Genetic Epistemology and Piaget's Philosophy of Science

Piaget vs. Kuhn on Scientific Progress

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Abstract. This paper concerns Jean Piaget's (1896–1980) philosophy of science and, in particular, the picture of scientific development suggested by his theory of genetic epistemology. The aims of the paper are threefold: (1) to examine genetic epistemology as a theory concerning the growth of knowledge both in the individual and in science; (2) to explicate Piaget's view of 'scientific progress', which is grounded in his theory of equilibration; and (3) to juxtapose Piaget's notion of progress with Thomas Kuhn's (1922–1996). Issues of scientific continuity, scientific realism and scientific rationality are discussed. It is argued that Piaget's view highlights weaknesses in Kuhn's 'discontinuous' picture of scientific change.

Key Words: evolutionary epistemology, Kuhn, philosophy of science, Piaget, scientific progress, structural realism

Genetic epistemology is typically understood as a theory of cognitive development in individuals. However, understanding Piaget's theory in this manner is misleading insofar as it fails to appreciate the scope of genetic epistemology and, in particular, its character as an epistemology of scientific thought (Kitchener, 1986). Inasmuch as Piaget can be labeled a child psychologist or cognitive developmental theorist, he can rightfully be viewed as a philosopher of science.[1]

The aim of this paper is to examine the philosophy of science suggested by genetic epistemology, focusing on Piaget's notion of scientific progress. The paper proceeds in three sections. In the first section, I explicate genetic epistemology as a theory concerning the growth of knowledge both in science and in the individual. In the second section, I examine Piaget's view of scientific progress, which is grounded in his theory of equilibration. In the third and longest section, I compare Piaget's notion of scientific progress with Thomas Kuhn's in order to clarify aspects of both thinkers' views. As a substantive point, I argue that Piaget's analysis highlights some weaknesses in Kuhn's discontinuous conception of scientific progress.

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In many ways, Kuhn is a natural point of comparison for Piaget's views on scientific progress. Kuhn's views are well known, and it is only a slight exaggeration to say that his ideas have been definitive of contemporary views on scientific change. Moreover, Piaget and Kuhn both expressed indebtedness towards the other's ideas (see, e.g., Kuhn, 1962/1996, p. viii; 1977, pp. 21–23, 243–247, 251, 264; 2000, pp. 279, 283; Piaget, 1970/1971b, p. 3),[2] and Piaget has explicitly discussed and criticized Kuhn's views on scientific change (Piaget & Garcia, 1983/1989, ch. 9). Finally, both Kuhn and Piaget discuss scientific change in terms of 'scientific progress'. My main motivation for comparing Piaget and Kuhn's notions of scientific progress is to highlight their fundamental disagreement on the issue of scientific continuity. In particular, I argue that Piaget's continuous view serves as a useful remedy for Kuhn's discontinuous view, and can thus illuminate the nature of scientific change. In the process, I hope to show the relevance of Piaget's ideas for contemporary philosophy of science.

Genetic Epistemology: A Theory on the Development of Knowledge

What is genetic epistemology? It apparently deals with the 'genesis of knowledge', but what is its agenda? According to Piaget (1970): 'Genetic epistemology attempts to explain knowledge, and in particular scientific knowledge, on the basis of its history, its sociogenesis, and especially the psychological origins of the notions and operations upon which it is based' (p. 1). In what follows, I examine some of the central features of genetic epistemology, focusing on how it shapes Piaget's philosophy of science (and, in particular, his views on the development and progress of scientific knowledge).

According to Piaget (1970), knowledge is an active (operative) human process rather than a passive (figurative) copy of reality; knowledge is a *process* rather than a state, and knowing involves assimilating 'reality into systems of transformations' (p. 15). Although he adopts a constructivist stance, Piaget assumes the existence of an independent reality, which is evident in his discussion of knowledge:

> . . . human knowledge is essentially active. . . . *To know is to transform reality in order to understand how a certain state is brought about*. . . . knowing an object does not mean copying it—it means acting upon it. . . . *Knowing reality means constructing systems of transformations that correspond*, more or less adequately, *to reality*. . . . Knowledge . . . is a system of transformations that become progressively adequate. (p. 15, emphasis added)

It is perhaps an oversimplification to label Piaget as an unqualified 'realist'.[3] For the purposes here, I want to highlight the fact that, for Piaget, knowing

involves constructing (cognitive) systems that 'correspond to reality'. At the very least, this commits Piaget to a correspondence theory of knowledge (since knowing requires constructing systems that *correspond* to reality) and, hence, a modest (referential) form of realism (in the third section of this paper, I suggest that Piaget's 'realism' can be understood as a version of 'structural realism').

Piaget's bold hypothesis is that the development of knowledge in the individual (*ontogenesis*) draws certain parallels to the development of knowledge in science (*phylogenesis*) since scientific theories are constructions of the human mind and all epistemic structures are constructed in similar ways (Piaget, 1970, p. 13). Piaget's epistemological hypothesis appears to be derived from the doctrine of 'recapitulation' (or 'biogenetic law')—associated with Ernst Haeckel—which asserts that 'ontogeny recapitulates phylogeny', that is, the embryonic stages of an animal recapitulate its evolutionary history. The isomorphism that Piaget draws (with respect to the epistemic development of individuals and science) does not concern the content of knowledge, but rather the mechanisms of development that underlie transitions from lower to higher forms of knowledge.

From Piaget's writings, it is clear that he is a firm believer in the progress of human knowledge (both in individuals and in science). Reality is the object of knowledge (the 'epistemic object') and it can be endlessly approached but never attained. According to this assumption—what Piaget calls the 'metaphor of the limit' (Bringuier, 1977/1980, p. 63)—human knowledge, by a series of successive approximations, is improving and approaching the object, but only as a mathematical limit. Piaget's notion of the 'metaphor of the limit' finds its origins in a particular vision of biological evolution espoused by Piaget. Kitchener (1987, pp. 345–350) explains that Piaget (along with Marx, Comte and Spencer) believes that all development and evolution has a direction towards an ideal (*orthogenesis*). Orthogenesis, according to Piaget, is a directional tendency (as opposed to a final cause or *a priori* agent directing evolution) towards an ideal (or 'optimizing') equilibrium between organism and environment. Piaget (1967/1971a) maintains that there is orthogenesis in biological evolution as well as in epistemic development.

