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Abstract

In the early 1990s, Thomas Kuhn addresses what went wrong with the 1960s historical philosophy of science revolution in which a dynamic view of science replaced a traditional static view. According to Kuhn, two chief pillars of traditional philosophy of science—the priority of facts to theories and the mind-independent nature of truth—were demolished leaving philosophers of science little recourse for explaining the nature of science and its progress. In the revolution's aftermath in which philosophers of science either reverted to adulterated notions of these pillars or continued to proceed without substantive replacements for them, Kuhn responds with a paradigm shift in his philosophy science and proposes a *tertium quid* in which he likens science and its progress to biological evolution. For him, scientific progress, particularly in terms of the emergence of new scientific disciplines, is akin to biological speciation with incommensurability serving as an isolation mechanism. In this paper, I reconstruct Kuhn's shift from a historical to an evolutionary philosophy of science (EPS), beginning with his initial articulation of EPS in the early 1960s and concluding with its mature expression in the early 1990s. After a brief discussion of the reaction to Kuhn's EPS within recent philosophical literature, I argue that Kuhn's exclusive dependence on both a gradual tempo and a mode of speciation prohibits him from capturing fully the diversity exhibited in scientific progress. I conclude proposing additional evolutionary tempos and modes to explicate such diversity more fully.

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Introduction

Thomas Kuhn, with the publication of *The Structure of Scientific Revolutions* (*SSR*) in 1962, played a significant—if not pivotal—role in the 1960s Historiographic Revolution in which the notion of the natural sciences changed dramatically from that bequeathed by the Logical Positivists and the movement associated with them (Marcum, 2005). According to Kuhn's reading of the Positivist notion of science, as he summarizes it in the inaugural 1991 Rothschild distinguished lecture, 'The Trouble with the Historical Philosophy of Science' (THPS), 'Science proceeds from facts given by observation. Those facts are objective in the sense that they are interpersonal: they are, it was said, accessible to and indubitable for all normally equipped human observers' (2000a, 107). From these facts, scientists then construct theories and laws to explain observed natural phenomena. Such, according to Kuhn's reading of the Positivists, is the scientific method, first promulgated in the seventeenth century. 'Something of this sort we had all been taught,' reminisces Kuhn, 'and we all knew that attempts to refine that understanding of the scientific method and what it produced had encountered deep, though isolated, difficulties that were not, after centuries of effort, responding to treatment. It was those difficulties,' he goes on to contend, 'which drove us to observations of scientific life and its history, and we were considerably disconcerted by what we found there' (2000a, 107).

What those historians and philosophers of science involved in the Historiographic Revolution found, according to Kuhn, was a notion of science in which facts are not fixed for all times and places but rather 'pliable' in the sense that they are obtained not through observation alone but also through interpretation of observational evidence using antecedent theories. In other words, facts are theory-laden. Thus, scientists working with different theories, including theories being tested, could arrive at different facts while observing the same natural phenomenon. The agonizing predicament was how to test and then to verify or falsify with assurance a theory, if the theory itself formed part of the apparatus for testing it. The solution for the proponents of the Historiographic Revolution was predicated upon a historical reading of science in which 'individuals committed to one interpretation or another defended their viewpoint in ways that violated their professed canons of professional behavior' (Kuhn, 2000a, 108). The violation was not unethical behavior, such as fraud, but rather a matter of personal psychology. According to the historical philosophers of science, science and particularly its progress were more dynamic or robust than the static or formal view promulgated by a previous generation of philosophers of science. And, it was this dynamism in science and its progress predicated on the pliancy of scientific facts that accounted especially for the emergence of new scientific disciplines.

