Chapter 13
Constructivism

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Introduction

In one of his first papers, Thomas Kuhn (1959) addressed the "essential tension" implicit in scientific research, i.e., the contrast between convergent and divergent thinking. He considered both to be central to the advance of science. Convergent thinking is what scientists do in their daily "normal research projects," where the "scientist is not an innovator but a solver of puzzles, and the puzzles upon which he concentrates are just those which he believes can be both stated and solved within the existing scientific tradition" (*ibid.,* p. 234). The convergent mode is "neither intended nor likely to produce fundamental discoveries or revolutionary changes in scientific theory" (*ibid.,* p. 233). As he would describe in greater detail in *The Structure of Scientific Revolutions* (1970), this is because students are already discouraged from developing divergent-thinking abilities, partly because their education is based on textbooks, which "exhibit concrete problem solutions that the profession has come to accept as paradigms… Nothing could be better calculated to produce 'mental sets' or *Einstellungen*" (Kuhn, 1959, p. 229). Clearly, from this perspective, mental sets (or "mental inertia") play an important role in paradigms as they prevent the normal scientist from gazing beyond the limits of her paradigm. Kuhn also emphasized the importance of convergent thinking as "no part of science progressed very far or very rapidly before this convergent education and correspondingly convergent normal practice became possible" (*ibid.,* p. 237). However, Kuhn also recognized the divergent method because in order to assimilate new discoveries and theories "the scientist

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must usually rearrange the intellectual and manipulative equipment he has previously relied upon, discarding some elements of his prior belief" (*ibid.,* p. 226).

For psychologists, this interplay between convergent and divergent thinking – Kuhn's essential tension – is strongly reminiscent of Jean Piaget's notion of the ongoing attempts of the subject to restore her equilibration on the basis of assimilation (trying to fit the new puzzle pieces to the already existing pieces, or in Kuhn's view: "convergence thinking") and accommodation (trying to come up with new innovative ways of changing the game in the light of non-fitting pieces, or "divergent thinking," according to Kuhn). Is the continuous integration of new information into pre-existing structures, the transformation of existing structures, and the construction of new ones that are based on experience to accomplish assimilation what Kuhn had in mind? It leaves us with the question: How much constructivist (in the sense of Piaget) was Kuhn? In a series of papers several authors have also argued that Piaget and Kuhn have opposing viewpoints: while the former proposes continuous and cumulative progress, the latter emphasizes discontinuity (cf. Kitchener, 1985, 1987; Tsou, 2006; Burman, 2007). Also, Ernst von Glasersfeld, who founded radical constructivism (RC) in the 1970s, is clearly on Kuhn's side: "The history of scientific ideas shows all too blatantly that there has been no overall linear progression." (Glasersfeld, 2001, p. 32) Furthermore, according to Bird (2009), "Kuhn… denied any constructivist import to his remarks on world-change [but] acknowledge[d] a parallel with Kantian idealism." This, however, sounds odd because Kuhn claimed that "the proponents of competing paradigms practice their trades in different worlds… Practicing in different worlds, the two groups of scientists see different things when they look from the same point in the same direction" (Kuhn, 1970, p. 150)."[1]

Clearly, a statement like this sounds very constructivist, for constructivism expresses the idea that mental structures and operations are actively constructed by one's mind rather than passively acquired. "Constructing" means that there is a developmental path from some initial state, rather than a teleological progress towards some final state (Burman, 2007). It comes as no surprise then that different individuals take different paths resulting in different (momentary) states. Given these observations, is constructivism an over-arching perspective that accommodates both Kuhn's and Piaget's respective philosophies of science?

In this paper I will first describe the paradigm of constructivist approaches, in general, and radical constructivism, in particular. I will then investigate the notion of mental sets through the constructivist lens. The paper's goal is to show how central notions in Kuhn's theory can be interpreted in terms of constructivism and its emphasis on an alternative approach to knowledge.

[1] In his autobiography, von Glasersfeld (2010, p. 245) described how Kuhn grew indignant over von Glasersfeld's comment that Fodor's talk about "representations" was irresponsible if it did not add that they could never be representations of reality. So we can assume that in the above quote Kuhn interpreted "different worlds" as hypothetical or even fictitious worlds that are not corroborated by experiments whereas for von Glasersfeld these were different experiential worlds with no ontological connotation (Marco Bettoni, personal communication, 2011).

Constructivist Paradigms

Constructivism is not a homogenous paradigm. Various strands of empirical insights and philosophical reflections have led (and are still leading) to the formulations of a number of constructivisms. Vincent Kenny (2010) speaks of "ever branching new sub-disciplines." And even though many constructivist scholars have known each other personally, and have even been bound by ties of friendship, their respective approaches – including radical constructivism, social constructivism, constructionism, etc. – have remained at a certain distance from each other. So instead of speaking of *the* constructivism, I will use the term "constructivist approaches." It refers to the idea that the mental world – or the experienced reality – is actively constructed or "brought forward," and that the observer plays a major role in any theory.[2]

In some sense the variety of constructivist approaches seems to resemble that which Kuhn called "immature science" (Kuhn, 1970), which lacks consensus and where "much intellectual energy is put into arguing over the fundamentals with other schools instead of developing a research tradition" (Bird, 2009). However, there is a crucial difference. Constructivist approaches are not a discipline-bound endeavor but rather a horizontal "meta science" way of thinking that covers a variety of disciplines and interdisciplinary topics: neural networks, cognition, learning, living systems, organizations, architectural design, sociology, literary sciences, media sciences, and systemic family therapy (cf. Müller, 2010).