In explaining epistemic development, Piaget utilizes a framework of continuous epistemic stages that necessarily grow from previous stages and lead to transition into subsequent stages:

> . . . the stages in the construction of different forms of knowledge are actually sequential—so that each stage is at once the result of possibilities opened up by the preceding stage and a necessary condition for the following one . . . each stage begins with a reorganization, at another level, of the principal acquisitions that occurred at the preceding stages. (Piaget & Garcia, 1983/1989, pp. 1–2)

Piaget's view of knowledge as a continuous process of structural construction and reorganization leads him to the conclusion that the central problem of genetic epistemology concerns the mechanisms that operate to transform lower forms into higher forms of knowledge. Structures of knowledge are constructed by the 'epistemic subject' and are constantly evolving via mechanisms that mediate interactions between the epistemic subject and epistemic object.[4] According to Piaget, it is through understanding these mechanisms that we can begin to explain the nature of scientific progress.

Mechanisms of Epistemic Development and Scientific Progress

In one of his final works, which was co-authored by the physicist Rolando Garcia,[5] Piaget wrote specifically on the isomorphisms between psychogenesis and the history of science. The aim of Piaget and Garcia's book *Psychogenesis and the History of Science* (1983/1989) is to demonstrate that the mechanisms mediating transitions in phylogenetic (scientific) stages are analogous to those mediating transitions in ontogenetic (individual) stages. Piaget and Garcia adopt a historico-critical method in examining the development of concepts in physics, geometry and algebra.[6] Supplemented with the method of psychogenesis, the authors attempt to identify the common ('transitional') mechanisms operating in phylogenesis and ontogenesis. The two mechanisms identified by the authors are (1) equilibration and (2) the 'intra–inter–trans' dialectical triad (pp. 28–29, 273–275). In the following section, I examine these two mechanisms, focusing on Piaget's associated notion of scientific progress.

Equilibration in Psychogenesis and the History of Science

The key to understanding Piaget's stance regarding the progress and change of scientific knowledge lies in—the most central and controversial concept of genetic epistemology—the concept of equilibration.[7] Piaget (1975/1985) states that 'in explaining cognitive development, whether accounting for the history of science or psychogenesis, the concept of improving or optimizing equilibration imposes itself as fundamental' (p. 139). A key assumption that Piaget makes here is that the basic feature of life is 'adaptation' or 'autoregulation', that is, regulating oneself to one's environment (Piaget, 1967/1971a, pp. 171–85). The essential feature of autoregulation consists of two aspects: (1) the need to expand one's ambient environment; and (2) the need to increase one's capacities to affect it (Piaget, 1974/1980). It is important to distinguish Piaget's notion of adaptation from contemporary evolutionary biological notions of adaptation as survival or fitness. For Piaget, adaptation is a tendency to master one's environment, and it displays a certain direction or orthogenesis towards 'optimizing equilibration'. More-

over, Piaget maintains that the 'development of knowledge has its source in biological organizations and tends toward the construction of logico-mathematical structures' (Piaget & Garcia, 1983/1989, p. 274; also see Piaget, 1967/1971a, pp. 305–333).

Since Piaget views the development of scientific knowledge as being isomorphic to the development of knowledge in an individual, his theory of cognitive development based on his lifelong studies with children—namely psychogenesis—is crucial for understanding genetic epistemology.[8] In psychogenesis, equilibration is the most important process that interacts with three others (namely maturation, experience with the physical environment and influence of the social environment) to bring about cognitive development. Equilibration is, roughly, an individual's active *self-regulatory processes* that aid her in adapting to the environment (Piaget, 1967/1971a, pp. 35–37; 1975/1985, chs 1–2). Equilibration is the result of the interaction between two complementary processes (Piaget, 1967/1971a, pp. 172–174; 1975/1985, pp. 5–7): (1) *assimilation* (i.e. integrating new information into pre-existing structures) and (2) *accommodation* (i.e. changing and building new structures to understand information). When there is a balance between these two processes, there is adaptation, and a level of equilibrium is achieved. Piaget proposes that knowledge develops universally through these mechanisms in an invariant sequential order of successive stages, in which new knowledge incorporates and transcends knowledge from previous stages.

In Piaget's theory, the motivating force behind all cognitive development is 'disequilibrium' (Piaget, 1975/1985, pp. 10–15). A state of disequilibrium is motivating because it requires the psychological subject to restore equilibrium and satisfy its need. This state of rupture may be due to a number of things: an actual external need (e.g. a problem that requires solving), an actual internal need (e.g. the recognition of an anomaly) or potential external or internal disturbances. The crucial point here is that disequilibrium tends to take a subject out of a current state of equilibrium and, thus, poses a cognitive *gap*. But this gap is relative to particular subjects insofar as it is only disturbing when the gap is, in some sense, recognized and acknowledged by a subject.

Piaget argues that as an individual grows chronologically, his knowledge increases, that is, his knowledge becomes increasingly equilibrated through time. This equilibration occurs because of the modification of earlier cognitive structures; an individual continually constructs better cognitive structures due, in part, to the disequilibrium occurring at earlier stages. In this sense, an individual's knowledge progresses because there is a universal tendency towards increasing equilibration ('reequilibration' or 'optimizing equilibration'), which amounts to an increase in one's mastery over and extension of one's cognitive environment.

The isomorphic relationship between the equilibration of structures of knowledge in the individual and science can be drawn quite clearly. First, equilibration is a continuous process that is contingent on pre-existing structures of knowledge, although the authors emphasize that this continuity in the regulatory mechanisms of epistemic development does not exclude discontinuities or 'ruptures' (Piaget & Garcia, 1983/1989, p. 264). Second, the desideratum for equilibration results from some state of disequilibrium—periods of 'reequilibration' involve the assimilation of novelties to existing structures and the accommodation of new discoveries. Third, all epistemic development is associated with a universal notion of 'optimizing equilibrium' in the sense that there is a progression and superiority of knowledge over time. The basic idea is that the epistemic subject becomes more successful in satisfying its epistemic needs. On the level of science, this amounts to the claim that scientific theories become more equilibrated in time since they can solve more problems, answer more questions and explain more phenomena.

