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DEVELOPMENTS IN THOMAS KUHN'S THEORY OF PERCEPTION OF SIMILARITY RELATIONSHIPS IN SCIENCE

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INTRODUCTION

By 2012, it would be 50 years since the first edition of Thomas S. Kuhn's provocative *magnum opus, The Structure of Scientific Revolutions,* was published. Some of the contentious views expressed in that work, such as the essential role of perception of similarity relations in the acquisition and consolidation of scientific knowledge, the notion that revolutions in science lead to incommensurability and partial communication across the revolutionary divide, the non-cumulative nature of the conceptual hiatus between the developmental stages separated by scientific revolutions etc, are still being debated by scholars. As a contribution to the debate on Kuhn's philosophy of science, this paper focuses on developments in the theory of scientific perception and cognition which Kuhn developed in deliberate opposition to logical positivism and falsificationism. Kuhn, it must be said, articulated his distinctive doctrines with the "rationality" claims of positivists and falsificationists concepts. He dissected the weaknesses of those claims, and presented a theory he hoped would liberate science from what he saw as the procrustean bed built for it by the rationalists. To contexualise Kuhn's ideas on scientific learning through perception, the paper undertakes a brief critique of selected epistemological schools of thought in the philosophy of science. It discusses Kuhn's theory on the role of perception of learned similarity relationships in the world-constituting activity of scientists. The paper investigates the development of the theory by Paul Hoyningen-Huene, Nancy Nercessian and Howard Margolis to further substantiate the claim that shared neural reprogrammable pattern-recognition processes, not adherence to explicit rules and definitions, constitute the major epistemological strategy in the scientific cognition of reality. Finally, the paper argues that, contrary to Kuhn's hyperbolic interpretation of communication difficulties across the revolutionary divide, cognitivist analysis of conceptual change and its aftermath shows that scientists can operate fluently with new theories and the old ones they replace.

Questions about the best method for arriving at scientific knowledge of the world have been posed and answered in different ways by philosophers since the time of the pre-Socratics. However, it was Immanuel Kant's *Critique of Pure Reason* that presented the first comprehensive theoretical groundwork for the possibility of such knowledge. Since then, philosophers have continued to discuss the epistemological principles and core cognitive processes that inform the kind of knowledge generated through scientific research. Furthermore, after the major revolutions in macro and micro physics inaugurated by the theory of relativity and quantum mechanics respectively, concerted efforts have been made to unravel the philosophical implications of these revolutions.[1] From these reflections, three major epistemological perspectives have crystallised which mirror the diverse interests, motivations and concerns of philosophers. The first one (not necessarily in the historical order in which they emerged) is epistemological realism. This position underscores the factual basis of all scientific knowledge and the logical contingency that this basis entails for all substantive propositions of science. Logical positivists (empiricists) and falsificationists generally espoused realism, although there are major differences between positivism and falsificationism or critical rationalism.[2]

At the opposite extreme is a strict conventionalist position that stresses the constructive role of the scientist's theory articulation, with the logical necessity which, as a consequence, is built into the resulting conceptual structure.[3] According to conventionalism, apparently real scientific differences, such as that between describing space in terms of a Euclidean and a non-Euclidean geometry, in fact reflect the acceptance of different systems of conventions for describing space. Henri Poincare suggests that both descriptions do not state the fundamental empirical properties of space. Rather, they are conventions governing the description of space whose adoption is determined by their utility in furthering the purpose of description. Hence, the question of which one out of the two descriptions is true does arise: one can no more ask whether Euclidean or non-Euclidean geometry is true than whether the metric system is true.

Operationalism, first proposed by Ernst Mach towards the end of the 19th century, seeks to avoid the central opposition between realists and conventionalists. Largely, operationalists regard theoretical propositions in science as meaningful to the extent that scientific practice includes specific operations in terms of which those propositions were given operational meaning.[4] Nothing is then to be read into any item of scientific knowledge beyond its operational meaning: in particular, scientists are not to be understood as claiming or disclaiming anything about the reality or conventionality of the state of affairs they report.