Looking closely at the differences among constructivist approaches one will recognize that they vary in function of how far they are willing to take the idea that reality is constructed. In the following section the attempt is made to classify constructivist approaches into two dimensions: (1) disciplinary paths to constructivisms and (2) dualistic versus non-dualistic approaches with regard to the dichotomy between mind and reality. For each of these categories I will paradigmatically discuss a typical – exemplary – proponent.

Paths to Constructivism

Phenomenological Constructivism: Ernst Mach

Some authors embrace a phenomenological perspective that considers perception to be the grouping of experiential complexes. For example, in the late nineteenth century, Ernst Mach, a precursor of constructivism,[3] claimed that "things" consist

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[2] Cf. Maturana's "Everything said is said by an observer to another observer who can be himself or herself" (Maturana, 1978, p. 31) and von Foerster's "Objectivity is the delusion that observations could be made without an observer" (quoted in Glasersfeld, 1995, epigraph).

[3] It should be emphasized that this is the very same Ernst Mach whose name was used for the *Verein Ernst Mach*, which later became known as the Vienna Circle of the logical positivists. However surprising this "double life" might be, in his first publication on radical constructivism, von Glasersfeld (1974) already considered Mach (together with Percy Bridgman) an ally. They both neglected developmental aspects, which are crucial for constructivism.

of a functional assembly of sense elements, i.e., they are thought symbols for a sensational complex of relative stability (cf. also von Foerster's reference to eigenbehavior, see below). Consequently, the actual elements of the world are not things and bodies but rather sensations such as colors, sounds, pressures, spaces, and times as well as moods, emotions, and the will (Mach, 1959, ch. 1.2). However, this does not imply that the world is a mere sum of sensations. Rather, Mach defined the world in terms of "functional relations of the elements" (Mach, 1959, p. 363). These also include "psychical" entities such as the self, which are characterized as sensations that are related to each other in different ways. From this perspective, according to Mach, science is the "discovery of functional relations… the dependence of experiences on one another." (Mach, 1959, ch. 1.14) and the growth of knowledge is nothing more than the adaptation of thoughts to facts and "the discovery of logical relations via the accommodation of thoughts with each other" (Mach, 1992, p. 27). Indeed, it was on this basis that Mach developed the concept of the "economy of thoughts," which emphasizes the importance of compressing experiences into laws. He considered the object of science to be "to replace, or save, experiences, by the reproduction and anticipation of facts in thought. Memory is handier than experience, and often answers the same purpose" (Mach, 1960, p. 577).

For the non-dualist Mach, a (scientific) fact is a conscious sensation (Blackmore, 1972, p. 32) because experiential elements are always of the same sort:

> The antithesis between ego and world, between sensation (appearance) and thing … vanishes, and we have simply to deal with the connection of the elements *a b c* [the complex composed of volitions, memory-images, and the rest] *A B C* [complexes of colors, sounds, and so forth, commonly called bodies] *K L M* [the complex known as our own body] … This connection is nothing more or less than the combination of the above-mentioned elements with other similar elements (time and space). (Mach, 1959, ch. 1.7)

From his phenomenological perspective, according to which the world consists only of our sensations, knowledge does not refer to material entities but to sensations only.

Furthermore, Mach's perspective claims that the idea that experiences are the result of the effects of an external world extending into consciousness should be rejected. It is not bodies that produce sensations but complexes of (sensational) elements that make up bodies. Ultimately, "the world does not consist of mysterious entities which, by their interaction with […] the ego, produce sensations, which alone are accessible. For us, colors, sounds, spaces, times, etc. are provisionally the ultimate elements, whose given connection it is our business to investigate." (Mach, 1959, ch.1.13)[4]

[4] Some 100 years later, Francisco Varela shared Mach's strong emphasis on the first-person perspective. Having a complementary interest in phenomenology and neuroscience (rather than physics, as was the case with Mach), he developed *neurophenomenology* (Varela, 1996). It combines systems neuroscience with a pragmatic approach to becoming aware of our lived experience (Froese, Gould, & Barrett, 2011).

Biological Constructivism: Maturana et al.

Many variations of constructivism are founded in empirical (mostly biological) results rather than philosophical considerations. All these approaches emphasize: (1) the primacy of the cognitive system and (2) its organizational closure.

Building on a large number of insights into biological mechanisms, which he had collected in his long career as a neuroscientist, Rudolfo Llinás expressed the primacy of the cognitive system in very clear sentences: "[al]though the brain may use the senses to take in the richness of the world, it is not limited by those senses; it is capable of doing what it does without any sensory input whatsoever" (Llinás, 2001, p. 94). He goes on to claim that since the ability of the nervous system is to generate a sensory experience of any type, "we are basically dreaming machines that construct virtual models of the real world." (*ibid*.,). In his view, the mind is primarily a self-activating system, "one whose organization is geared toward the generation of intrinsic images," (*ibid*., p. 57) which conveys weight to the idea that cognition acts independently of the environment. It merely requests confirmation for its ongoing dynamical functioning and otherwise works autonomously. In other words, the mind is organizationally closed, which implies that the mind must construct its reality and the entities it is populated with in the first place. Perturbations from the outside may, at best, modulate the dynamical construction process of the mind but may not determine it.

