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A comparison of two models of scientific progress

Rogier De Langhe

Tilburg Center for Logic and Philosophy of Science (TiLPS), Tilburg University, The Netherlands

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ABSTRACT

Does science progress *toward* some goal or merely *away from* primitive beginnings? Two agent-based models are built to explain how possibly both kinds of progressive scientific change can result from the interactions of individuals exploring an epistemic landscape. These models are shown to result in qualitatively different predictions about what the resulting system of science should be like.

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1. Introduction

Progress is the product of scientific change. Accounts of scientific change roughly fall into two categories, one and two-process change (Godfrey-Smith, 2003). One-process views hold that scientific change is a single process of movement toward an independent point of reference, for example Popper's cycle of conjecture and refutation, (Popper, 1959). One of the most influential criticisms of this view is by Thomas Kuhn (1962), who held that standards for science are not independent, but coevolve with scientific activity itself. Science then does not evolve toward a goal but away from goals previously set, with no fixed point left to compare its progress against. Without such a stable "Archimedean platform," there is nothing against which science can meaningfully be said to cumulate. Moreover, changes of standard caused by scientific change can cause cascades of further scientific changes. For both accounts an agent-based model is constructed that explains how possibly cumulative, linear and non-cumulative, nonlinear progress can be generated from the local interactions between individual agents. Agent-based models are corroborated to the extent that they reproduce the target pattern and useful to the extent that they suggest novel empirical hypotheses. Therefore the model is first validated by showing its capacity reproduce these respective patterns. Then four conflicting hypotheses are deduced about the expected statistical properties of the resulting system of science.

2. Adaptationist and coevolutionary analogies for scientific change

Philosophers of theory change are well-known for their use of analogies from biology. One of the more striking ones is the analogy between one- and two-process scientific change and adaptationist and coevolutionary views of change in evolutionary biology. Popper held that falsification of theories is analogous to biological evolution: random conjectures and selective refutation, with the standard for refutation being objective and independently testable observations. By abandoning unfit theories, science is a gradual and cumulative process of adaptation to that standard. The evolutionary analogue of the one-process view of scientific change is the "adaptationist" program in biology which explains organisms' adaptations by reference to the stable environment they inhabit. Just as organisms adapt to an exogenous environment, so do theories adapt to the world which exists independently of our theories about it. The world is, as it were, lying there waiting to be discovered.

Analogously, in biology, "if evolution is described as the process of adaptation of organisms to niches, then the niches must exist

E-mail address: rogierdelanghe@gmail.com

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before the species that are to fit them" (Lewontin, 1978, p. 159). In line with this analogy Bird argues that scientific change is like the evolution of one species to a given environment rather than coevolution of two species because, "the results of experimental tests do not change. A good experimenter is one that is replicable; it gives the same results whenever performed" (Bird, 2000, p. 212). There is only one process of change: theories can only change if our knowledge about the world changes.[1] Progress then resembles the discovery of a fixed landscape. Bird (2000) would agree with the assumption of a *fixed* landscape because it "captures the idea that in science our theories may change but the features of the world that they respond to are what they are independently of our theories, and are by and large constant over time" (Bird, 2000, p. 213).

By contrast on a two-process view such as Kuhn's there are two processes. Theories not only adapt to standards, but standards can also adapt to theories. For example, in the second half of the 18th century the requirement to explain qualities such as color and texture was a standard in chemistry, and Lavoisier's theory did not meet this standard. With time it was not Lavoisier's theory that was rejected, but the standard that changed.[2] There is, "a feedback loop through which theory change affects the values which led to that change" (Kuhn, 1977, p. 336). By way of this feedback loop, standards *coevolve* with the very theories they regulate. So, what is specific to this view is not just that standards change, but that they can change *because* of a change in what they regulate, "historically, value change is ordinarily a belated and largely unconscious concomitant of theory choice" (Kuhn, 1977, p. 335). Standards are thus made endogenous to scientific change; they not only regulate the process of change but are themselves also a function of it. As a consequence, "there is no neutral algorithm for theory choice" (Kuhn, 1977, p. 330). Because standards evolve as a function of our scientific knowledge, they will only be fixed after all knowledge has been acquired, "though the experience of scientists provides no philosophical justification for the values they deploy (such justification would solve the problem of induction) those values are in part learned from that experience, and they evolve with it" (Kuhn, 1977, p. 335). Although Kuhn agrees the world exists independently of our theories, for something to be a "fact" involves not only a recognition *that* something is, but also a theoretical understanding of *what* it is.[3] As a consequence, for Kuhn scientists have no access to the world in itself. There is no stable or pre-existent environment against which our theories could be said to adapt. Rather that environment is constituted in part by those very theories, "theories do not evolve piecemeal to fit facts that were there all the time. Rather, they emerge together with the facts they fit" (Kuhn, 1962, p. 141). There is no "truth" lying there waiting to be discovered. The world does not contain a pre-existent set of puzzles. While the world can discriminate between rival solutions to a puzzle, it is silent as to what the puzzle should be. This is itself a function of scientific knowledge and as such subject to change:

