the explanation in question (see also Pincock, 2014).

These approaches to idealisations are not exhaustive and I cannot discuss their plausibility. But it is useful to have them in mind when we turn to examining how well the dominant accounts of scientific progress can accommodate the fact that (indispensable) idealisations persist in many of our empirically successful scientific inquiries.

3. Accounts of scientific progress and the challenge from idealisation

'Scientific progress' is a normative notion. In the sense relevant here, it is a form of *cognitive improvement* (Niiniluoto, 2019, §2.2).[7] Advancing from the lymph theory of cancer to the blastema theory was such an improvement. But what precisely constitutes cognitive improvement in science? Following Niiniluoto (2019) and Dellsén (2018a), I focus on four dominant accounts. They respectively explicate scientific progress in terms of an increase or decrease: a decrease in *unsolved problems* (the problem-solving account), an increase in the *truthlikeness* of scientific theories (the truthlikeness account), an increase in *knowledge* (the epistemic account), and an increase in *understanding* (the noetic account).

In what follows, I briefly characterise these accounts and examine how they can cope with the challenge from idealisation. I start with the account that *prima facie* can do this most easily because it lacks a factivity requirement, i.e., a requirement that every progressive claim, theory, or solution must be true: the problem-solving account (§3.1). Then, I turn to the accounts that explicate progress in terms of epistemic achievements: the noetic account (§3.2) and the epistemic account (§3.3). I end with the truthlikeness account (§3.4); it might struggle the most because it focuses on the truth of theories.

My analysis has an eye on whether idealisations or idealised accounts can *constitute*

[7] *Cognitive* scientific progress differs from other forms of progress (Niiniluoto, 2019, §2.). For instance, developing more precise microscopes or securing more external funding are non-cognitive improvements.

or merely *promote* progress on a given account of progress (if at all). This distinction has been emphasised by Bird (2008, 280) and Dellsén (2018b, 73). Something *constitutes* progress when the relevant achievement is thereby fully or partially realized, such as an increase in, say, knowledge or understanding. By contrast, something *promotes* progress when it merely renders it more likely that this increase can be achieved. For instance, buying better lab equipment does not constitute cognitive progress. We do not automatically gain more, say, understanding by having better equipment. But it arguably promotes cognitive progress by raising the probability that we will increase our understanding in the long run. Likewise, idealisations might merely increase such a probability.

3.1. The problem-solving account and the challenge from idealisation

The problem-solving account of scientific progress was suggested by Kuhn (1970) and has been developed by Laudan (1977, 1981). Shan (2019) offered a related account.

3.1.1. The Kuhn-Laudan problem-solving account

The Kuhn-Laudan account identifies *scientific problems*[8] as the key currency for scientific progress. Laudan suggests to define progress in terms of *problem-solving effectiveness*, considering the *amount* of the solved and unsolved problems and their *significance* relative to a research tradition (see below). We progress by decreasing the amount of significant unsolved problems—by solving or dismissing problems, or downgrading their significance.

Importantly, scientific problems are determined relative to a *research tradition*,[9] which involves various methodological, conceptual, and ontological commitments, e.g., assumptions about how to test theories or what kinds of entities exist. The research tradition that is dominant in a given discipline at a given time determines its problems and their importance. There are no objective factivity requirements for identifying a problem. If a problem presupposes what later turns out to be incorrect or if its target phenomenon is not real, it is still a problem for that research tradition. As Laudan (1977, 16, emphasis in original) puts it: "A problem need not accurately describe a real state of affairs to be a problem: all that is required is that it be *thought to be* an actual state of affairs." For instance, according to the caloric theory, 'caloric' (a self-repelling fluid) is the substance of heat. It is now known that caloric does not exist. To explain how caloric accounts for temperature phenomena was nonetheless a problem for this theory's research tradition.