Piaget and Garcia's claim—with respect to equilibration in psychogenesis and the history of science—is that this mediating mechanism leads to epistemic progress insofar as knowledge that is surpassed is always integrated with the new. In discussing the transition from one theory to another in science, the authors emphasize that the surpassing theory *integrates* the surpassed theory. In illustrating this parallel with reference to the history of physics, Piaget and Garcia (1983/1989, pp. 205–208) draw a distinction between 'observables', which are directly measurable (e.g. space in the theory of special relativity), and 'theoretical constructions', which are derived from observables through 'reflective abstraction' (e.g. space in Newtonian mechanics).[9] Piaget and Garcia claim that the process by which one theory surpasses another involves the theoretical constructions of the surpassed theory becoming conceived as observables in the surpassing theory (cf. Reichenbach, 1920/1965; Sneed, 1971; Stegmüller, 1973/1976). As such, the surpassing theory is an instantiation of scientific progress insofar as it is *more general* than the surpassed theory, and its observables are qualitatively different and more encompassing.

The Intra–Inter–Trans Triad

The intra–inter–trans (Ia–Ir–T) triad is a mechanism, expressed in the form of a stage theory, meant to explain the development of knowledge (for both individuals and science). This dialectical triad is, roughly speaking, a functional mechanism that proceeds from simple object analysis, to the analysis of relations via transformations, to the building of cognitive structures—it is a mechanism meant to explain the construction of epistemic structures. Piaget and Garcia (1983/1989) summarize the nature of the Ia–Ir–T process as follows:

> The intra phase leads to the discovery of a set of properties in objects and events finding only local and particular explanations. The 'reasons' to be established can thus be found only in the relations between objects, which means that they can be found only in 'transformations.' These, by their nature, are characteristic of the inter level. Once discovered, these transformations require the establishment of relations between each other, which leads to the construction of 'structures,' characteristic of the trans level. (pp. 273–274)

The sequence proceeds from a state where totalities are not possible in a concept (Ia), to the concept gaining new properties (Ir), to the possibility of totalities (T).

According to Piaget and Garcia (1983/1989), the relationship between the Ia–Ir–T triad and equilibration is that the triad is the '*expression of the conditions imposed* on all cognitive acquisition *by the laws of assimilation and equilibration*' (p. 133, emphasis added). This suggests that equilibration is the more general mechanism, and that the triad is one of the most common instantiations of equilibration (cf. Piaget, 1975/1985, pp. 7–10). The Ia–Ir–T triad is more specific than equilibration insofar as the former *presupposes* the latter. That is, each successive stage of the triad is associated with an increased level of equilibrium (or 'reequilibration'): for example, the trans stage is more equilibrated than the Inter stage, and so on (see Piaget & Garcia, 1983/1989, pp. 133–140). Furthermore, Piaget and Garcia state that these two mechanisms 'constitute a single mechanism in terms of their general significance' (p. 273). The general significance is that, taken together, equilibration and the Ia–Ir–T triad can *explain* the progressive nature of epistemic development.

Piaget and Garcia (1983/1989) maintain that the Ia–Ir–T triad is isomorphic to certain notions in psychogenesis, namely the centration on the elements, transformation and mode of production within a total system. Specifically, they contend that the triad is isomorphic to the three stages of psychogenesis: (1) the pre-operational, (2) concrete operational and (3) formal operational stages (pp. 174–179). The pre-operational stage (ages 4–5) in psychogenesis is characterized by egocentric thought and the child's understanding that objects can be systematically categorized (e.g. by shape or color). The intra (Ia) stage is isomorphic to the pre-operational stage insofar as both stages are characterized by a focus on single (repeatable) operations. The concrete operational stage (ages 7–10) in psychogenesis is characterized by a child's understanding of reversibility, conservation and that certain classes (e.g. daffodils) may be included in a larger class (e.g. flowers). The inter (Ir) stage is isomorphic to the concrete operational stage as both stages involve the establishment of systematic relations (or co-ordinations) between identical operations, in the form of grouping structures. The formal operational stage (ages 11+) in psychogenesis is characterized by a child's basic understanding of deductive logic, and ability to use general

theories to predict specific outcomes. The trans (T) stage is isomorphic to the formal operational stage insofar as both stages are characterized by an integration of operations of different kinds into systems of transformations.

In illustrating the Ia–Ir–T triad in science, Piaget and Garcia (1983/1989, ch. 3) investigate the history of geometry and the historical traditions associated with each phase of the triad. The intra phase corresponds to the tradition of Euclidean geometry—spanning from antiquity to the modern era—because investigations are focused on the geometric properties of figures, which are seen as *internal relations* between elements of the figures. The inter phase corresponds to the tradition inaugurated by analytic geometry (associated with Descartes) and continued by projective geometry (associated with Poncelet and Chasles)—from the modern era into the 19th century—because investigations are focused on the relationships *between* figures, as manifested by the search for transformations relating figures according to various forms of correspondences. Finally, the trans phase corresponds to the tradition of algebraic geometry (exemplified by Felix Klein's *Erlangen* program)—from the 19th century into the 20th century—because it is characterized by the predominance of structures (p. 109). Some of the historical examples become quite complex as the Ia–Ir–T triad is conceptualized as having sub-levels, for example 'trans–intra' levels and 'trans–trans' levels (ch. 6). The essential point is that the Ia–Ir–T triad implies that scientific development 'requires the reconstruction of what had been acquired during the preceding stages . . . to advance to a higher level. It involves a reorganization of knowledge in . . . light of new information and a reinterpretation of basic concepts' (p. 109).[10]

Piaget and Kuhn on Scientific Progress

As outlined above, scientific progress for Piaget consists in the 'increasing equilibration' over time between the epistemic subject (scientific structures) and the epistemic object (reality). In the following section, I further elucidate Piaget's notion of scientific progress by comparing his view to Thomas Kuhn's. Three points of comparison that I focus on are issues of continuity, realism and rationality. In comparing Piaget and Kuhn on these three variables, my aim is to clarify aspects of both Piaget's and Kuhn's notions of scientific progress. As a substantive point, I argue that Piaget's continuous view of scientific change highlights some weaknesses in Kuhn's view. Before comparing Piaget and Kuhn, I briefly state my own interpretation of Kuhn's notion of 'scientific progress'.