There are different versions of realism. But the core realist assumption that the world exists "out there" independently of human consciousness is widely accepted by philosophers and scientists, because it is intuitively compelling, and in accord with the object-subject dichotomy which underpins the research methods of experimental science. However, there are two recurrent difficulties associated with realism: the problem of logical underdetermination of scientific theories and the non-existence of a theory-neutral language which can be used te express observational reports in science.[5]

Conventionalism is right in drawing attention to the conventional features of scientific research, and to the crucial role accepted theories play in the gathering and interpretation of scientific data. Yet, it is difficult to explain, in strictly conventionalist terms, why, for example, contemporary physicists prefer Einstein's theory of gravitation, which is predicated on a non-Euclidean conception of space, to Newton's theory of gravity, despite the fact that the latter presumes the more "conventional" Euclidean idea of space. Appeal to "our linguistic conventions" just cannot explain why scientists generally prefer theories with greater explanatory power and precision to those with less.

Operationalism was supported by Einstein's famous operational definition of the concept of simultaneity, which demonatrates the strong nexus between theorising and actual experimental procedures in science. But it entails the view that theoretical entities are logical constructions from experience, a notion now widely held to be untenable, since it is logically necessary to distinguish between a theory and the evidence that either confirms or refutes it.[6]

THE COGNITIVE PARADIGM-SHIFT AND PROBLEMS OF THE FORMALISTS' AGENDA IN THE PHILOSOPHY OF SCIENCE

On a general note, the major Achilles' heel of these epistemological orientations towards science can be traced to the fact that most of the philosophers who proposed them did not reckon with research findings in cognitive science as a legitimate source of relevant ideas and data for tackling the multi-faceted issues and problems in the philosophy of science. Thus, they spurned the use of theories and insights from cognitive science research, especially cognitive psychology, because such theories and insights cannot be reconciled with the rationalist agenda in the philosophy of science. Nevertheless, there is no doubt that a reasonable acquaintance with cognitive science can help philosophers discuss more realistically and fruitfully problems such as the role of perception in the acquisition of scientific knowledge, objectivity, theory choice and the nature of representation and conceptual change in science.

It should be remarked that logical positivists and falsificationists enphasised logical principles in the philosophical analysis of science. They presented a relatively tidy image of science as a rational enterprise - 'rational' construed in a logic-dominated sense. This is not surprising, considering the fact that positivists and falsificationists were inspired in differing degrees by the logicist programme of Gottlob Frege and Bertrand Russell in mathematics.[7] Hence, recourse to cognitive psychology and other science studies disciplines was ruled out a priori, on the ground that their findings, though interesting, are completely irrelevant to the philosophy of science. Thomas Kuhn is one of the major philosophers of science who rejected the excessive rationalism of positivism. He made important contributions to what is sometimes referred to as the historical turn in the philosophy of science.

According to Kuhn, the positivist account of science cannot explain realistically some important features of scientific development, especially the nature of perception, representation, concept formation, consolidation and change. Therefore, he constructed an alternative image of science that pays close attention to the psychological processes of scientitic perception and cognition. The epistemological bridge he forged linking relevant information in psychology, sociology and history of science to the philosophy of science legitimises the need for epistemologists to go beyond the post-positivist preoccupation of defending a certain disciplinary division of labour among the science studies disciplines.[8] In particular, Kuhn employed research findings in experimental psychology and history of science to challenge the positivists' claim that the central problems of the philosophy of science are better handled with the tools of formal logic alone. Kuhn's major theories, from the vantage point of cognitive research, are truly remarkable and insightful, because they contain important ideas on perception, concept learning and representation which agree with findings in cognitive psychology. But paradoxically, until his very last writings, Kuhn made few references to psychology after the publication of the second edition of *The Structure of Scientific Revolutions* in 1970, at a time the cognitive sciences were starting to provide well-documented accounts of perception, learning and problem solving that are germane to his intuitive insights on these topics.[9] Nonetheless, it is a measure of the philosophical significance of Kuhn's analysis of perception of similarity and dissimilarity and how it functions during normal and revolutionary science that scholars are now exploring with renewed vigour the fecund overlapping areas between his theory and cognitive-historical research.[10]