These were also the conclusions made by Heinz von Foerster, Humberto Maturana and Francisco Varela years before Llinás. Von Foerster picked up an old neurophysiological insight, the "principle of undifferentiated encoding," which is thought to highlight the peculiarity of the nervous system: "The response of a nerve cell does not encode the physical nature of the agents that caused its response. Encoded is only 'how much' at this point on my body, but not 'what'." (Foerster, 2003a, pp. 214–215). Together with the insight that a large majority of the synapses in the primary visual cortex (as well as in other areas such as the lateral geniculate nucleus of the thalamus) do not seem to be devoted to signals coming from the sensors (Sillito & Jones, 2002), the question arises: What is the brain, in its isolation, busy with? Maturana suggested that we can compare the situation of the mind to that of a pilot using instruments to fly a plane (or a submarine navigator piloting in the dark depths of an ocean). All he does is "manipulate certain internal relations of the plane in order to obtain a particular sequence of readings in a set of instruments" (Maturana, 1978, p. 42). Von Foerster suggested a solution based on the idea of (infinite) repetition, or *eigenbehavior*.[5] He pointed out that "what is referred to as 'objects' … in an observer-excluded (linear, open) epistemology, appears in an observer-included (circular, closed) epistemology as 'token for stable behavior'" (Foerster, 2003b, p. 261).[6] He argued these eigenbehaviors, or attractors, result from the recursion of accounting for the changes in an organism's sensations by its actions that in turn are

[5] A simple example often used by von Foerster himself is that of repeatedly applying the square root operator to the result of its own operations, which at its limit will always result in one irrespective of the initial number.

[6] In the terminology of complexity research it is called an "attractor."

described in terms of its sensations. Therefore, what appear to us as objects are equilibria that determine themselves through circular processes. They reside "exclusively in the subject's own experience of his or her sensorimotor coordination" (Foerster, 2003b, p. 266). This agrees with Piaget's (1954) insight that in the sensorimotor period children repeat certain actions over and over again in order to gain sensorimotor mastery.[7] Eventually they will also have to do this as scientists who are drilled during their educational period (see Feyerabend's criticism of stereotypical research below, and Burman, 2008).

The idea of circularity was also picked up by Humberto Maturana and Francisco Varela in their work on autopoietic systems (or "biology of cognition"). What began as an answer to the question, "What is life?" has become a fully encompassing explanatory network that includes living, cognition, languaging, and emotioning (cf. special issue of *Constructivist Foundations*, Riegler & Bunnell, 2011). At the focus of their work is the biological individual, who is a particular type of self-organizing system, a so-called "autopoietic system" (cf. Maturana & Varela, 1980). It obeys the following criteria: (1). Its components take part in the recursive production of the network of production of components that produced those components. (2). An entity exists in the space within which the components exist by determining the topology of the network of processes. (A system that does not fulfill these criteria is called allopoietic, e.g., it is a machine that serves a different purpose than maintaining its own organization.) Due to its circular organization, an autopoietic system is clearly "an inductive system and always functions in a predictive manner: what occurred once will occur again. Its organization (both genetic and otherwise) is conservative and repeats only that which works." (Maturana & Varela, 1980, pp. 26–27). It should therefore come as no surprise that science, carried out by autopoietic living systems, works inductively, too.

Many have criticized Maturana and Varela on the grounds of being self-contradictory due to their emphasis on biology: How can biology of cognition explain its own axioms, i.e., the biological a priori of cognition?[8] As will be pointed out below, the biological link can be considered superfluous, which makes the idea of autopoietic systems a formal rather than biological theory, thereby avoiding the criticism.

Dualism vs. Non-dualism

Dualistic Approaches: Cognitive Constructivism

Many constructivist approaches assume a dualistic relationship between constructed reality and mind-independent reality.[9] They maintain that constructed mental structures gradually adapt to the structures of the real world. Such a "cognitive

[7] Cf. Mach, "We have become accustomed to regarding an object as existing permanently." (Mach, 1970, p. 30).

[8] This criticism is also applied to evolutionary epistemology, cf. Riegler (2005b).

[9] In the German-speaking literature on constructivism, the distinction is often made between *wirklichkeit* (from the German "wirken", meaning "to have an effect on") – the world as the domain of our experience – and reality (from Latin "res" = thing) – the world as the domain of things in themselves.

constructivism" was championed by Jean Piaget. He suggested an interplay of assimilation (integration of experience) and accommodation (modification of the cognitive apparatus based on new experience to enable assimilation) that progressively leads to knowledge of reality: "Knowing reality means constructing systems of transformations that correspond, more or less adequately, to reality." (Piaget, 1970, p. 15).

Based on Piaget, Ulric Neisser (1976) defined perception as the "pickup of information" controlled by the mental structure that is constructed from earlier perceptions. He called this "schemata-controlled information pickup." It expresses the view that an individual's cognitive apparatus determines the way she looks at the environment. The apparatus constructs anticipations of what to expect and thus enables the organism to perceive the expected information. Without these anticipations the individual would not be able to see anything.

For example, a circle drawn in sand is perceived as a circle not because of sophisticated image processing in our head, which compresses the perceived trace into the mathematical concept of a circle, but due to the projection of a (mathematically ideal) circle onto sensory data and anticipating not too much of a difference (Riegler, 2006).[10]

The idea that perception and cognition in general are based on anticipation forces us to reconsider the information-processing paradigm, which portrays cognitive organisms as computers transforming information input into behavioral output. In this paradigm, organisms have to filter all the available information to find relevant features in order to control their behavior. This seems computationally implausible as the combinatorial variety is simply too large for biological brains and artificial computers alike. Very much in the sense of Karl Popper's (1979) "searchlight view of mind," the alternative would be "perceptive interaction on demand."