In THPS, Kuhn addresses what he considers went wrong with the Historiographic Revolution and its historical philosophy of science. 'The trouble with the historical philosophy of science,' to quote Kuhn, 'has been that by basing itself upon observations of the historical record it has undermined the pillars on which the authority of scientific knowledge was formerly thought to rest without supplying anything to replace them' (2000a, 118). The two chief pillars demolished by historical philosophers of science were the priority of facts to theoretical beliefs and the mind-independent nature of truth. The demolition of these pillars left historians and philosophers of science little recourse for explaining the nature of science and its progress, particularly in terms of the emergence of new scientific disciplines. In the revolution's aftermath, according to Kuhn, historians and philosophers of science either attempted to erase all vestiges of the Positivist agenda or to reinstill a chastened version of it. Kuhn, however, offers a *tertium quid* in which he likens scientific progress to biological evolution, with the emergence of new scientific disciplines akin to speciation. According to Kuhn, then, science is not 'a single monolithic enterprise, bound by a unique method. Rather it should be seen as a complex but unsystematic structure of distinct specialties or species, each responsible for a different domain of phenomena' (2000a, 119). Kuhn makes an 'evolutionary turn' in his philosophy of science, scraping the historical philosophy of science for an evolutionary philosophy of science (EPS).

In this paper I reconstruct the development of Kuhn's EPS, beginning with its initial articulation in *SSR* and concluding with its mature formulation in the early 1990s, when Kuhn was working on what he considered a definitive statement on the subject in a book tentatively entitled, *Word and Worlds: An Evolutionary View of Scientific Development* (*WW*). Although he was unable to finish the book before his death in 1996, he left several published and unpublished papers, along with a 1989

National Science Foundation (NSF) grant application, in which he outlined in reasonable detail a mature notion of EPS. Concisely, Kuhn adopts a gradual tempo for scientific progress to explicate the emergence of new scientific disciplines, with incommensurability serving as the mode, i.e. speciation, and providing a selection mechanism through the isolation of untranslatable lexicons. I then discuss briefly the reaction in the philosophical literature to Kuhn's EPS. I do not critique this literature but contribute to it, arguing that Kuhn's use of only a single tempo and mode for explaining science and its progress prevented him from accounting for the diversity and richness of scientific progress, especially with respect to the emergence of new higher-taxonomic disciplines and fields. I use several case studies from the history of science to demonstrate that additional evolutionary modes and tempos are required to account fully for the diversity and dynamism of scientific progress.

Development of Kuhn's EPS

In *SSR*'s last chapter, 'Progress through Revolutions,' Kuhn rejects the idea that scientific progress is teleological, i.e. science is marching towards an ultimately true or a fixed explanation of the world. He replaces the teleological idea of 'towards' with an agnostic idea of 'away from,' with no ability to presage with certainty the future of scientific knowledge. In other words, scientific progress is movement away from one paradigm to another, as the newer paradigm is able to resolve anomalies the older paradigm could not. Growth of scientific knowledge *vis-à-vis* biological evolution involves the steady, slow changes or anomalies (or what he refers to as mutations that verification then selects for, see Kuhn 1996, 146, and 2002b, 98) that emerge during the articulation of a ruling paradigm until it is over thrown by another paradigm, which resolves the anomalies. The structure of scientific progress is analogous to biological evolution, according to Kuhn, in which periods of 'revolutionary selections' are separated by periods of normal science. Scientific knowledge, then, is not so much true as it reflects an adaptation by which scientists articulate an understanding of the world through paradigms. Scientific progress for Kuhn, consequently, is 'an increase in articulation and specialization. And the entire process may have occurred, as we now suppose biological evolution did, without benefit of a set goal, a permanent fixed scientific truth, of which each stage in the development of scientific knowledge is a better example' (1996, 172-173). Contra Positivism, the justification of scientific knowledge, especially with respect to its advancement, is not a logical process, for Kuhn, but rather one based on competition and selection.