Kuhn is notoriously murky on the issue of scientific progress. In the postscript of *The Structure of Scientific Revolutions* (1962/1996), he maintains—in response to accusations of 'relativism'—that he is a firm believer in scientific progress:

> . . . scientific development is, like biological [development], a unidirectional and irreversible process. Later scientific theories are better than earlier ones for solving puzzles in often quite different environments . . . . That is not a relativist's position, and it displays the sense in which I am a convinced believer in scientific progress. (p. 206)

On the same page, Kuhn rejects the 'correspondence theory of truth', 'universal criteria for comparing theories' and the notion 'of a match between the ontology of a theory and its 'real' counterpart in nature' (p. 206).

Kuhn's notion of scientific progress assumes that 'scientific progress' should not be tied to something like 'closer approximations of truth', but to the weaker criterion of utility (namely 'puzzle-solving efficacy'). Hence, his notion of scientific change suggests that science is progressive and improving insofar as scientific theories (or 'disciplinary matrices') become better puzzle-solving instruments over time (cf. Laudan, 1977). Kuhn (1962/1996) writes: 'I do not doubt . . . that Newton's mechanics improves on Aristotle's and that Einstein's improves on Newton's as instruments for puzzle-solving. But I can see in their succession no coherent direction of ontological development' (p. 206). As such, a distinctive feature of Kuhn's notion of scientific progress is that it is an instrumentalist notion explicitly divorced from issues of scientific realism (and, hence, truth and reference).

Scientific Continuity

One difference between Piaget and Kuhn's notions of scientific progress is that Piaget presents a more continuous and cumulative view of science compared to Kuhn. In what follows, I argue that Piaget's position provides a cogent rejoinder to Kuhn's position insofar as it (1) illustrates that Kuhn's appeal to 'incommensurability' fails to establish his conclusions regarding the discontinuity of scientific change, and (2) illuminates continuous aspects of scientific change that are neglected and obscured by Kuhn's analysis.

Kuhn's position on the continuity–discontinuity of scientific evolution requires drawing a distinction between normal and revolutionary science. In periods of normal science, scientific progress is continuous insofar as there is an accumulation of puzzles solved, whereas in periods of revolutionary science, progress is discontinuous and consists in the fact that successive paradigms are better puzzle-solving instruments (what Kuhn [1962/1996, ch. 13] calls 'progress through revolutions'). Put in another way, Kuhn maintains that on small time-scales (i.e. the time-scale of normal science), science is continuous and cumulative; however, on larger time-scales (i.e. the time-scale that can capture scientific revolutions), scientific evolution is discontinuous and non-cumulative because it involves the *replacement* of a paradigm 'in whole or in part by an incompatible new one' (p. 92).

Piaget's position on the continuity–discontinuity of scientific progress is amenable to Kuhn's view, but with an important qualification. On the time-

scale of normal science, Piaget's view is essentially the same as Kuhn's. On large time-scales, however, Piaget's view of scientific evolution diverges significantly. Piaget's view of large-scale change in science is similar to Kuhn's insofar as Piaget acknowledges that scientific progress often involves discontinuities or 'ruptures' (Piaget & Garcia, 1983/1989, pp. 259, 264). Unlike Kuhn, who maintains that there are no rules that govern such changes (cf. Kuhn, 2000, pp. 87, 157–162), Piaget contends that there is an 'internal logic' governing such transitions. Specifically, Piaget conceives of a scientific revolution as an *integrative process* (as opposed to the *replacement* of one paradigm with another) that results from processes of assimilation and accommodation (see Piaget & Garcia, 1983/1989, pp. 263–267). Piaget and Garcia write:

> The consideration of the evolution of scientific theories in a framework such as that specified by Kuhn must confront a . . . difficulty: any knowledge, no matter how novel, is never a first, totally independent of previous knowledge. *It is only a reorganization, adjustment, correction, or addition with respect to existing knowledge*. Even experimental data unknown up to a certain time must be integrated with existing knowledge. But this does not happen by itself; *it takes an effort of assimilation and accommodation*. (p. 25, emphasis added)

Given this position on the functional mechanisms governing large-scale scientific changes, Piaget endorses a more continuous view of science compared to Kuhn.

Piaget's qualification on the continuity of large-scale scientific change, I think, brings to light weaknesses in Kuhn's discontinuous picture of science. Kuhn's denial of continuity, in instances of revolutionary science, ultimately rests on his incommensurability thesis. Specifically, Kuhn's judgment that transitions between paradigms are discontinuous ultimately rests on the idea that the terms of alternative paradigms are 'untranslatable' (see, e.g., Kuhn, 1962/1996, chs 9–10; 2000, chs 2–4). The problem with this picture is that Kuhn's judgment of discontinuity suggests that 'inter-translatability' should be regarded as the sole criterion for 'continuity' between paradigms (and it is not clear that anyone, including the logical positivists whom Kuhn apparently took himself to be opposing, ever argued that it was).[11] Piaget's view, by contrast, downplays the relevance of 'translatability' issues, and points to other aspects of paradigm change that can legitimately be judged to be continuous. As such, I think that it is clear that there can be scientific continuity without satisfying Kuhn's condition of 'inter-translatability' (cf. Kuhn, 2000, ch. 7; Sneed, 1971; Stegmüller, 1973/1976). In particular, Piaget's point that transitions between paradigms often involve an attempt to integrate and reinterpret preceding paradigms highlights a continuous aspect of scientific change that is obscured by Kuhn's analysis.