According to what I called the "constructivist-anticipatory principle" (e.g., Riegler, 1994, 2007), it is not all the available information from outside that is filtered for relevant issues in order to control the behavior of an organism. Instead, the cognitive system constructs cognitive structures in the first place and occasionally uses sensor signals to verify their validity (or as von Glasersfeld would say: viability). It may be compared with a relay race where the participants focus solely on their running, except for the short moments of coordination when they pass the baton to the next runner. One could describe the moments of coordination as "checkpoints" (Riegler, 1994, 2001a, 2007), where runners verify whether they are still on track so that the race can go on with the subsequent team member.

As a consequence of this, cognitive decisions are not taken in response to an environmental challenge but are a consequence of internal cognitive dynamics. Clearly, this emphasizes the key role of the cognitive apparatus in the process of reality construction, which is not simply the (passive) representation of a mind-independent reality. Therefore, cognition is not about information processing but rather about information generating.

[10] Similarly, George Kelly (1963) emphasized that a "person's processes are psychologically channelized by the ways in which he anticipates events."

The information-generating paradigm has great implications for science since it rejects the predominant positivist view (for example of the Vienna Circle) which considers observation (expressed, e.g., in protocol sentences describe sense-data) as the neutral arbiter between competing theories. From Kuhn's perspective, however, observation is influenced by prior beliefs and experiences (cf. Bird, 2009). This "theory-ladenness" was emphasized by Kuhn when he noted that a pendulum was seen by Aristotelians as body that "was simply falling with difficulty" while for Galileo it was a body "that almost succeeded in repeating the same motion over and over again ad infinitum" (Kuhn, 1970, p. 119). He concluded that "[t]wo scientists who perceive the same situation differently, but nevertheless use the same vocabulary to describe it, speak from incommensurable viewpoints" (Kuhn, 1970, p. 201).

Some 30 years before Kuhn, Ludwik Fleck (1935) had already emphasized the theory-ladenness of observation. What he described as "thought-style" determines not only the meanings of the concepts used by the scientists, but also the perception of the phenomena to be explained (Oberheim & Hoyningen-Huene, 2009).

The idea of "incommensurable viewpoints" can easily be accounted for by Neisser's perceptual cycle in which the mind "accepts information as it becomes available at sensory surfaces and is changed by that information; it directs movements and exploratory activities that make more information available, by which it is further modified" (Neisser, 1976, p. 55). In this view, reality is cognitively constructed on the basis of the mutual interplay between the mind and the "experiential data" it assimiliates into the existing network of schemata. For Piaget, too, understanding is a dynamical network process: in order to include phenomena it is necessary "to include them in a network of relations becoming increasingly remote from appearance and to insert appearance in a new reality elaborated by reason." (Piaget, 1954, p. 381). The emphasis on networks and their dynamical self-modification due to its accommodation to new experience makes it clear that constructivist accounts of reality construction and cognition cannot be based on static propositional knowledge but must – methodologically – include insights from the newly emerging network sciences (cf. chapter on "Towards a formal interpretation of radical constructivism" below).

Unfortunately, epistemologically speaking Piaget et al.'s cognitive constructivism is flawed as there are two problems with this (as von Glasersfeld calls it, "trivial constructivist") view. First, there is no way to prove the validity of our knowledge, i.e., whether we have constructed "an adequate representation of reality" (Piaget, 1954, p. 381), since all the means at our disposal to verify our knowledge are the very senses through which we gathered the empirical evidences for this knowledge in the first place (see von Glasersfeld's skeptical attitude below in the section, "Radical constructivism"). Therefore, we cannot be sure of the correctness of our beliefs about a mind-independent reality and consequently of our scientific theories. Secondly, notions such as observation, cognitive apparatus, and nervous signals are constructions, too. The situation is reminiscent of Wittgenstein's ladder: having it climbed we are obliged to throw it away, and with it any claim to be able to know the "true nature" of reality – whatever this denotes. Von Glasersfeld was very clear about this when he wrote that "those who merely speak of the construction of knowledge, but do not explicitly give up the notion that our conceptual constructions can or should in some way represent an independent, objective reality, are still caught up in the traditional theory of knowledge." (Glasersfeld, 1991b, p. 16). Therefore, any form of constructivism must necessarily strive for completeness with its claim to uncompromisingly apply the idea of constructions on all levels. Two such non-dualistic approaches, which try to dispense with the dichotomy between mind and reality, are reviewed next.

Non-dualistic Approaches: Theory of Cognitive Operators

While the dualistic position is intuitively easily comprehensible, it has been rejected by several authors on philosophical grounds. For example, it can be argued that the relationship between environment and sense organs resembles the constellation in scientific experiments where measurement devices gauge reality. While many intuitively assume that reality influences the reading on the measurement device, some assume that perceived patterns and regularities have to be regarded as invariants of inborn cognitive operators. This idea goes back at least to Immanuel Kant, who referred to the notions of space and time as being a priori and as indispensable for understanding raw sensory experience.