Just as Darwin's critics attacked his non-teleological approach to biological evolution, so Kuhn's critics attack his non-teleological approach to scientific progress—especially the fruit of this approach, the notion of paradigm—claiming it makes scientific truth irrational and relative (Lakatos and Musgrave, 1970; Shapere, 1964). Kuhn's initial response to critics was to focus on articulating the paradigm notion more accurately and precisely in terms of disciplinary matrix and exemplars, as he does in the 1969 Postscript to *SSR*'s second edition, to address the charge of irrationalism in particular. In addition, he returns to the evolutionary analogy—introduced in the last chapter of *SSR* to explicate scientific progress—at the end of the Postscript to address especially the charge of relativism. According to Kuhn, 'scientific development is, like biological, a unidirectional and irreversible process. Later scientific theories are better than earlier ones for solving puzzles in the often quite different environments to which they are applied. That is not,' he asserts, 'a relativist's position' (1996, 206). Beginning in the late 1970s, Kuhn turns his attention to articulating an evolutionary framework, with emphasis on a gradual tempo and on speciation through incommensurability as its mode. He is convinced that the analogy between biological evolution and scientific progress as disciplinary specialization holds the key for explaining progress in science and pursues the EPS project almost exclusively for the rest of his career.

Before reconstructing Kuhn's mature version of EPS, however, a concise summary is needed to guide the reconstruction: by gradual, incremental changes in a particular discipline's practice and knowledge a new discipline emerges and is isolated from the parent discipline through incommensurable entries in its lexicon so that after a given period the new discipline splits from the parent discipline forming an independent discipline. In the NSF grant, Kuhn outlines *WW* and articulates the essential features of a mature notion of EPS. Briefly, he divides the book into three sections, with three chapters in each section. In the first section, Kuhn takes up the notion of 'an evolutionary perspective towards scientific development' (1989, 4). To that end, he introduces the notion of a community's lexicon and the notion of untranslatability between incommensurable lexicons. Because entries within a lexicon are interrelated to one another as the lexicon develops or evolves, scientists must be bilingual in order to utilize incommensurable lexicons. In the next section, Kuhn introduces the notion of taxonomic categories. These categories consist of the sets of entries within a particular lexicon. Different taxonomic categories compose incommensurable lexicons and no two lexicons can share identical categories, which forms the foundation of what he calls the 'taxonomic no-overlap' principle. 'The lexicon…is for use, not in all possible worlds,' as Kuhn links its formation to evolutionary development, 'but in the world which it's evolved to fit' (1990a, 8). In the final section, Kuhn 'is concerned with the process of lexical change and its implications for the development of knowledge' (1989, 6). Although he proposes no specific process or mechanism for lexical change, he does pose several questions about how (un)translatability factors into such change. As for implications, Kuhn addresses both relativism and realism. 'What the book's position makes relative to culture, time, and place is not truth-value,' as Kuhn confronts the relativism issue, 'but stability' (1989, 6). For realism, he champions an instrumental notion. 'Cognitive development produces,' as Kuhn explains, 'better and better instruments for solving problems and puzzles at the interface between man and nature' (1990b, 6).

As part of the NSF grant application, Kuhn includes a Preface he wrote in 1988 for a volume of nine essays translated into Chinese. Although the volume was not published, in the Preface he outlines a version of EPS in terms of eight previously published papers and one unpublished paper, 'Scientific Knowledge as Historical Product,' in which he identifies initially two important parallels between biological evolution and scientific progress. First, biological evolution and scientific progress are group-related processes. In other words, the basic unit involved in scientific progress is not the individual scientist but the scientific community. The second parallel is that 'both processes are blind' in that the processes are non-teleological (1989, 10). From these two parallels, Kuhn suggests a third parallel particularly in terms of a selection mechanism. Because scientists are trained to choose 'esoteric puzzles,' argues Kuhn, and 'if talk of "puzzle solving" catches something about the selective mechanism which directs scientific advance, then,' he concludes, 'it may provide a way to think usefully about the circumstances likely to foster or to inhibit science's further advance' (1989, 10). He ponders this insight for determining the selection mechanism for scientific development and reports his progress in the 1990 presidential address to the Philosophy of Science Association, 'The Road since Structure' (RSS).