> "The puzzles of contemporary normal science did not exist until after the most recent scientific revolution. They cannot be traced back to the historic beginning of the science. Earlier generations pursued their own problems with their own instruments and their own canons of solution. Nor is it just the problems that have changed. Rather, the whole network of fact and theory that the textbook paradigms fit to nature has shifted" (Kuhn, 1962, pp. 140–141).

Also for this program there is an analogue to be found in biology. Biologists such as Eldredge and Gould (1972) and Lewontin (1978) have claimed that the local environment to which organisms adapt coevolves with the creatures that inhabit it. Similarly, for Kuhn the standards to which our theories adapt change as a result of those very theories. Scientific successes in one area raise the bar for successes in other areas. Whether or not an approach deserves pursuit is in part affected by the evolution of other approaches. In biology this process of endogenous change is called "coevolution" and the resulting pattern of change called "punctuated equilibrium" is not gradual but largely stationary with violent bursts of extinction, analogous to Kuhn's description of scientific change as, "a succession of tradition-bound periods punctuated by non-cumulative breaks" (Kuhn, 1970, p. 208).

In sum, then, both accounts agree that standards regulate science but the essential difference between one- and two-process views is whether these standards are exogenous or endogenous to science.

3. Fixed and moving epistemic landscapes

In as far as agent-based models aim to isolate the essential mechanism behind an aggregate pattern, namely the mechanism that is sufficient to produce a pattern and without which it would not be generated, they must attempt to replicate the aggregate pattern with as little means as possible.[4] In the previous section, it was argued that the possibility of endogenous standard change is the essential difference between one and two-process views of change. In this section, the epistemic landscapes framework by Weisberg and Muldoon (2009) is extended to construct a very simple agent-based model of theory change that captures this essential difference. The model of change is validated by showing that it can possibly produce both accounts of scientific progress.

Since the seminal work by Sewall Wright, evolutionary changes in biology are represented as trajectories of organisms on fitness landscapes. Fitness landscapes typically represent the relationship between genotypes and fitness as a landscape of which the coordinates represent different genotypes and the topography their associated fitness. Recently this framework was adapted to philosophy of science by Michael Weisberg and Ryan Muldoon to represent different approaches and their associated significance—*Approaches* specify what the relevant questions are, what count as solutions, and how they can be obtained. The height or topography of the landscape corresponds to the *significance* of the results yielded by scientists adopting an approach. Weisberg and Muldoon describe the trajectories of different types of agents on a fixed landscape and argue that mixed strategies foster scientific progress. Progress on their account is defined as the percentage of the landscape explored, or as the speed with which peaks in the landscape are discovered. This is a simple but powerful framework for the study of one-process change. The fixed topography of the landscape elegantly captures the one-process assumption of an exogenous standard. Extending this framework with the possibility of endogenous change means

[1] According to Kitcher (1978, p. 151) this was the view held by many logical empiricists: "Without new observations, science would be static. I do not know whether anyone has held exactly this picture of scientific change, but something very close to it seems to be implicit in the writings of many logical empiricist philosophers of science."

[2] "One of the objections to Lavoisier's new chemistry was the roadblocks with which it confronted the achievement of what had previously been one of chemistry's traditional goals: the explanation of qualities, such as color and texture, as well as of their change. With the acceptance of Lavoisier's theory, such explanations ceased for some time to be a value for chemists; the ability to explain qualitative variation was no longer a criterion relevant to the evaluation of chemical theory" (Kuhn, 1977, p. 335).

[3] Kuhn's most elaborate example is the discovery of oxygen, which according to Kuhn was not the instantaneous realization of the existence of a gas called oxygen that can easily be ascribed to a single person such, but rather a process of theoretical assimilation of a novel fact that takes time and involves multiple persons, (Kuhn, 1962, p. 53–56).

[4] Kuhn for one declared at the end of his life that "many of the most central conclusions we drew from the historical record can be derived instead from *first principles* [...that] are necessary characteristics of any developmental or evolutionary process," (Kuhn, 2000, pp. 112–119). For recent work on finding these first principles, see De Langhe (2012).

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