Kant's notion of the "Copernican Turn" addresses the question of how reality and knowledge relate to each other: does reality inform our knowledge or does knowledge inform reality? Konrad Lorenz's (1941) intention was to re-interpret Kant's a priori categories as *phylogenetically* acquired categories "fixed prior to individual experience." What is of interest to the constructivist, however, is the question how these (and other) categories occur in *individual* ontogeny. Olaf Diettrich's (2001) "theory of cognitive operators" is an attempt to shed light on this question. It starts with the claim that properties of scientific entities are defined as invariants of measurement devices. This means that certain notions in science cannot be defined independent of the measurement. Diettrich claims that this does not only apply to science but also to observations in general, i.e., they have to be considered the results of measurements of cognitive operators in the mind. In other words, observations are invariants of these cognitive measuring devices. Observations are therefore human specific in the sense that they do not represent independent ontological elements of an outside reality. Diettrich stresses that reality is simple and predictable "if and only if the way we describe the world is closely related to the way we act upon the world" (Diettrich, 2001, p. 277) and has nothing to do whether the world is simple and predictable *in itself*. For Diettrich this is even a way to account for the "unreasonable effectiveness of mathematics" because that which is perceived and the mathematical structures are invariants of the same mental operators (*ibid*., p. 296), which means that any mind-independent reality is not part of the equation.

With regard to Kuhnian philosophy of science, we can identify two important implications and parallels:

1. Truth as the correlation between knowledge and reality cannot serve as an arbiter in assessing the former. According to Diettrich, this applies to the evaluation of scientific theories too. Lacking this arbiter, theory building must look for alternative criteria such as consistency. Similarly, Kuhn rejected the correspondence theory of truth. He claimed that scientific progress should not be equated to closer approximations to truth but to the weaker criterion of utility, i.e., that of puzzle-solving efficacy: "We… have to relinquish the notion… that changes of paradigm carry scientists… closer to the truth." (Kuhn, 1970, p. 170). Rather, scientists appeal to shared standards such as accuracy, consistency, scope, simplicity and fruitfulness (cf. Tsou, 2006, p. 216), or simply accuracy of predictability: "Theories are… to be evaluated in terms of such considerations as their effectiveness in matching predictions with the results of experiment and observation." (Kuhn, 2000, p. 209). This instrumentalist view in science is shared by Kuhn with von Glasersfeld (as pointed out in the next section).
2. The fact that different sets of cognitive operators bring forth different cognitive phenotypes makes it virtually impossible to communicate with beings equipped with those alternative operators. Variations among cognitive operators do not need to have biological roots – Diettrich mentioned the immense difficulties with alien races from outer space – but can also result from the ongoing ontogenesis of individuals resulting in a profound incommensurability among human beings. Similar to what Kuhn wrote, such incommensurabilities do not necessarily mean a gradation in consistency or efficiency among these sets of cognitive operators.

Non-dualistic Approaches: Radical Constructivism

A wide-spread objection to dualistic versions of constructivism starts with the question: Can the structures of the real world be compared with mental ones at all? Some are skeptical about this possibility as this would require a comparison independent of those senses through which the mental structures were constructed in the first place. For example, Ernst von Glasersfeld (1995), following this tradition of skepticism, criticized the realists' assumption that we can determine the truth content of our knowledge by comparing it with reality, as Wittgenstein's "in order to tell whether a picture is true or false we must compare it with reality" (Wittgenstein, 1922, Sect. 2.223) suggests. Von Glasersfeld vehemently objects to the possibility of comparing one's knowledge with reality as we would need to be able to stay outside our own knowledge (i.e., we would need to know that which we perceive before we perceive it).

Instead, von Glasersfeld proposes a different route to knowledge. Starting with defining reality as "a black box with which we can deal remarkably well" (Glasersfeld, 2007, p. 81) he maintained that knowledge about this black box is the result of trying to find regularities in its input–output behavior. So, in RC, the construction of reality is based on the recurrent extraction of repetitive patterns from the flow of experience. It is crucial to note that these regularities are not presented in the flow of experiences as such. Rather, repetition is created by the cognitive operation of assimilation (Glasersfeld, 2001, p. 42), i.e., the act of abstracting from details. The constructive aspect of knowledge was molded into the first principle of RC: "1. Knowledge is not passively received either through the senses or by way of communication, [rather] knowledge is actively built up by the cognizing subject." (Glasersfeld, 1991a, p. 233).

It is furthermore crucial to note that our apparent success in recognizing patterns says nothing about any ontological existence of these patterns. So even "if we posit causes for the sense data […], this does in no way entail that these causes exist in the spatio-temporal or other relational structures into which we have coordinated them." (Glasersfeld, 2007, p. 82). Therefore knowledge can only fit reality, similarly to a picklock fitting a lock, rather than match reality in the sense of an iconic representation of it. The fit describes the capacity of the key rather than the property of the lock. His second principle reads thus as follows: "The function of cognition is adaptive, in the biological sense of the term, tending towards fit or viability; cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality." (Glasersfeld, 1991a, p. 233).

Influenced by the writings of Piaget, for von Glasersfeld the construction of reality includes four steps (e.g., Glasersfeld, 1982): (1) Through (tedious) repetition, the subject organizes her sensorimotor experience into operational structures, i.e., three-part action schemata, which consist of an perceptual compound, an action, and an expected result.[11] The subject retains those schemata that lead to an equilibrium in the face of perturbations. Later on, perceptual compounds are externalized as objects. (2) By including sensory material from various source, perceptual compounds become multi-modal and the externalized objects "more real." (3) As soon as the subject uses schemata to construct other schemata, she is capable of "reflective abstraction" that allows the abstraction from these organizational structures of the sensorimotor content that led to their construction in the first place. It also makes it possible to reuse organizational structures in different contexts. (4) The final level of reality is reached as soon as the subject constructs herself as experiencer among others, which adds further ways of validating schemata, i.e., agreement and confirmation by others.