In RSS, Kuhn continues to utilize and enumerate the details of the analogy between biological evolution and scientific development. After scientific revolutions, he notes, the number of scientific disciplines generally increases often through branching from a parent discipline. 'Over time,' concludes Kuhn, 'a diagram of the evolution of scientific fields, specialties, and subspecialties comes to look strikingly like a layperson's diagram for a biological evolutionary tree' (2000b, 98). He next focuses on the role incommensurability plays in the evolutionary development of scientific knowledge. That role, according to Kuhn, is 'an isolating mechanism' (2000b, 99). In other words, just as a new biological species evolves from its parent population isolated by a geographical boundary, so a new scientific discipline emerges from its parent discipline isolated by an incommensurable lexicon. He goes on to specify the analogy in even greater detail, likening the biological population's gene pool and its genetic information to the scientific community's lexicon and its technical information. Importantly, the basis of this selection mechanism that isolates one lexicon from another involves the puzzles a community chooses to solve. The puzzles solved dictate lexical entries; change the puzzles solved, change the lexicon. Kuhn is now in a position to define precisely a scientific lexicon: 'the unit which embodies the shared conceptual or taxonomic structure that holds the community together and simultaneously isolates it from other groups' (2000b, 104). Finally, he denotes EPS as an example of 'post-Darwinian Kantianism,' except that Kuhn's categories, although like Kantian categories in making experience possible, are changeable over time.

At the end of RSS, Kuhn presages the tempo at which scientific progress occurs. He cites the Copernican Revolution as an example in which incremental changes affect wholesale changes. A little over a year later, Kuhn delivers the Rothschild lecture, THPS, in which he again confirms a commitment to the analogy between Darwinian evolution and scientific progress. Importantly, Darwin, as Kuhn was well aware of, advocated a gradual rate for evolution, in contrast to rapid or saltatory rate in which small, steady changes in species morphology yields a new species, i.e. speciation. Kuhn adopts Darwin's gradualism for the tempo or rate of evolution as evident from his use of terms like 'gradually' and 'incrementally' to describe changes in scientific beliefs. By adopting Darwin's tempo, he now has a sufficient outline for explaining progress in scientific beliefs. Kuhn concludes the lecture by enumerating the basic elements of EPS, as he envisions it. Briefly, a scientific revolution is akin to biological speciation in the sense that after a revolution the number of scientific disciplines (specialization) increases and the disciplines remain separated from one another through incommensurable lexicons. For Kuhn, the implication of increasing specialization is analogous to biological species occupying different niches. The result of scientific progress, then, is not a single mind-independent world but a multiplicity of worlds or niches. 'Those niches, which both create and are created by the conceptual and instrumental tools with which their inhabitants practice upon them,' asserts Kuhn, 'are as solid, real, resistant to arbitrary change as the external world was once said to be. But, unlike the so-called external world,' he insists, 'they are not independent of mind and culture, and they do not sum up to a single coherent whole of which we and the practitioners of all the individual scientific specialties are inhabitants' (2000a, 120). What was left for Kuhn to articulate in *WW* was a robust notion of EPS, which he was unable to accomplish before his death.

Reaction to Kuhn's EPS

Since Kuhn's death, philosophers of science have analyzed and critiqued his EPS (Andersen, 2001; Gattei, 2008; Kuukkanen, 2012; Wray, 2011). Alexander Bird (2000), in one of the first critiques, agrees with Kuhn that biological evolution provides a fecund analogy for analyzing scientific development and progress but questions whether the analogy, as Kuhn develops it, necessarily leads to the denial of verisimilitude, i.e. scientists through their theories are getting closer to truth. 'The [evolutionary] mechanisms that Kuhn describes might not have truth as their goal, but,' contends Bird, 'they may nonetheless be well suited to producing the truth' (2000, 214). Interestingly, Kuhn's use of the term niche has provoked strong reaction among philosophers of science (Renzi, 2009; Kuukkanen, 2012; Sharrock and Read, 2002). For example, Barbara Renzi claims Kuhn's EPS depends on a misconceived notion of biological niche. According to Renzi, Kuhn mistakes niche for a geographical locality, which is what coevolves with the species/niche dyad. With respect to niche, the species defines or shapes it through adaptation to a given locality. The external world then does not constrain a niche, as Kuhn conceives it, but rather a locality, as evolutionary biologists conceive it. 'The net effect of Kuhn's erroneous interpretation,' concludes Renzi, 'is that, on the scientific side of the analogy, the scientific niche becomes the only world "visible" to the group, the only reality the group can interact with' (2009, 158). For Renzi, Kuhn's notion of scientific niche does not connect with the external world, since Kuhn does not provide an analogue for locality, and experiments conducted within a niche do not provide the information needed to assess the external world's constraints on scientific knowledge. Kuhn's EPS then, according to Renzi, is confused with respect to current notions of evolutionary biology and fails to provide reasonable defense for explicating scientific progress *via* an evolutionary analogy.