This relativity of the problem-solving account is inspired by Kuhn's famous observation that theoretical frameworks (or 'paradigms') can radically change in the event of 'scientific revolutions'—think of the change from Ptolemaic cosmology to a Copernican one. Kuhn argued that such frameworks are *incommensurable*. Accordingly, whether a scientific problem is solved, can be dismissed, or downgraded is also determined by the scientists in a research tradition. Again, there are no objective factivity requirements. If a solution to a problem turns out to be incorrect but fulfilled the tradition's solution criteria, the problem is solved in that tradition.[10] Accordingly, 'progress' and 'regress' are relative notions. For instance, a problem concerning cancer causes can be solved in one research tradition but unsolved in a subsequent one, say, because it rejects the solution's assumptions.

This brief characterisation shall suffice for our purposes (for details and discussion see, e.g., Bird, 2016, Dellsén, 2018a, Niiniluoto, 2019, Shan, 2019).

[8] Laudan's term 'scientific problem' is akin to a Kuhnian *puzzle*.

[9] Laudan's term 'research tradition' roughly corresponds to a Kuhnian *paradigm* or *disciplinary matrix*.

[10] Solving a problem is not an arbitrary matter. For instance, Laudan (1977, 22-34) claims that a theory needs to entail an approximate account of a problem in order to solve it.

3.1.2. The Kuhn-Laudan problem-solving account and the challenge from idealisation

Prima facie, the problem-solving account can cope well with idealisations. Because no objective factivity requirements are imposed on problems or their solutions, idealised accounts can be progressive if they solve problems (or leave fewer problems unsolved).

However, the mere fact that inaccuracy is not considered an obstacle to progress is not enough to account for idealisations. For a start, the problem-solving account has factivity constraints albeit *subjective* ones. The phenomenon a problem targets must thought to be actual, and solutions to a scientific problem should be recognised as correct or adequate by the respective scientists. Such an 'apparent correctness' condition is *prima facie* in conflict with the fact that idealisations are *deliberate* falsehoods. Accordingly, the problem-solving account faces a similar challenge as factive accounts of progress (i.e., ones that have objective factivity requirements): It must show how accounts known to be idealised can provide (seemingly) correct solutions (or be part of them).

The problem-solving account, however, has more flexibility in meeting this challenge. Factive accounts of progress must demonstrate that even indispensable idealisations can generate de facto correct scientific accounts, for instance, by adapting a version of the extraction approach described above according to which idealisations function as a (perhaps indispensable) tool to generate such accounts. The problem-solving account can follow suit, but it can also adopt a version of the rationalisation approach according to which idealisations can be part of justified non-factive explanations or accounts—as long as these are (part of) solutions that the relevant scientists accept as correct or adequate.

Note that idealisations only *constitute* progress if they are part of the problem solutions. If the problem-solving account adopts an extraction approach, idealisations merely promote progress by increasing the probability that such solutions can be found.[11]

The problem-solving account can also explain why some idealised models continue to be used even when de-idealised versions are available. As long as they still solve relevant problems or have another function (e.g., a pedagogical one) and do not hinder solving problems, there is no need to abandon them.

Although the challenge from indispensable idealisations can be met by adopting a suitable idealisation approach, the problem-solving account struggles with an aspect of *Galilean* idealisations. Consider a case where a mathematically simplified model is ultimately replaced with a de-idealised version, with there being intermediate stages with increasingly more accurate models. Let us suppose that all involved models are empirically successful. The predictions made by the initial model roughly match the data, the predictions made by its first revision match them better, and so forth, until we have a de-idealised model that accurately matches all data. One issue is that it is not clear how many problems we are concerned with.[12] Either way, these models solve at least a problem of the form 'Construct a model that matches the data to the proximity degree x.' However, this is not enough for progress. An improved model needs to solve *more* problems. We could say that it additionally solves the problem 'Replace the idealisations used in its predecessor model with more accurate idealisations,' or 'Construct a model that matches the data to a higher proximity degree than the previous model.' But this does not fully solve the issue. Such problems are solved exactly once (at least if scientific

[11] This also seems to apply to Pincock (2021)'s view: Idealisations have non-representational functions in explanatory practice, and only explanatorily relevant truths are part of explanations.