The continuing viability of operational structures in the face of further experiences gives rise to the belief in the mind-independent "existence" of the regularities they express and, consequently, of the objects into which they are projected. Therefore knowledge about the world is and can only be knowledge about our own experiential reality rather than an ontological mind-independent reality. Reality is a network of concepts that so far have proven to be viable in the light of the experiences of the subject because they have repeatedly served as a tool for successfully surmounting problems of life or for assimilating complexes of experiences (Glasersfeld, 1997, p. 47).

[11] The last part distinguishes these action schemata from stimulus-response schemata used for example by behaviorists.

These considerations led von Glasersfeld to the formulation of what he called "radical constructivism." It is crucial to understand "radical" not as "extremist" but rather as "thoroughly consistent" so that it avoids the criticism of being self-contradictory and circular. The radical constructivist paradigm rests on four pillars (Schmidt, 1993, p. 329): skepticism (as sketched above), instrumentalism (as "truth" is replaced by "viability," i.e., the utility of theories, mental models, and ideas), Kantian philosophy, and developmental psychology (in the tradition of Jean Piaget). Von Glasersfeld himself characterized RC as an "unconventional" (some say, "unintuitive") approach to the problem of knowledge and knowing because it maintains that "knowledge, no matter how it is defined, is in the heads of persons, and that the thinking subject has no alternative but to construct what he or she knows on the basis of his or her own experience." (Glasersfeld, 1995, p. 1). Similar to Mach's position, experience constitutes the only world we consciously live in. Experience, according to von Glasersfeld, "can be sorted into many kinds, such as things, self, others, and so on. But all kinds of experience are essentially subjective, and though I may find reasons to believe that my experience may not be unlike yours, I have no way of knowing that it is the same. The experience and interpretation of language are no exception." (Glasersfeld, 1995, p. 1). It is the insight that there cannot be any exceptions that makes von Glasersfeld constructivism "radical," and so avoiding the criticism of being self-contradictory (see also next section). Importantly, this is not to say that RC is "more true" than other philosophies. To claim that something is more true than something else means to neglect a basic principles of RC, namely the self-applicability of its findings. As von Glasersfeld (1991b, p. 13) puts it, "I would be contradicting one of the basic principles of my own theory if I were to claim that the constructivist approach proved a true description of an objective state of affairs…[I]ts values will depend mainly on its usefulness in our experimental world."

Towards a Formal Interpretation of Radical Constructivism

In the early 1980s, von Glasersfeld's approach was widely popularized in Watzlawick's book *The Invented Reality* (1984). Later, a group of German communication scientists around Siegfried J. Schmidt started to propagate a new amalgamated paradigm, developed from the philosophies of von Glasersfeld, von Foerster and Maturana and Varela, under the umbrella term of "radical constructivism" (Schmidt, 1987; cf. Scholl, 2010), which ultimately confused both proponents and opponents. In Riegler (2001b), I presented a reconciliatory interpretation of RC which also avoids criticism such as biological/psychological self-refutation. The interpretation is based on four formal principles.

(P1) describes RC as an approach focusing on organizationally closed systems, i.e., systems which can be characterized as networks with hierarchically arranged components of short characteristic path lengths between them and a high clustering coefficient. (P2) defines the agnostic perspective with regard to an "external/objective" reality: whether or not the world is amorphous is left to speculation. There is no need to assume external order parameters since order arises from within the system. (P3) emphasizes the circularity of the trains of thoughts, i.e., that experiential components are linked with each other thus forming a network of relations. Trains of thoughts can be described in terms of state cycles in the network. (P4) demands that reality construction in such systems is severely constrained rather than arbitrary. The limitation arises from inherent properties of the hierarchical network.

The last principle deserves a more in-depth discussion as it, on the one hand, responds to the criticism that RC is a self-contradictory doctrine and, on the other hand, serves a main goal of this paper, i.e., to interpret Kuhn's central notions of mental sets (which characterize the normal scientist) and incommensurability (arising from the operational closure of cognitive systems) from the perspective of constructivism.

Since in the "stream of consciousness" (James, 1890) sensations and experiences are made and linked to each other over the course of time, cognition is a *historistic* process and construction complexes are historistic collections in which experiences are positively or negatively related with each other. Consequently they form a *network of hierarchical interdependencies* (Riegler, 2001b). The components of such a network become mutually dependent: removing one component may change the context of another component. In this sense they impose constraints on each other. Consider the following analogy: by car, you can reach only those points that are connected to the road network; on foot, all the points (such as mountain peaks) in between can be accessed, but only if they are within walking distance. The basic component in both cases is the means of transportation that restricts the availability of reachable destinations. Free arbitrariness is not possible since different means of transportation have different degrees of flexibility and speed. This analogy may also be applied to the notion of incommensurability, which translates to the situation in which scientists from different paradigms are located at mutually unreachable positions because they use different (cognitive) vehicles. Similarly, the construction network envisaged by RC is also necessarily non-arbitrary. It follows the canalizations that result from the mutual interdependencies among constructive elements. Once a certain path is taken relating elements to each other in a particular manner, existing constructions are used as building blocks for further constructions. In other words, the dynamics of reality construction resemble a ratchet (Riegler, 2001a): the constructions run into "canalizations" (i.e., the radical reduction of freedom in future developments) or "constructivist entrenchments" which result from the requirement of assembling and fitting experiences.