My goal is not to engage or critique the above literature, although the issues raised in it are important for contemporary Kuhnian studies, but to add to it an analysis of Kuhn's EPS by critiquing his dependence on only a single tempo and mode to account for scientific progress. To that end, I introduce G.G. Simpson's taxonomy of tempos and modes for biological evolution. In a major contribution to the Neo-Darwinian synthesis of the twentieth century, *Tempo and Mode in Evolution*, Simpson (1944) identifies three tempos associated with biological evolution (Damuth, 2001). The first is the 'standard' rate of evolution, which he calls horotelic. It is standard or intermediate in comparison to the other two tempos, which are on opposite poles from one another. On one pole is bradytelic tempo representing a slow rate of evolution, while on the other is tachytelic tempo representing a rapid rate. In addition, he identifies three modes of evolution, loosely corresponding to the three tempos. The first is speciation, which may be erratic in its tempo but it is often associated with a horotelic tempo. This mode consists of a new species branching from its parental stock. It is also known as gradualism and involves the accumulation of small changes in species morphology until a new species emerges that can no longer interbreed with the parental species. The next mode encompasses phyletic evolution, with its bradytelic or horotelic tempo. This mode involves a slow pathway shift that is linear in nature. 'It is not the splitting up of a population,' according to Simpson, 'but the change of the population as a whole' (1944, 202). It is also known as phyletic gradualism. The final mode comprises quantum evolution and its tachytelic tempo. This mode is often associated with major morphological changes that result in the appearance of new species or higher-order taxa over relatively short periods.

As mentioned previously, Kuhn depends on only a single tempo—gradualism—and mode—speciation—in his mature EPS to account for scientific progress. Such dependence, I argue, is adequate to explicate some scientific progress but not all. Moreover, closer scrutiny of the historical case studies upon which Kuhn relies to articulate a mature EPS indicates that he was selective in choosing particular case studies to support it (Andersen, 2001; Gattei, 2008; Kuukkanen, 2012). Indeed, the case studies he chooses change dramatically from *SSR* to later writings. 'In his later works the scope of revolutions,' observes Stefano Gattei, 'is considerably restricted: they occur on a much lesser scale and do not involve major changes of world-view' (2008, 170). The historical case studies he relies on exemplify speciation or the emergence of new scientific disciplines, particularly through incremental changes. As noted earlier, Kuhn claims that even the Copernican Revolution is the result of such changes.

To demonstrate the potential of a robust EPS—based on additional modes and tempos, as developed by Simpson—to analyze science and its progress, I reconstruct briefly several case studies on the role of microorganisms, especially viruses, in disease pathology. I initially discuss the major shift from the miasma and contagion theories of infectious disease to the germ theory and then the emergence of virology, and conclude with two examples of speciation—tumor virology and retrovirology. These case studies demonstrate the inadequacy of Kuhn's EPS to account for particular examples of scientific growth and progress.