In fairness to Kuhn, it should be mentioned that in some of his post-*Structure* writings, he himself expressed dissatisfaction towards his earlier

conclusions on the discontinuous and non-cumulative nature of scientific change (see, e.g., Kuhn, 2000, pp. 57, 86–89, 182–195), and it is unclear whether he would reject Piaget's claim that there is an 'internal logic' governing large-scale theory change. However, Kuhn did not appear to recognize that his discontinuous picture of scientific change was readily implied by his incommensurability thesis, a thesis that he defended throughout his career (see Kuhn, 2000, chs 2–4). Now, I do not want to argue that Kuhn's thesis of incommensurability is *incorrect*, but I do want to argue that this thesis cannot sustain the substantive conclusions on discontinuity that he drew from it. Even if Kuhn recognized problems in his earlier formulations, many of his enthusiasts, regrettably, have not. At the very least, Piaget's position is useful for bringing attention to relevant issues, resulting in a more balanced analysis on the continuity–discontinuity of scientific progress. In this sense, Piaget's analysis can be viewed as complementing Kuhn's view by elucidating transitional mechanisms of scientific change that are left unexamined by Kuhn.

Scientific Realism

Another issue that, arguably, places Piaget and Kuhn in stronger opposition with respect to scientific progress is the issue of 'scientific realism'. In particular, Piaget's view of scientific progress, grounded in his 'metaphor of the limit', leads him to a more 'realist' picture than Kuhn's. One way of interpreting Piaget's realism, I argue, is as a version of structural realism, a view that has been of great interest among philosophers of science recently. This interpretation is helpful for further elucidating aspects of scientific continuity that are ignored in Kuhn's analysis.

Kuhn is an anti-realist insofar as he defends a notion of scientific progress that is entirely divorced from notions of truth and reference (i.e. Kuhn attempts to provide a *non-referential* account of meaning change in science). In the final chapter of *Structure*, Kuhn (1962/1996) proclaims that: 'We . . . have to relinquish the notion . . . that changes of paradigm carry scientists . . . closer to the truth' (p. 170). In response to abductive-style 'success of science' arguments for realism, Kuhn appeals to an evolutionary story to account for the apparent success of science (cf. van Fraassen, 1980, pp. 39–40). Kuhn (1962/1996) writes:

> The . . . resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practice future science. The net result of a sequence of such revolutionary selections . . . is the wonderfully adapted set of instruments we call modern scientific knowledge. . . . [This] entire process may have occurred, as we now suppose biological evolution did, without the benefit of a set goal, a permanent fixed scientific truth. (pp. 172–173; also see Kuhn, 2000, pp. 95, 307–308)

Kuhn's argument, roughly, is this. To explain the success of science, one need not make realist appeals. In the struggle for existence among competing paradigms, the success of a paradigm can be accounted for solely with reference to the relevant 'environment' in which paradigms compete, namely the scientific community. Kuhn's explanation of the success of science is not entirely empty insofar as he argues that the puzzle-solving efficacy of a paradigm will be most prominent in determining which paradigms win out (cf. note 13). It is also important to note that Kuhn's view supposes that as science evolves, the problems often change (which is related to his argument on the discontinuity of scientific change). For the purposes here, I want to highlight the fact that Kuhn adopts a notion of scientific progress that does not assume a realist framework.

In contrast with the neo-Darwinian, neo-teleological conception of scientific evolution motivating Kuhn's view, Piaget's evolutionary analogue for science is derived from the sort of Lamarckian, goal-directed, conception of evolution eschewed by Kuhn (see Kitchener, 1987, pp. 343–347). This different conception of evolution leads Piaget naturally towards a more 'realist' notion of scientific progress. It is worth recalling here a telling passage from *Genetic Epistemology*:

> . . . knowing an object does not mean copying it—it means acting upon it. . . . Knowing reality means constructing systems of transformations that correspond, more or less adequately, to reality. They [i.e. the transformational systems] are more or less isomorphic to transformations of reality. The transformational structures of which knowledge consists are not copies of the transformations of reality; they are simply possible isomorphic models among which experience can enable us to choose. Knowledge, then, is a system of transformations that become progressively adequate. (Piaget, 1970, p. 15)

Piaget's realism, as expressed in this passage, resembles the sort of experimental realism championed by Hacking (1983, ch. 16) insofar as Piaget maintains that knowing reality consists of acting upon, interfering with and transforming reality. Piaget's resulting realist notion of progress ultimately reflects his assumption of the metaphor of the limit. This assumption maintains that by a series of successive approximations (i.e. logical and mathematical structures that are continually being elaborated and revised), scientific theories more closely approach reality as a mathematical limit.[12]

Piaget's realist notion of scientific progress bears striking similarities to the 'structural realism' that has been under considerable discussion among contemporary philosophers of science (see, e.g., Ladyman, 1998; McArthur, 2003; Psillos, 1995; Worrall, 1989).[13] This view maintains that *what* scientific theories are capable of capturing are structural properties of reality. More precisely, the 'structure' in structural realism can be understood as (discovered) relationships between phenomena that are expressed by mathematical equations. A key point of agreement between structural realists and

Piaget is that both views maintain that the structure of reality is capable of being captured (or expressed) by the mathematical structures of scientific theories. In the case of Piaget, this idea rests on the assumption that there is a 'harmony between mathematics and the real world' (see Piaget, 1967/1971a, pp. 339–345).

Another similarity between structural realism and Piaget's realism—which bears on the issue of scientific continuity—is that both views maintain that there is often *retention of mathematical structure* in instances of theory change. For example, in the transition from Fresnel's wave theory of light to Maxwell's electromagnetic theory in the history of optics, Fresnel's mathematical equations are *fully retained,* but given a new interpretation (see Worrall, 1989). In the history of physics, the more typical pattern is that the mathematical equations of surpassed theories *re-emerge as limiting cases* in successor theories: for example, the mathematical form of Newton's laws appear as a limiting case in the special theory of relativity, and the mathematical form of most of the laws in the caloric theory of heat are reproduced in thermodynamics.[14] As such, both structural realists and Piaget locate the continuity of scientific change in the retention or assimilation of mathematical structures.

Fleshing out the details of and arguments provided for the sort of realism adopted by Piaget would go beyond the scope of this paper. For the purposes here, I simply want to highlight the species of convergent structural realism that comes out of Piaget's view of scientific progress as a point of contrast against the discontinuous, anti-realist, position defended by Kuhn. It is interesting to note that while Piaget and Kuhn seem to disagree on the issue of realism, both their notions of progress are grounded on the idea that, over time, scientific theories become more adequate at solving problems. Whereas Piaget adds the caveat that increasing equilibration is associated with constructed structural systems that correspond more adequately to reality, Kuhn adds the opposite caveat that increased puzzle-solving efficacy is not necessarily associated with better approximations to reality.