In order to sharpen the points of disagreement between him and the positivists on the key epistemological strategy through which scientists arrive at reliable knowledge of nature, Kuhn criticised philosophers who promoted formalist and reductionist agenda under the title "unity of science."[11] Now, formalists such as Rudolf Carnap and Patrick Suppes construed a scientific theory as an uninterpreted formal system which, when perfected, is an account of the knowledge deployed by the scientific community that uses the formalism. They also posited that empirical reference enters scientific theories from an empirically definable basic vocabulary at the lower rungs of the cognitive ladder, and then connects with theoretical terms at the top through correspondence rules (somtimes called bridge laws).[12] In this connection, Carnap suggested that scientists correlate symbolic generalizations to nature in terms of correspondence rules expressible in the form of either operational definitions of scientific terms or as a set of necessary and sufficient conditions for the applicability of such terms. Carnap articulated his views within the backdrop of the concept of protocol sentences in which the contents of immediate sense perception (the so-called protocol experiences) were expressed.

Probably, some correspondence rules can be identified by a close investigation of a selected, relatively advanced, scientific community. Nevertheless, D. Hull and Philip Kitcher have underscored some of the intractable theoretical problems of using correspondence rules to carry out the reductionist program in biology, an indication that it might not work at all, or at best has a severely limited range of applicability, in other sciences as well.[13]

THE ROLE OF PERCEPTION OF SIMILARITY RELATIONSHIPS IN THE ACQUISITION OF SCIENTIFIC KNOWLEDGE

Kuhn rejected the notion of correspondence rules as the epistemological link between symbols and the phenomenal world, and argued that even if such rules were discovered by analysing the technical papers of members of a scientific specialty, they may not be sufficient in number or logical force to explain the actual correlations between symbolic formulas and experiments made routinely and unproblematically by practitioners. He proposed a theory which is concordant with, and also explains, the actual processes by which scientists unproblematically attach the lexicon and symbolic generalisations of their specialties to the phenomenal world. The basic assumption of his theory in “Second Thoughts on Paradigms” is the ‘continuum hypothesis,’ which states that the cognitive activities of scientists are extensions of the types of cognitive practices people use to solve the ordinary problems they deal with in their daily activities. The major difference between the two is that the cognitive activities of scientists are aimed at producing knowledge of a more general kind than the type generated through ordinary cognitive activities. In this connection Kuhn, extrapolating from ordinary learning situations, argues that an acquired ability to see similar patterns between apparently disparate problems in science provides a natural epistemological strategy for grasping the language-nature link which forms a key component of scientific knowledge. In the process of undergoing the requisite training in a scientific discipline, the student is exposed to exemplars, the standard examples of problems and their solutions in the community to which she would later belong, and to symbolic generalizations, which constitute an integral part of the community’s disciplinary matrix or paradigm. Without exemplars, she would not learn much of what the community knows about such key concepts as acceleration and gravitation (physics), element and compound (chemistry) and cell, chromosome and gene (biology). The exemplars enable the student to internalise the tradition-bound pattern-recognition schemas that she would use in the course of her research.

Perception, especially with instruments, is essential in this regard, because a theory in science, no matter how abstract or mathematical it might be, must make contact with the phenomenal world. In traditional empiricist theory of knowledge, expressions like “circular plane here”, “the red patch of color over there” or “sweet aroma in here” represent archetypes or paradigms for a datum. It is generally assumed that phrases like these report the experientially given or the minimum stable elements provided by our senses, and express what Bertrand Russell called knowledge by acquaintance. Now, anytime a scientist consciously processes data in order to identify an object, discover a regularity or invent a theory, she must have recourse to several sensations of this kind or compounds of them.[14] Yet, on closer inspection, it is stimuli that connect directly with her sense organs, although she has access to them indirectly through a scientific theory. A complex network of information processing by the nervous system occurs between the receipt of a stimulus and the sensory response which constitutes a sense-datum.[15] Researches in cognitive psychology have demonstrated that the emergence of data from stimuli is not entirely innate, since data are shared responses to stimuli within the membership of a relatively homogenous linguistic, educational or scientific community.[16] Kuhn insists that although knowledge which might be embedded in generalizations and rules form part of the epistemic repertoire of scientists, its role is subordinate to the data processing mechanism based on learned perception of similarity. His strategy here is a deliberate attempt to undermine Karl Popper's argument that "...while the logic of discovery has little to learn from the psychology of research, the latter has much to learn from the former."[17] Popper's antipathy towards any appeal to what he called "spurious sciences" in resolving challenging issues in the philosophy of science is well known. However, cognitive psychology has developed powerful theories and rigorous methods of investigation, and the results produced with their help, if taken into account by philosophers in their analysis of science, will enrich the philosophy of science .

