Building Blocks and the Principle of Plurality: Model-Building Heuristics in Long-Term Research Collectives

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In both history of science and philosophy of science the question of how science and its theories develop in the long run is no longer considered a fashionable topic. Textbook introductions still present the classic suggestions by Karl Popper and Thomas Kuhn, sometimes complemented by Imre Lakatos, although the shortcomings of these approaches are well known. It is a widespread tactic to either accept one of them despite its obvious problems, or drop the question altogether, because the evolution of scientific knowledge seems too diverse to be captured by a general scheme. The latter seems even truer if one includes non-Western forms of privileged knowledge.

However, these objections granted, it is still an open question whether or not there are schemes of middle-range applicability that describe patterns of how scientific knowledge evolves in certain fields, over limited time periods. This paper sets out to describe some of these patterns in the evolution of models of biochemical pathways, notably models of the photosynthetic reduction of carbon dioxide between 1840 and 1920. In contrast to the usual fine-grained reconstructions of how one specific mechanism was elucidated, step by step, the paper focuses on a sequence of six different models that were suggested by renowned chemists of the time, including Justus Liebig, Adolf von Baeyer and Richard Willstätter. Some common features of these models are highlighted, while particular attention is given to the question of how they relate to each other; and how this relationship reflects heuristic strategies that guided the evolution and development of this body of knowledge. The paper argues that in this case two strategies were of particular importance: a plurality of concurrent options; and the variation of models through creatively recombining established building blocks with newly suggested modules.

Photosynthesis research is not one of the nineteenth-century showcase fields of science. Hardly anything was then known about the photosynthetic reactions. The only consensus was that carbon dioxide was part of the starting materials, while sugar and oxygen were among the products; and light, chlorophyll and some properties of the living cell played important roles on the way. Even worse, hardly any methods were available to improve this situation; investigating metabolism in these decades came down to dealing with a black box. It is, hence, an interesting question how scientists nevertheless developed and defended different models of the photosynthetic mechanism.

On closer inspection, these models had some features in common. All of them shared a highly simplified conception of the process; all were dramatically underdetermined in terms of empirical evidence; and all of them focused on one specific aspect or partial reaction that resonated with the authors' general research interest at the time. The paper argues that at least some scientists were aware of the shortcomings of their suggestions but still found them valuable enough for publication, which, at the very least, kept the conversation going. Scientists, who explicitly contributed to this conversation while struggling with the same problems, can be considered, I suggest, as members of a "research collective" that, in this case, spanned several generations.

The long-term conversation within this collective is apparent if we observe how the models relate to each other. They were published in a clear temporal sequence; yet, although each of them was severely criticised, none was completely abandoned over the period under consideration. In fact, at regular intervals, selected elements were revived, modified, and re-examined. The strategy to keep as many models as possible in the game is well founded if one regards the model-building process as a collaborative enterprise of a collective that pursues a common goal. It was not obvious to the nineteenth-century chemists which of the models were epistemically more or less promising. In this situation of uncertainty, a plurality of options was not only advantageous for the community as a whole but also for individual scientists who were able to place different bets.

Yet, the later authors clearly reacted to their predecessors' strengths and weaknesses. Strikingly, parts of earlier models were integrated into subsequent suggestions, as "modules", so to speak, or "building blocks". These frequently resulted from a decomposition of the mechanism in functional subunits that were then recombined in newly amalgamated assemblages. Interesting cases in point are the reduction of carbon dioxide via formaldehyde, which was part of all models after 1870; or the forming of oxygen through the decomposition of peroxides. These well-established elements were combined, however, with new modules, which usually emerged from the scientists' work on other themes, and which they transferred to sub-problems of photosynthesis.

This modular procedure, and the pursuit of multiple options at the same time, was, arguably, the most promising way at the time to investigate the photosynthetic mechanism. These strategies, however, only become apparent from a bird's eye perspective that observes longer periods of time and thinks in terms of research collectives rather than linear sequences of individual scientists.