[12] As Bird (2016, 548) and Niiniluoto (2019, §3.2) emphasise (and Kuhn and Laudan admit), finding a framework for identifying problems is difficult. Any theory arguably entails answers to infinite questions.

problems are genuine challenges), and we can have more than one intermediate stage between the initial model and the fully de-idealised one. One might think that the more accurate models solve all problems of their predecessors and thus more problems, but that is not straightforwardly true. If we are concerned with constructing a model that matches the data to a specific proximity degree, then a fine-grained model does not solve the problem of a more coarse-grained one. It is the other way around. A *less precise* model can capture a wider proximity range.[13] If so, the more idealised models solve *more* problems than the less idealised ones. Perhaps the more advanced models progress by solving more *significant* problems. Constructing a less idealised model might be more valuable than constructing a more idealised one. However, it is not clear how to weigh the number of problems solved against their significance—a general challenge for the problem-solving account.

To sum up: Although the problem-solving account has great flexibility in accounting for idealisations, it might struggle with cases where a more de-idealised representation does not solve more problems.

3.2. The noetic account and the challenge from idealisation

The *noetic* account defines progress in terms of an epistemic achievement, namely *understanding*. Scientific progress consists in an increase of scientific understanding. Making progress researching cancer causes consists in obtaining a better understanding of them.[14] This account has been developed by Dellsén (2016, 2018b, 2021) (see also Bangu, 2015).

3.2.1. Dellsén's noetic account

Dellsén's account proceeds from the assumption that understanding is not reducible to corresponding knowledge.[15] Understanding requires an epistemic commitment to a systematic account of the target phenomenon, e.g., to an explanation of it. The nature of this commitment is contested (for details see Hannon, 2021). For instance, it is debated whether understanding is *factive* and whether the commitment must be *epistemically justified* (i.e., roughly speaking, whether one needs to possess good reasons or evidence for it). Accordingly, there could be vastly different noetic accounts.

Dellsén (2021) couples his view with the following analysis of understanding: Someone understands a target phenomenon if and only if they grasp an adequately accurate and comprehensive *dependency model* of it. Such a model primarily specifies the dependence relations the phenomenon is involved in, such as causal relations to other things, but it can additionally specify what the phenomenon does *not* depend on. Realising this can be important, e.g., discovering that a disease was not genetic can help to better understand its origins. Dependence relations encode information about how the phenomenon would have been different if other things had been different. So, someone who grasps a dependency model acquires the ability to *explain* the phenomenon and to *predict* how its features would change in different circumstances. The degree of someone's understanding can be determined based on how accurate and comprehensive the model is that they grasp. An understanding subject does not have to believe the dependency model or be epistemically justified in committing to it. It suffices that the subject accepts the model

[13]If the problem is 'Construct a model that matches the data to *at least* the proximity degree x,' then all models offer solutions to the very same problem.

[14]Dellsén (2021) discusses whose understanding is decisive. I leave this issue aside.

[15]Others defend that understanding is a form of knowledge (see Grimm, 2021 for details).

(where accepting roughly means treating it as given for a certain purpose). Dellsén (2016) tries to show that an unjustified theory (or model) can foster understanding and progress.

This brief characterisation shall suffice for our purposes (for details see Dellsén, 2021).

3.2.2. Dellsén's noetic account and the challenge from idealisation

How the understanding component is specified matters for a noetic account's ability to cope with the challenge from idealisation. For instance, an account that assumes that understanding involves *believing* the dependency model in question cannot straightforwardly explain how scientists progress with deliberate falsehoods. Dellsén's account does not face this issue; he only requires that the scientists accept the models. However, his resources to cope with idealisations are limited; his account is broadly *factive*. That a dependency model is adequately *accurate* is necessary for understanding and thus for progress. Dellsén (2021, §3.2) allows for inaccuracies when they increase the *comprehensiveness* of the model, but many idealisations are substantial inaccuracies. Dellsén is aware of this issue. To solve it, he adopts the non-difference maker view of idealisations developed by Strevens (2008, 2013, 2017). According to it, idealisations are compatible with factive reasoning as long as they "[...] indicate that certain factors make no difference to the phenomenon to be explained [...]" (Strevens 2017, 37)—or as Dellsén (2021) puts it, point to the absence of a dependence relation. For instance, assuming that a population can be arbitrarily large indicates that the precise population size is not explanatorily relevant. An idealised model's content has then two parts (Strevens, 2008, 318):

> The first part contains the difference-makers for the explanatory target. [...] The second part is all idealization; its overt claims are false but its role is to point to parts of the actual world that do not make a difference to the explanatory target.