The roots of the miasma theory of disease, which states that infectious diseases are transmitted though dirty air, extend back to Hippocrates and Galen (Temkin, 1991). Although the causative agent was unknown, the theory was prevalent and influential into the late nineteenth and early twentieth centuries in shaping efforts, particularly in terms of sanitation, to combat the spread of infectious diseases. Besides the miasma theory, the contagion theory of disease, which states that infectious diseases spread through physical contact, was also influential and represented a rival theory to the miasma theory. Again, the causative agent was unknown, although Girolamo Fracastoro postulated in the sixteenth century seed-like entities as the cause of infectious diseases (Nutton, 1990). Eventually both theories were eclipsed by the germ theory, in which advocates hypothesized a causative role for microorganisms in the etiology of infectious diseases. The 'germ revolution'—as John Waller (2002) calls it—represents a phyletic evolutionary mode of scientific progress because it accounts for both the miasma and contagion theories in terms of disease transmission and thereby represents a shift in the path of scientific advancement. Moreover, the tempo of the revolution was bradytelic, since it took centuries of scientific development, especially in terms of innovations in technology like microscopy, before sufficient evidence was obtained to support the theory. Once the scientific community accepted the germ theory, the discovery of viruses—as causative agents of disease—occurred quickly and dramatically (Hughes, 1977; Waterson & Wilkinson, 1978; Wray, 2011). The naissance of virology as a major discipline distinct from bacteriology represents a quantum mode of progress in the biomedical sciences, with a tachytelic tempo.

Now, we turn to two examples of speciation. The first involves the discovery of the role viruses play in carcinogenesis. In 1911, Payton Rous published results indicating that a virus (later named after him as the Rous Sarcoma Virus or RSV) was responsible for spontaneously inducing cancer in chickens. The scientific community did not immediately accept these results, but by mid-twentieth century the viral basis of some cancers became an established fact through the meticulous work of Richard Shope, a younger colleague of Rous, and others (Marcum, 2001). Eventually, a subdiscipline investigating the role of viruses in cancer—tumor virology—emerged from virology, which then led to the discovery of oncogenes in the latter part of the century. The tempo for establishing the new subdiscipline was horotelic compared to germ theory's bradytelic tempo and virology's tachytelic tempo. Interestingly, Rous did not receive the Nobel Prize in Physiology or Medicine until 1966—55 years after the publication of the paper announcing RSV's discovery. In the second example of speciation, Howard Temin proposed in 1964 the DNA provirus hypothesis to account for the mechanism by which certain RNA viruses, such as RSV, induce cancer (Marcum, 2002). After the discovery in 1970 of reverse transcriptase (RT), the enzyme responsible for producing the provirus, Temin's hypothesis became the paradigmatic foundation of a new subdiscipline—retrovirology—branching off from virology (Vogt, 1997). The speciation of retrovirology represents a tachytelic tempo in conceptual change, compared to the horotelic tempo for speciation of tumor virology. Finally, in contrast to Rous, Temin received the Noble Prize in 1975—only 5 years after announcing the discovery of RT.

Conclusion

Jouni-Matti Kuukkanen (2012) compares Kuhn's 'evolutionary turn' to contemporary historiography's 'practical turn,' with the latter's emphasis on scientific practice and performance. Although Kuukkanen identifies differences between the two turns, especially in terms of the social constructivism associated with the practical turn, he acknowledges a similarity between them in that both turns explicate the complexity of science and its practice, as well as its growth and progress, in dynamic and multifaceted terms. For Kuhn, the practice of science is organic and not simply social; and, consequently, the evolutionary analogy best captures the dynamism and complexity in the growth of scientific knowledge, especially with respect to the proliferation of scientific specialties and subspecialties. Unfortunately, his reliance on a single tempo—gradualism—and mode—speciation—prohibits him from accounting for a full range or diversity of scientific progress, particularly in the emergence of higher taxonomic-level disciplines. To account for that diversity, Kuhn needed to utilize additional evolutionary tempos and modes for analyzing and explicating scientific progress, as demonstrated with the historical case studies in the previous section. As evident from these case studies, a robust EPS, which relies on various evolutionary tempos and modes, enables analysis of a fuller range of scientific progress. Kuhn's work on EPS was certainly moving in the right direction; but, he may have finished his book had he incorporated a larger array of evolutionary mechanisms than simply gradualism and speciation.

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