Constructivist Entrenchment

In *Structure*, Kuhn argued that normal science was puzzle solving, i.e., that it is concerned with solving tricky problems within the confines of the currently valid paradigm. It is in particular this relationship between scientists and their paradigm which is interesting from a constructivist perspective. Kuhn (1970, p. 46) wrote: "Scientists work from models acquired through education and through subsequent exposure to the literature often without quite knowing or needing to know what characteristics have given these models the status of community paradigms." And it is such continuous repetitions of a particular methodical schema that inevitably define the scientists' capability (or "mental set") for problem solving. Long before Kuhn, José Ortega y Gasset (1929) pointed out that scientists work with available methods like a machine. To achieve a wealth of results, scientist can go about in a very pragmatic-instrumentalist fashion, which makes it superfluous to have a clear concept of the meaning and the foundations of these methods. It is the way in which many average savants contribute to the progress of science as they are locked in their laboratories. Amusingly, Ortega compares their situation to that of a donkey in its whim. And Wolfgang Stegmüller (1971) ridicules this dogmatism even more. He wrote that we should feel sorry for the average scientists since they are uncritical, narrow-minded dogmatists who want to educate students in the same way. This tight link between paradigm and dogmatism was characterized by Josef Mitterer (1994) with his neologism "paradogma." For others, such as Karl Popper, Kuhn's characterization went too far and he accused him of exaggeration. He wrote that "In my view the 'normal' scientist, as Kuhn describes him, is a person one ought to be sorry for" (Popper, 1970, p. 52).

Can this dispute be solved from the constructivist perspective?

As pointed out, in RC the hierarchical networks of relational dependencies lead to entrenchment. The older a relational element (sensation, experience) is, the deeper is its embeddedness. In other words, such elements are more difficult to remove than more recently added elements. They constitute what we refer to as "habits of thought" in common language. In philosophy, Wittgenstein (1953) associated them with the fact that humans are "profoundly enmeshed in philosophical – i.e., grammatical confusions", out of which they cannot be easily pulled. In cognitive psychology they are known as "set-effects" in (logical, mathematical, etc.) problem-solving tasks (Duncker, 1945; Luchins, 1942; see below). And in psychotherapy they turn out to lay at the root of social and family problems, which need "habitual reframing": "To reframe […] means to change the conceptual and/or emotional setting or viewpoint in relation to which a situation is experienced and to place it in another frame which fits the 'facts' of the same concrete situation equally well or even better and thereby changes its entire meaning" (Watzlawick, Weakland, & Fisch, 1974, p. 95).

Levels of Constructivist Entrenchment

While both problem solving and social habits can be changed, the question arises of whether there are elements in the network of experiences which defy access and hence change?[12] Can we escape that which Paul Feyerabend addressed as stereotypical

[12] This is not to say that mentals sets *have* to be changed in an everyday context as they play a crucial role, e.g., in personal identity.

research schemata and their possible origins and enjoy the fruits of the divergent method as described in the introduction? He localized their roots in the cognitive development starting in early childhood: "From our very early days we learn to react to situations with the appropriate responses, linguistic or otherwise. The teaching procedures both shape the 'appearance', or 'phenomenon', and establish a firm connection with words, so that finally the phenomena seem to speak for themselves…" (Feyerabend, 1975, p. 72). In other words, he argued that starting from early on people (and scientists are no exception here) are subjected to an education that distinctly outlines both the way they have to view the world and the way they have to act in the world. Alternatives to these entrenchments are suppressed or referred to the realm of fantasy.

Annette Karmiloff-Smith (1992) identifies three levels in her theory of "representational redescription." The content of level E3 is consciously accessible and can be described verbally, such as the intellectual problems we find in science. E2 eludes verbal description. Here, expertise (cf. the difficulties in transferring the "knowledge" of a human expert to an expert system, Dreyfus & Dreyfus, 1988) and common sense (Varela, 1988) are located. Finally, E1 can be neither consciously accessed nor verbally described. Could our belief in the mind-independence of objects be the expression of the fact that we fail to access consciously their construction process?[13]

As pointed out above, von Foerster (2003b) defined objects as the result of sensorimotor attractors. This suggests that objects which were constructed in the network of experiences at a very early stage elude conscious access and hence the modification which we can apply to other more recent constructions such as social and intellectual entities. On Karmiloff-Smith's scale they are located on E1 and are inaccessible to the consciousness: this is commonly referred to as "childhood amnesia."[14] It is striking that once individuals start reasoning in language, they cannot reach older non-verbal (unconscious) sensorimotor sensations, as the experiment of Gabrielle Simcock and Harlene Hayne (2002) suggests. According to their findings, very young children's verbal descriptions of an event are "frozen in time, reflecting their verbal skill at the time of encoding, rather than at the time of the test." Usually we hold an outside reality responsible for the existence of "things." However, the different degrees of changeability of constructed mental complexes suggest that our belief in the existence of "things" results from constructing mutual relationships among sensations. Since this construction process eludes conscious access we are led to

[13] Von Glasersfeld admitted that we "build that world for the most part unaware, simply because we do not know how we do it" (Glasersfeld, 1984, p. 17). However, we claimed that this ignorance was quite unnecessary because "the operations by means of which we assemble our experiential world can be explored" (*ibid.*). He referred to Silvio Ceccato's notion of "consapevolezza operativa", i.e., to become aware of one's own mental operations, which can lead to different and perhaps better constructions.