An explanation involving idealisations "[...] is correct if the propositions expressing its explanatory content, as opposed to its literal content, are true." (Strevens, 2013, 512) This content contains veridical counterparts of the idealisations (Strevens, 2017, 45):

> [The idealised model] derives [the representation of?] the phenomenon to be explained from a mix of real difference-makers and fictional non-difference-makers. Take the fictional non-difference-makers away (substituting veridical statements such as "Long-range forces are small") and you can still derive the phenomenon.

Dellsén (2016, 2021) follows Strevens (2008, sect. 8.2) in using the ideal gas law to illustrate this analysis. Indeed, it seems possible to explain the gas regularities in question with the veridical parts of the ideal gas law and veridical counterparts of its idealisations. Let us stipulate that this example and related cases work well. Then, replaceable *Galilean* idealisations can be accommodated similarly. Because we can ultimately deidealise the model, it seems that the idealised aspects do not make a difference to the analysed phenomenon and that veridical counterparts can be used for the desired explanations. Moreover, Dellsén could classify models of the intermediate stages as progressive because he does not demand that the dependency models be fully accurate.

Indispensable idealisations pose a greater challenge. Although Strevens' account is meant to apply to all idealisations (Strevens, 2008, 316, Strevens, 2017, 38), it is not clear that it fully works for such idealisations. Recall what makes them special: They might be necessary for the model's mathematical representation or be entrenched with the non-idealised assumptions such that the models are no longer empirically successful once they are removed or replaced. Strevens' proposal to explain phenomena using the idealisations' veridical counterparts and the correct parts of the model thus does not seem to work, as Rice (2018) highlights. Perhaps indispensable idealisations nonetheless point to non-difference makers, as Strevens (2019) argues for the case of asymptotic idealisations.[16] But Rice (2018) gives examples of such idealisations that *distort* difference-makers.

While Dellsén adopts the non-difference maker concept, he neither endorses nor rejects the derivation part of Strevens' account. But since he does not address the issues with indispensable idealisations, the noetic account lacks a solution for them. Dellsén could adopt a version of the extraction approach. However, this would come with a cost. On Dellsén's view, idealisations *constitute* progress, as he (2018b) highlights. Re-interpreted as non-difference makers they are part of the dependency models; they highlight what the phenomenon does not depend on. Dellsén (2021, §3.2) emphasizes that this explains why we sometimes keep idealised models alongside their de-idealised counterparts; they contain additional information about non-dependence relations. On the extraction approach, idealisations are not part of dependency models, but only *promote* their construction, e.g., by providing information about non-difference makers.

To summarise: Dellsén's noetic account can accommodate replaceable Galilean idealisations and other idealisations that can be analysed with Strevens' non-difference maker view. Its struggle with indispensable idealisations can be solved by adopting the extraction approach (at least for indispensable idealisations) and sacrificing the proposal that all idealisations can constitute progress.

While Dellsén's account is broadly factive, a noetic account coupled with a *non-factive* understanding view (and thus a non-factive progress view) would have more options to deal with the challenge from idealisation, such as adopting a rationalisation approach.

3.3. The epistemic account and the challenge from idealisation

The epistemic account also offers a definition of progress in terms of an epistemic achievement: Science progresses just in case it increases scientific *knowledge*. The more knowledge we acquire, the more we progress. This account has been suggested by Barnes (1991) and Cohen (1980), but was only recently developed by Bird (2007, 2008, 2016).