Scientific Rationality

A final point of difference that separates Kuhn and Piaget's respective notions of scientific progress is the issue of 'scientific rationality'. Whereas Kuhn adopts an 'arational' view of scientific change (with some qualifications), Piaget believes that scientific progress is a decisively rational process. As indicated above, Piaget defends a rational notion of scientific progress that results from his positions on continuity and realism. For Piaget, scientific reason does not change without reason, or, put in another way, *reason evolves rationally* ('la raison n'en peut changer qu' avec raison').

In his post-*Structure* work, Kuhn has discussed the issue of rationality at length, consistently denying charges that he adopts an *irrational* notion of

scientific progress (see, e.g., Kuhn, 1977, ch. 13; 2000, pp. 91, 112–116, 119, 126–135, 155–162, 208–215, 251–252). In a 1991 interview, Kuhn characterized the nature of scientific change as *arational* (see Kuhn cited in Horgan, 1996, p. 42). Kuhn (1977, ch. 13; 2000, ch. 9) outlines this view both by articulating the limitations of scientific rationality and by providing a positive account of rationality. Because he conceives of scientific change as the successive *replacement* of older paradigms by newer ones (which is implied by his [1962/1996, p. 92] definition of 'scientific revolutions'), he addresses questions of scientific rationality in terms of paradigm choice (or 'theory choice'). Kuhn's resulting 'arational' conception of scientific progress denies that scientific change is rational in any absolute (i.e. objective) sense; however, it grants that scientific progress is rational in an instrumental sense.

According to Kuhn, choosing between competing paradigms cannot be decided in a purely 'objective' manner (e.g. by appeal to a universal criterion such as 'truth'). On his picture, in deciding the relative merits of a paradigm, scientists typically appeal to objective (i.e. shared) standards such as: accuracy, consistency, scope, simplicity and fruitfulness. However, Kuhn emphasizes that—in application—such standards function as *values*, and necessarily involve a subjective (i.e. personal) component inasmuch as the interpretation of and relative weights attached to these particular values are idiosyncratic. Kuhn (1977) writes that 'little knowledge of history is required to suggest that both the application of these values and, more obviously, the relative weights attached to them have varied markedly with time and also with the field of application' (p. 335). Moreover, he also emphasizes that there is no (non-question-begging) 'philosophical justification' for such values, and that they 'are in part learned from [scientific] experience, and they evolve with it' (p. 335). Because choices between competing paradigms inevitably involve an appeal to 'subjective' factors and because there is no 'Archimedean perspective' of values that can be employed to settle debates between incommensurable value orientations, Kuhn concludes that theory choice (and, hence, scientific change) cannot be rational in the sense of being objectively (or 'algorithmically') decidable (see Kuhn, 1977, pp. 320–330; also see Kuhn, 2000, pp. 112–116, 155–162).

Although Kuhn denies the rationality of scientific change—where 'rationality' is identified with 'objective' (or intersubjective) grounds for 'theory choice'—he also offers a positive account of rationality corresponding to his instrumentalist notion of scientific progress. Kuhn maintains that insofar as later paradigms are better puzzle-solving instruments, scientific progress has been rational. This is what he means to convey when he states that 'in paradigm choice—there is no standard higher than the assent of the relevant community' (Kuhn, 1962/1996, p. 94; also see Kuhn, 2000, p. 113). Kuhn's historical claim that scientists have chosen paradigms 'rationally' assumes that

> . . . the scientist's aim in selecting theories is to maximize efficiency in . . . 'puzzle-solving.' Theories are . . . to be evaluated in terms of such considerations as their effectiveness in matching predictions with the results of experiment and observation. Both the number of matches and the closeness of fit then count in favor of any theory under scrutiny. (Kuhn, 2000, p. 209)

Kuhn suggests—on the assumption that the general aim of science is puzzle-solving and scientists share criteria for theory choice such as accuracy, scope and fruitfulness (see Kuhn, 1977, p. 335; 2000, pp. 209–10, 214–215)—that scientific progress has been rational insofar as later paradigms have tended to be better puzzle-solving instruments. However, as indicated above, Kuhn is not willing to accept more robust notions of scientific rationality (e.g. rationality as objectivity) than this instrumentalist notion.

While Kuhn discusses issues of rationality in the narrow framework of 'theory choice', Piaget's discussion focuses on mechanisms of epistemic development. In contrast to Kuhn's skepticism regarding the rationality of scientific change, Piaget's entire philosophy of science can be understood as an attempt to explain the rationality of scientific progress, and to identify the rational mechanisms of scientific development. For Piaget, the rational nature of epistemic development—whether it be for an individual or for science—is never in question. Rather, the rationality of scientific progress is taken as an obvious fact that requires explanation.

In locating their own views of scientific rationality in relation to Kuhn's, Piaget and Garcia write:

> Kuhn claims to be able to guarantee a certain rationality on the basis of the rules of the game observed by the scientific community in the exercise of science. However, he presents neither the 'rational mechanisms' of change in science nor the criteria to gauge progress. (Piaget & Garcia, 1983/1989, pp. 261–262)

Piaget and Garcia's first complaint, I think, is a fair criticism. This complaint should be regarded as an important and cogent criticism of Kuhn's view because it highlights an important aspect of scientific change that is neglected by him, yet relevant to his conclusions. With respect to the second complaint, however, Piaget and Garcia's presentation is somewhat misleading insofar as Kuhn does defend 'puzzle-solving efficacy' as a criterion for scientific progress. Piaget and Garcia's oversight here, I think, reveals a significant similarity with respect to Kuhn and Piaget's positions on scientific progress.

For Piaget, the general mechanism that explains the rationality of scientific progress is equilibration. In Kuhnian terms, equilibration functions as a normative (i.e. rational) standard of evaluation because more equilibrated theories are—from an epistemic point of view—better or superior (i.e. rationally preferable) than less equilibrated theories (cf. Kitchener, 1987). As an evaluative standard for theory choice, equilibration appears to serve a

very similar function that 'puzzle-solving efficacy' serves within Kuhn's 'arational' framework. Like Kuhn's instrumentalist notion of rationality, which maintains that scientific progress is rational insofar as science becomes a more powerful puzzle-solving instrument over time, Piaget maintains that scientific progress is rational insofar as science becomes 'more equilibrated' over time, which itself seems to translate into a form of instrumental rationality.