[14] This notion refers to the phenomenon that we forget our experiences from our earliest childhood until the age of three or four.

assume that if humans cannot translate their preverbal (unconscious) memories into language, basic sensorimotor constructs made in that early period cannot be reasoned about and be claimed to be part of a mind-independent reality (Riegler, 2005a).

Orthogenesis of the Construction Process

The reality construction process has at least two *endogenous* properties, as discussed in the following section. It was perhaps Jean Piaget's most important contribution to psychology to show that as knowledge can only be acquired incrementally and that the individual builds on previous steps to reach the highest level of cognition, it therefore takes the shape of a hierarchical organization. Analogously, it can be claimed that the purpose of paradigms is to secure acquired scientific knowledge and to provide a base for extending developments in this knowledge, thus forming a hierarchical structure.

Herbert Simon (1969) provided a good argument for hierarchical organization being important. There are two insights to be drawn from his well-known watchmaker analogy, which shows that the hierarchical-modular way of constructing watches is superior to the non-modular way.[15]

1. As Simon (1969, p. 195) put it, "hierarchic systems will evolve far more quickly than nonhierarchical systems of comparable size." Kuhn has always emphasized that normal science is the most productive phase while in the periods of pre-science progress is small: one of the major advantages of convergent thinking as described in the introduction. Simon's argument confirms the idea that only in a system where you can firmly build on the previous insights of others can you increase your knowledge.
2. The hierarchical organization introduces a developmental direction that "is provided […] by the stability of the complex forms, once these come into existence" (Simon, 1969, p. 203). Also for Piaget there is "orthogenesis" (Piaget, 1971), a directional tendency, in epistemic development toward epistemic subject and epistemic object (as well as in biological evolution towards an ideal equilibrium between organism and environment; Kitchener, 1987).

However, Kuhn's orthogenesis introduces a burden with respect to the number of available options which makes people incapable of (experientially and conceptually) perceiving concrete and abstract entities outside the habitual context. This phenomenon

[15] His watchmakers are building clocks consisting of n parts. Each time their work is interrupted at random moments of probability p an unfinished clock falls apart. For the watchmaker who tries to assemble each watch in one go, the probability of actually finishing one is $p_1 = (1-p)^n$. However, for a watchmaker whose watch consists of stable subassemblies of k parts each, the probability of completing a watch is $p_2 = (1-p)^k$. For example, for $n = 1{,}000$ parts and probability $p = 0.01$, the second watchmaker will produce watches 3,775 times faster than his colleague.

of “mind set” or “mechanization of thoughts” was described in the psychological literature long before Kuhn used the expression. Duncker (1945), for example, claimed that our thinking is canalized (or fixed) with respect to the way we have learned to deal with things.[16] In his experiments, subjects failed to use a box filled with tacks as an unusual yet effective support for candles by emptying it and tacking it to the wall. Luchins (1942) reported that subjects easily got stuck in an initially learned action procedure of applying a certain lengthy sequence of pouring water from one jug into another to measure out specific quantities of water. They failed to notice that for new tasks a simpler procedure would have yielded the same result. While such “mental sets” clearly reduce the cognitive efforts of learning something new, they prevent new, innovate ways from being found. As with the adage which says, “It ain’t broke so don’t fix it,” their mind was set to the previously successful strategy.

In this sense, progress in terms of knowledge can be considered a trade-off between stability and acceleration, on the one hand, and becoming burdened, on the other. The long-term effects of this interplay can be seen in evolution, most notably in what happened after the “Cambrian explosion” some 600 million years ago (Gould, 1989). At that time a vast variety of new forms appeared in the animal kingdom but after a while development slowed down because the number of hierarchical interdependencies constantly increased up to the point at which no significant innovations were possible anymore.

The consequences are clear. During academic education scientists are subject to courses and seminars in which they are drilled in a certain way of solving problems. On the one hand, this consolidates paradigmatic thinking, which makes it possible to assign cognitive resources to new problems as entire branches in the search space can be pruned, thus leaving more time to concentrate on the unknown part. However, on the other hand, it disregards a (probably vast) amount of (probably better) alternatives.

In the context of Kuhnian revolutions, we can observe the same laws: each time a new discipline appears with a different set of paradigms, it has to start from scratch but is free to explore a much richer set of challenges and questions than later on when this pre-scientific phase has turned into the period of normal science with all its limiting entrenchments.

All these observations strongly suggest that the formation of scientific paradigms is an inherent property of the process of scientific knowledge construction.

Conclusion

We have seen that many notions in Kuhn’s theory can be explained in constructivist terms. Two such terms, “mental sets” (as a crucial characteristic of the normal scientist working according to a paradigm) and “incommensurability” are at the focus of

[16] This is reminiscent of Piaget’s claim that “all knowledge is tied to action and knowing an object or an event is to use it by assimilating it to an action scheme” (quoted in Glasersfeld, 1982, p. 613).

this chapter. After reviewing some exemplary cases of constructivism ranging from Mach's phenomenological constructivism to dualistic and non-dualistic versions we finally arrived at radical constructivism. One of the four defining core elements of this paradigm (i.e., that reality constructions are entrenched due to the hierarchical organization of the constructed knowledge) is of particular interest not only because it saves RC from being a self-contradictory biologism but also because it explains the advantages of paradigms and accounts for Kuhn's notion of incommensurability (being the unavoidable result of the different developmental paths which arise in entrenchment) as well as orthogenesis in Piaget's philosophy of science.

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