3.3.1. Bird's epistemic account

As in the case of understanding, there is no universally accepted theory of knowledge, but it is generally agreed that knowledge implies a true belief that is epistemically justified. The nature of epistemic justification is contested (for details see Ichikawa and Steup, 2018), and there might be other necessary conditions for knowledge. Accordingly, there could be different variants of the epistemic account. Bird (2007, 72) does not commit to a specific analysis of knowledge, but he emphasizes that the beliefs should not be *accidentally* true, as in the case of Gettier (1963)'s famous examples.[17]

On the epistemic account, progress demands justification. Discovering truths about, say, cancer causes, is only progressive when these are justified, e.g., by having sufficient scientific evidence. Lucky guesses are not progressive (Bird, 2007, 2016).[18]

While the problem-solving account requires solutions to problems for progress and the noetic account dependency models, Bird (2007, 76) offers a broad concept of progressive

[16] Strevens (2019) does not address how the derivation proposal applies to asymptotic idealisations.

[17] In a footnote, Bird (2007, 87) suggests that knowledge might not be analysable.

[18] Others disagree that justification is necessary for progress (e.g., Rowbottom, 2008, Cevolani and Tambolo, 2013, Niiniluoto, 2014, Dellsén, 2016).

achievements: “Scientific knowledge will (locally) grow when any scientific proposition becomes known [...].” For instance, we progress by gaining knowledge of unreliable methods. Assuming that understanding reduces to knowledge, Bird (2007, 84) suggests to supplement his account with an analysis of the *significance* of pieces of knowledge for progress, e.g., a gain in knowledge that is also a gain in understanding might be more significant and thus more progressive than a collection of irrelevant data.

This brief characterisation shall suffice for our purposes (for details and discussion see, e.g., Rowbottom, 2008, Cevolani and Tambolo, 2013, Dellsén, 2018a, Niiniluoto, 2019, Saatsi, 2019).

3.3.2. Bird’s epistemic account and the challenge from idealisation

Any variant of the epistemic account is straightforwardly factive because knowledge is taken to be factive. Only true beliefs can constitute progress. It is thus more restricted than the problem-solving or the noetic account.

To address progress from false theories to false theories, Bird (2007, §3.3) initially focused on the concept of *approximate truth*. Approximately true claims can be interpreted as truths by using an ‘approximately’ operator. For instance, the description of a nearly round object as round is approximately true, and the claim ‘It is approximately true that the object is round’ is true. This proposal is subject to serious objections (see, e.g., Niiniluoto, 2014, 2019, §3,6, Saatsi, 2019). But Bird (2016, §5) broadened his proposal: False theories can also involve other truths, such as claims like ‘The theory is highly truthlike,’ and false but progressive claims typically have *logical implications* that are true. For instance, the false claim that today’s humidity is 58% implies the true claim that today’s humidity is less than 60%. He thinks it is likely (but not guaranteed) that someone who believes a claim (dispositionally) believes such implications, and that such implications can account for the progress made in at least many cases featuring false theories.

Bird’s approximation proposal could be applied to idealisations that are approximately true. Some *Galilean* idealisations of intermediate stages with increasingly accurate models would be examples. Even if this works, the proposal cannot accommodate numerous other idealisations. As Niiniluoto (2014) emphasises, it does not work for idealisations that are vastly incorrect. For instance, that there is no intergenerational overlap is far from being approximately true. This issue can affect initial Galilean idealisations, and it affects many *indispensable* idealisations. Take the infinite population idealisation: It is not approximately true that the population size is arbitrarily large. Moreover, idealisations that are *entrenched* with the model’s true assumptions such that the model cannot produce (empirically successful) results if they are removed or replaced with veridical counterparts cannot be substituted with ‘It is approximately true ...’ statements.

While the approximation proposal is of limited use, Bird also broadens his implication proposal. When working with successful idealised models, scientists (Bird, 2016, 558-559)

> [...] will typically have some idea regarding some of the implications of theory that these are supported by the evidence and reasoning whereas others are not. For example, the simple kinetic theory of gases is clearly false [...] but scientists do believe nontrivial implications of the theory: that gases are constituted by particles; that the temperature of a gas is in large part a function of the kinetic energy of the particles; and that the ideal gas equation holds with a high degree of approximation for gases at moderate pressure and temperature. So false theories, even those known to be false, can contribute to progress on the epistemic view because they often have

> significant true content or true implications that are believed by scientists on the basis of good evidence and reasoning [...].