Piaget's stronger views on the rationality of scientific progress, however, diverge from Kuhn's insofar as Piaget's notion is characterized by not only increased instrumental (or puzzle-solving) efficacy over time, but also an accumulation (or assimilation) of prior theories and a universal tendency towards theories that more adequately capture (structural) characteristics of reality. That is, Piaget's conception of scientific rationality also incorporates his views on scientific continuity and his *regulative ideal* of convergent realism (i.e. 'the metaphor of the limit').[15] While Piaget would agree with Kuhn's (2000) contention that, in theory choice, 'comparative evaluation is all there is' (p. 115), he would disagree with his rejection of 'truth' and 'reality' as heuristic *ideals*. Moreover, Piaget would likely reject Kuhn's very framing of the problem of scientific rationality (cf. Piaget & Garcia, 1983/1989, pp. 263–267) insofar as Kuhn's analysis presupposes his discontinuous ('gestalt change') picture of scientific change, wherein issues regarding the rationality of scientific change are addressed in terms of the *choices* that scientific communities make between 'incommensurable' theories.

Conclusion

In explicating Piaget's genetic epistemology, I have inevitably neglected some concepts central to his project (e.g. reflective abstraction, empirical abstraction and the 'circle of sciences'). My aim has been to articulate some central aspects of genetic epistemology as a philosophy of science, and especially the notion of scientific progress implicit in Piaget's view.

The exercise of comparing Piaget and Kuhn's notions of scientific progress was to clarify aspects of both of their respective views. The differences between Kuhn and Piaget's views of scientific progress, I think, ultimately stem from their disagreement regarding the continuity–discontinuity of scientific change. As I argued, Piaget's claim that large-scale scientific changes come about via processes of assimilation and accommodation highlights a weak point in Kuhn's discontinuous view. If *all* scientific change can be seen as a continual process of successive re-interpretation and integration, then the usefulness in drawing a Kuhnian-style distinction between normal and revolutionary science appears to be wanting (cf. Feyerabend, 1970, pp. 201–208).

Despite the differences in Piaget and Kuhn's notions of scientific progress, it is important to acknowledge the many similarities (e.g. the emphasis of historical context, the understanding of scientific knowledge as a process, and the importance of dialectical conflict). Although the analysis in this paper focused primarily on the differences between their respective views, the potentially complementary nature of Piaget and Kuhn's ideas should not be overlooked. Whereas Kuhn emphasized the role of social factors in scientific practices and their implications for scientific growth, Piaget focused on articulating the mechanisms operating to transform less advanced to more advanced forms of knowledge. Piaget and Kuhn's ideas can be regarded as complementary rather than opposed, in the sense that a consideration of both views leads to a more comprehensive account of scientific change. As suggested in this paper, Piaget's analysis of the transitional mechanisms operating in scientific development provides a useful resource for reformulating some of Kuhn's ideas that have, for better or worse, become commonplace in contemporary discourse.

Notes

1. From 1925 to 1929, Piaget held the chair in philosophy of science at the University of Neuchâtel and, from 1929 to 1939, he held the chair in the history of scientific thought at the University of Geneva (Kitchener, 1987, p. 341, n. 13).
2. Kuhn reports that he had once told his teacher, Alexander Koyré, that he had learned to understand Aristotelian physics by understanding the children whom Piaget studied; in response, Koyré stated that it was Aristotle's physics that had taught him to understand Piaget's children (see Kuhn, 1977, pp. 21–22).
3. Michael Chapman (1988) notes that Piaget seems to adopt elements of both nominalism and realism, described by Piaget as a species of 'interactionism' or 'relativism'. Richard Kitchener (1986) argues that Piaget can be interpreted as an idealist, but must be some sort of a realist given his views regarding the progress of science (ch. 4).
4. The 'epistemic subject' is Piaget's notion of an idealized abstraction (rather than a single scientist or 'disciplinary matrix'). It is understood as the set of idealized structures that are universal at the same level of development (the counterpart in psychogenesis is the 'psychological subject'). Kitchener (1986) notes similarities between the epistemic subject and both Kant's 'transcendental ego' and Hegel's 'Geist' (p. 81).
5. Interestingly, Garcia was a student of Rudolf Carnap and Hans Reichenbach (see Piaget & Garcia, 1983/1989, p. vii), two of the leading proponents of logical empiricism. In the third section of this paper, I argue that Piaget and Garcia's position on the continuity of scientific change has affinities to the view of 'structural realism' that has been recently discussed by philosophers of science. In this connection, it is worth noting that Reichenbach's (1920/1965) early neo-Kantian account of scientific change in physics (see Friedman, 1999, ch. 3) appears to anticipate some of the key ideas of structural realism (e.g. the continuity of structures). Moreover, Stathis Psillos (2000) has recently argued (drawing on Grover Maxwell's earlier work) that Carnap's philosophy of

science in the 1950s and 1960s—despite Carnap's well-known agnosticism on issues of 'realism'—can also be understood as a version of structural realism (cf. Demopoulos & Friedman, 1985).