Kuhn employed the gestalt-switch metaphor culled from gestalt psychology to highlight salient holistic features of perceptual experience.[18] Gestalt psychologists generally investigate systematically the psychological processes that determine how stimuli are grouped together during perception, and thus, how a visual field is structured or interpreted in a certain way by the percipient.[19] Kuhn applied some of the insights revealed by Jean Piaget's classic laboratory experiments on how children interpreted motion in his analysis of how a child learns to differentiate various kinds of birds in perceptual space through a means of processing data into similarity sets or categories which does not depend on a prior answer to the question: similar with respect to what?[20] The fundamental idea which emerges from the discussion is that in learning to group geese, ducks, and swans into sets or classes, part of the neural mechanism by which the learner (a child named Johnny, on a walk with his father) processes visual stimuli is intuitively reprogrammed so that features relevant to the learning process such as the length and curvature of the swan's neck are highlighted while irrelevant ones like colour and size are suppressed or dampened. At the end of the learning process, Johnny has mastered the ability to group hitherto undifferentiated objects, - in this instance birds that had previously all looked alike (and also different) - into discrete clusters in perceptual space. Johnny's father has successfully taught his son how to attach symbolic labels to different waterfowls unequivocally and without much intellectual effort, that is, without recourse to definitions or correspondence rules. Johnny, after his learning experience can, just like his father, confidently apply a learned non-definitional perception of similarity and difference in readily identifiable physical features of a collection of waterfowls to recognize geese, ducks and swans and to differentiate between them also.

On the strength of Kuhn's admittedly simplified illustration summarised above, one can infer that, for the science student, the exemplars in his discipline embody solutions to problems that members of the scientific community to which he would later belong have resolved. Familiarising himself with those problems is part of the socialization process by which he is equipped to practice within that community. Therefore:

> Assimilating solutions to such problems as the inclined plane and the conical pendulum is part of learning what Newtonian physics is. Only after a number of such problems have been assimilated can a student or professional proceed to identify other Newtonian problems for himself. That assimilation of examples is, furthermore, part of what enables him to isolate the forces, masses, and constraints within a new problem and to write down the formalism suitable for its solution….Shared examples have essential cognitive functions prior to a specification of criteria with respect to which they are exemplary.[21]

Michael Polanyi (Polanyi, argues in the same direction as Kuhn. He asserts that scientific practice is dependent on the skill of the scientist which was acquired in the course of professional training.[22] It is through the exercise of his skill or tacit knowledge, which cannot be specified in explicit rules, that he achieves success in research.

Kuhn made explicit reference to Ludwig Wittgenstein's ideas on language learning and use to debunk the positivist notion that words denoting collections of objects should have clearly defined boundaries or range of application. This is important for Kuhn, because his theory of the language-nature link in science demands that kind-words should have fuzzy or plastic boundaries in order to accommodate novel data more naturally, thereby making it unnecessary to redefine the boundaries of these words every time scientists encounter such data. Wittgenstein, you would recall, drew attention to different uses of linguistic expressions of all kinds, and rejected his earlier theory that language pictures the world.[23] He described how words like "chair" or "game" are routinely applied effectively without provoking argument. According to the pictorial theory, for anyone to know what the word 'game' (or any other kind-word) means, the person must grasp some set of characteristics common to all games only. Perhaps, discussion of some attributes shared by a number of games may help someone learn how to correctly apply the word 'game' in concrete cases. However, there is no definite set of characteristics which all games have in common. Therefore, Wittgenstein claimed that 'games', 'chairs', etc, denote natural families, each made up of a network of overlapping crisscross family resemblances. Kuhn endorsed this claim, and went further to explain that It is only the absence of natural families, that is, if groups of objects gradually merged into one another, that the need to specify completely the class-defining characteristics of a collection in advance becomes important for learning how to apply a kind-word correctly.