Bird focuses on the knowledge that we can gain from the veridical parts of the models (i.e., the true assumptions) and from the models' empirical success (e.g., that the ideal gas law's predictions approximately match the data from real gases). His (not fully worked-out) proposal does not render it clear whether only the implications of the models' true assumptions are meant. If so, it could not accommodate indispensable idealisation and initial Galilean idealisations. However, Bird could adopt a version of the extraction approach. Then, the various pieces of true information we can extract from working with idealised models would be additional forms of model implications (in a broad sense). The true information extracted could be the basis for the knowledge gained from working with the idealised models. Since on the epistemic account any kind of scientific knowledge constitutes progress (to some degree), it could additionally adopt other proposals for how to gain knowledge from idealisations, such as Greco (2014)'s proposal that we can know how the idealisations relate to the target phenomenon.

Seemingly unaware of Bird (2016)'s implication proposal, Park (2017, 577) offers a suggestion in the vicinity of the extraction approach to support the epistemic account:

> [...] the generation of idealized theories counts as progress, given that they facilitate inferences about observables, and that those inferences are accompanied by an accumulation of observational knowledge.

As Dellsén (2018b) highlights, Park claims that such idealised theories would *constitute progress*, although they only facilitate inferences that lead to knowledge. This is because Park (2017) suggests that achieving the means to increase knowledge constitutes progress. However, Dellsén (2018b) correctly notes that for Bird (2008) facilitating knowledge acquisition promotes progress but does not constitute it. It only renders it likely that we gain knowledge. Bird (2016)'s own conclusion is that false theories can promote progress, and his approximation and implication views license that idealisations only promote it too. The re-interpreted or implied truths can constitute progress though.

Bird does not address how to account for the fact that we sometimes keep (or create) an idealised model although we have a de-idealised version. Dellsén (2016, 81) argues that the epistemic account cannot accommodate such cases because "[...] there would be no point in having [such] idealized theories from a purely epistemic point of view." However, Park (2017, 577) seems to be right that Bird

> [...] would reply that a non-idealized theory might be useless to generate observational knowledge. We should consider the increase and the decrease in observational knowledge when we determine whether idealizations are beneficial or detrimental to the accumulation of knowledge.

An idealised account might be more beneficial to knowledge gain than its de-idealised counterpart, and in any case, as long as it leads to new scientific knowledge, it is worth keeping. Take science education. Successfully teaching students, say, how gas regularities work using the ideal gas law leads to a potential gain in scientific knowledge (e.g., because these students might become the new gas experts).

To sum up: Because the epistemic account treats any piece of knowledge as constituting progress, it can adopt various proposals to accommodate idealisations, such as the approximation proposal for approximately true idealisations, and the extraction approach for indispensable ones. Because idealised models can be used to extract truths, they can have epistemic value even in light of de-idealised counterparts.

3.4. The truthlikeness account and the challenge from idealisation

The truthlikeness account builds on Popper (1963)'s work. Its basic idea is that progress in the case of one scientific theory replacing another one occurs when the former is more *truthlike* than the latter. The account was mainly developed by Niiniluoto (1984, 1987, 2014) (see also Kuipers, 2009, Cevolani and Tambolo, 2013). I focus on Niiniluoto's view.

3.4.1. Niiniluoto's truthlikeness account

The truthlikeness account does not require theories to be fully true in order for science to progress—among other things because most past theories turned out to be false. It suffices that they are 'truthlike.' Truthlikeness is not the same as *approximate* truth. Truthlikeness is also measured in how *informative* a theory or claim is, as Cevolani and Tambolo (2013) emphasize. For instance, the true claim that cancer cells are not made up from lymph (a negative claim) is less truthlike than the false but informative claim that cancer cells develop from blastema.