6. The historico-critical method is a French approach to philosophy of science adopted by writers such as Koyré, Duhem and Bachelard. Piaget conceptualizes it as a *history of concepts* (or a history of ideas). This conceptual history includes those 'categories' that a Kantian would consider 'necessary for thought', and especially scientific thought (e.g. logic, space, time, causality, quantity, etc.). It is important to note that although Piaget was concerned with Kantian categories, he believed that these categories evolved through time. Piaget once presented this view as a middle ground between Konrad Lorenz's apriorism and Poincará's conventionalism (see Piaget, 1967/1971a, pp. 116–120). Interestingly, Kuhn has also presented his own views in a neo-Kantian light (see, e.g., Kuhn cited in Horgan, 1996, p. 44; Kuhn, 2000, pp. 103–104, 207, 245, 264).
7. Piaget's theory of equilibration has been heavily criticized, and some have argued that his stage theory of cognitive development has been decisively refuted by empirical research (see, e.g., Case, 1999; Flavell, Miller, & Miller, 1993). For a more comprehensive and critical discussion of equilibration, see Chapman (1988, ch. 6) and Smith (2002). For the purposes of this paper, the specific details of Piaget's stage theory are not as important as the general mechanism of equilibration itself, and it is unclear whether empirical research has undermined the existence of equilibration as a functional mechanism of epistemic development.
8. Insofar as Piaget's views on epistemology (and, hence, philosophy of science) are informed by psychogenesis, genetic epistemology approaches the naturalist ideal prescribed by Quine's (1969) 'naturalized epistemology'. In this connection, Piaget chides Kuhn for drawing conclusions about science based on *a priori* theorizing, rather than the results of scientific inquiry:

> [Kuhn] has tried to show how a student would learn his 'exemplars' [see Kuhn, 1977, ch. 13]. He attempts to reconstruct the ways a child learns what a duck is without taking the trouble empirically (that is, by observing children) whether this is really the way that children learn. Several years of research with children have shown that children do not, in fact, learn the way Kuhn imagined. It is surprising to find Kuhn fall back on a neopositivist position—the very position he meant to demolish. (Piaget & Garcia, 1983/1989, p. 265)

9. It is important to note that Piaget draws a distinction between reflective and empirical abstraction (see Piaget & Garcia, 1983/1989, pp. 204–205, 213–245), which are both important sub-mechanisms of equilibration. Both of these sub-mechanisms are conceived as processes of abstraction or generalization; however, they 'are far from being parallel' (p. 213). Reflective abstraction applies exclusively to logical-mathematical domains, and involves abstracting from *actions and operations* (or 'coordinated actions'). Empirical (or 'physical') abstraction (which itself requires reflective abstraction) applies to empirical domains, and involves abstracting from *constructed 'objects' of reality* (or 'perceptions'). In the case of physical knowledge, Piaget maintains that these two processes interact to 'constitute the method of construction of all physical concepts' (p. 205). It is also worth noting that Piaget's distinction implies very

different forms of progression in the logical-mathematical sciences and the empirical sciences, respectively (see Chapman, 1988, ch. 5).

10. It is worth noting that, for Piaget, the progress of scientific knowledge also results from the *active interaction between various scientific disciplines* (see, e.g., Piaget, 1970/1971b, chs 5–6). Piaget thus endorses a 'unity of science' ideal, although he conceives of such an ideal in a holist (as opposed to a reductionist) fashion. He calls his conception of unity the 'circle of science' (pp. 116–120), and this ideal emphasizes the interdependent and complementary nature of various sciences (namely psychology, mathematics, physics and biology) that form a 'cyclical order' (cf. Kuhn, 2000, pp. 97–99, 116–120, 250–251).
11. With characteristic honesty, Kuhn would admit that *Structure* was formulated against a simplistic caricature of logical empiricism, and that he not even read many of important works of that tradition at the time (see, e.g., Kuhn cited in Borradori, 1991/1994, p. 157; Kuhn, 2000, pp. 227–228, 305–306). It is also evident that Kuhn's emphasis on the idea of incommensurability as untranslatability was the result of his attempts to come to grips with Quine's (1960, chs. 1–2) indeterminacy of translation thesis, and to provide an alternative (non-referential) account of meaning (see, e.g., Kuhn cited in Borradori, 1991/1994, p. 162; Kuhn 1962/1996, p. 202; 2000, pp. 37–40, 47–53, 60–63, 91–92, 279–280).
12. In an illuminating discussion, Kitchener (1987) relates Piaget's metaphor of the limit to Popper's (1963/1965, ch. 10; 1972) notion of 'versimilitude', namely the notion that scientific theories approach the truth more closely over time. Piaget's philosophy of science appears to be quite amenable to Popper's evolutionary epistemology (see Campbell, 1974), especially in terms of their conclusions regarding the nature of scientific change and progress (cf. Piaget & Garcia, 1983/1989, ch. 9). For a more comprehensive discussion of evolutionary models of knowledge defended by various philosophers of science (e.g. Campbell, Toulmin, Popper and Lakatos), see Richards (1981).
13. John Worrall (1989)—who traces the historical origins of structural realism to Poincaré—argues that structural realism is the 'best of both worlds' in the sense that it can accommodate the best arguments for realism (the success of science argument) and anti-realism (the pessimistic meta-induction). In this connection, it is worth noting that structural realists would regard Kuhn's 'evolutionary' response to the success of science argument to be unsatisfactory insofar as it fails to address what is at issue in this argument (namely the issue of reference).
14. Structural realists have (implicitly and explicitly) taken issue with the interpretations that Kuhn provides for two of the main historical case studies presented in *Structure*. With respect to Kuhn's interpretation of the transition from Newtonian mechanics to Einstein's theory of relativity (Kuhn does not distinguish between the special and general theories in *Structure*), structural realists regard Kuhn's analysis as misleading insofar as his observation that the terms (e.g. 'mass') of Newton's and Einstein's theories are 'incommensurable' does not diminish the fact that there is *structural continuity* in this transition (i.e. meaning change need not imply discontinuity). With respect to Kuhn's interpretation (also see Laudan, 1989) of the transition from phlogiston theory to

Lavoisier's oxidation theory in chemistry, structural realists have argued that Kuhn's analysis is faulty *in his own terms* because phlogiston theory was never a 'mature science', but an 'immature science' (see Worrall, 1989, p. 113). For a provocative and more general analysis—in the context of a discussion of Kuhn—on the problem of interpreting case studies in philosophy of science, see Pitt (2001).

15. Michael Friedman (2001) has articulated a neo-Kantian account of scientific change—formulated in opposition to Kuhn's instrumentalist notion of rationality—that leads to a conception of scientific rationality very similar to Piaget's *continuous* notion (pp. 47–68, 93–103). Moreover, Friedman's book features a conception of 'relativized *a priori* principles' that leads to a conception of scientific change similar to the general neo-Kantian 'revisable categories' view endorsed by both Piaget and Kuhn (see note 6 above).

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