Niiniluoto (1987)'s view implies that truthlikeness is *language dependent*. Theories are formulated in a language and truthlikeness is measured in how similar a theory's content is to the maximally specific claim formulated in that language that fully captures the truth about the subject of inquiry. (The details do not matter for our purposes.) Scientific progress is thus language dependent and tied to theories on this account. Gathering new information, conducting new kinds of experiments, etc. is only progressive when it goes hand in hand with theory change, such as developing a more truthlike theory, endorsing more truthlike claims, or correcting false claims. No such theory change has to be recognized as more truthlike to be progressive. Progress does not require its recognition.

This brief characterisation shall suffice for our purposes (for details and discussion see, e.g., Bird, 2016, Cevolani and Tambolo, 2013, Dellsén, 2018a, Niiniluoto, 2019).

3.4.2. Niiniluoto's truthlikeness account and the challenge from idealisation

The truthlikeness account can straightforwardly analyse replaceable *Galilean* idealisations or their intermediate stages. Replacing simplified models with more accurate ones is clearly an increase in truthlikeness. Niiniluoto (2014)'s example is Galileo's model of free fall. While it ignored air resistance, this resistance could be modeled using Newton's idealised account of mechanics. He also mentions the progress from the ideal gas law to the van der Waals equation (which was later refined in statistical thermodynamics). The truthlikeness account can also accommodate approximately true idealisations. As long as the scientific accounts featuring them are more truthlike than relevant competitors, we progress. In all these cases, idealisations constitute progress because they are part of the more truthlike accounts.

The truthlikeness account struggles with *indispensable* idealisations. Since these are considered to be irreplaceable, we do not get a more truthlike theory. Scientific accounts featuring them are also not always the result of being more truthlike than previous accounts. Take the honeybee model. It did not replace a previous model, but it looks to be progressive. We learned that honeybees presumably increase their energy efficiency rather than energy intake. The truthlikeness account could adopt the extraction approach to accommodate indispensable idealisations. This would come at the cost of not considering all idealisations to constitute progress. The truthlikeness account focuses on *theories* (or accounts) and not on the accumulation of various scientific truths (in contrast to the epistemic account). Adding single truthlike claims thus does not constitute progress. It does *promote* progress insofar as it increases the likelihood of new truthlike theories.

Dellsén (2021) argues that the truthlikeness account cannot explain cases of idealised accounts where a de-idealised or less idealised counterpart is available. We should focus on scientific accounts that are most truthlike. In contrast to the epistemic account, the truthlikeness account cannot use the extraction approach to rebut this objection. While indispensable idealisations might promote more truthlike accounts, we already have these accounts. However, the truthlikeness account can adopt the suggestion that *pedagogical purposes* can justify keeping the idealised account. Using the ideal gas law to successfully teach students how gas regularities work can lead to a gain in truthlike theories (e.g., because these students might develop them).

To sum up, the truthlikeness account can easily accommodate Galilean idealisations and other idealisations. It can account for indispensable idealisations if it adopts the extraction approach and accepts that such idealisations only promote progress.

4. Concluding remarks

The ubiquitous use of (indispensable) idealisations in empirically successful scientific theorizing poses a challenge to any account of scientific progress. I have argued that all four dominant accounts of progress can accommodate some idealisations and struggle with others. The *problem-solving* account can employ any suitable idealisation approach, but it has difficulties accommodating cases where a more de-idealised account does not solve more problems. Adopting the non-difference maker account of idealisations, the *noetic* account can accommodate many idealisations but not indispensable ones. This issue can be solved by using the extraction approach. The *epistemic* view can account for cases of Galilean idealisations but needs something like the extraction approach to account for all other kinds of idealisations. The *truthlikeness* account straightforwardly meets the challenge for all idealisations other than indispensable ones, but it can utilize the extraction approach to fill this explanatory gap.

The accounts differ in regards to whether idealisations can constitute progress rather than merely promoting it. On the problem-solving account, all idealisations other than the Galilean ones it struggles with can constitute progress. On the noetic and the truthlikeness account, all idealisations other than indispensable ones can constitute progress, whereas these can promote it. On the epistemic account, all idealisations merely promote progress.

All four accounts could adopt alternative views of idealisation or might find ways to fully accommodate idealisations without relying on approaches like the extraction approach. However, these and other issues have to be explored on another occasion.

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