THE NATURE OF PERCEPTION, REPRESENTATION AND CONCEPTUAL CHANGE IN SCIENCE: A COGNITIVIST APPROACH

Our discussion in the previous section highlights some of the salient points in the perception-based cognitive road-map explored by Kuhn. In the present section, we shall focus on how some scholars, standing on the platform of that road-map, have deepened, using the cognitivist paradigm, our understanding of Kuhn's views on perception, representation and conceptual change in science. Incidently, by so doing, we reenforce the growing awareness among philosophers sympathetic to interdisciplinary approaches that, although some degree of intellectual division of labour is needed in the investigation of science, better insights into how to resolve some of the traditional problems in the philosophy of science would be fostered if philosophers enlist the assistance of cognitive science in articulating their epistemological positions.[24]

In his thorough dissection of Kuhn's major works, Paul Hoyningen-Huene establishes two related notions of concept-learning without laws or theories identified by Kuhn.[25] In the first case, it is perception that grounds the cont act with the phenomenal world, which implies that to encounter the world is to see it. Clearly, the scientist's perception of reality is structured by a process in which the scientific community she belongs to plays a significant role. This is due to the fact that the learned reprogrammable similarity and dissimilarity relations which characterise that very community's epistemic repertoire are, to some extent, constitutive of perception. Also, they are reflected in the matrix of empirical concepts of the group. In the second case, connection with the world is mediated through language: to know the world is to capture it linguistically. Hoyningen-Huene maintains that, so long as the linguistic community is the proprietary subject of its lexicon, the scientist is linked to the world only as a member of that community. Perception, though still important, plays a subsidiary role here: it helps the individual scientist to achieve that mode of connection with the aspect of reality dictated by members of her linguistic community. The major difference between the two cases is this: the first conception stresses particular organisation of perceptual space through the intuitive production of similarity and dissimilarity by accentuating and dampenning features of objects in perceptual space. In the second, the emphasis shifts to the discovery of specific features of objects which make it possible for members of a scientific community to routinely apply concepts by identifying their referents and nonreferents.

Kuhn's increasing concern in his post-1969 writings with the lexicon of science marks simultaneously a deepening of his problems and shift of focus from the gestalt-switch metaphor which appropriately applies to a scientist, to a more general concern with the taxonomy or lexical structure shared by members of a scientific community. By so doing, he underscores the variability in the criteria for identifying the referents and nonreferents of an empirical concept, despite the fact that members of the same scientific community use the concept in the same way.[26] (Kuhn, 1997) The variability in question rarely shows up in the normal course of research, since researchers in the same field ascribe objects to, and exclude objects from, the extensions of empirical concepts in the same way. However:

> The difference becomes both apparent and important when criteria for identifying referents and nonreferents that heretofore produced the same identifications begin, in response to new phenomena, to produce divergent results. At this point, the group may begin to talk at cross purposes, if all speakers no longer match the same words with the same extensions.[27]

Accordingly, an empirical concept learned through perception of immediate similarity relations and applicable unequivocally to the research world of the scientist must have determinate meaning. According to Hoyningen-Huene, Kuhn applied a pragmatic condition or criterion to the adequacy of a concept of meaning in science: a scientist has mastered the meaning of an empirical concept if she can use the concept correctly vis-a-vis the scientific community of which she is a member. He then concludes:

> In Kuhn's work even the execution of a general analysis of the constitution of phenomenal worlds is necessarily and fundamentally moulded by the phenomenal world of the analyst. For this analysis demands a host of assumptions plausible only relative to the analyst's phenomenal world, because they refer to objects in this phenomenal world. Most of these assumptions are of the anthropological variety. Kuhn assumes a certain learning capacity on the part of humans, allowing them to undergo a process of instruction which significantly influences their conception of reality.[28]

In the sciences, especially those areas which are highly mathematical, only a limited range of scientific concepts can be picked out individually or costitute contrast sets. Instead, most of them, such as entropy and gravitational field, denote entities and processes learned by grasping concrete problem-situations to which a given law applies and in which an interlocking network of concepts are employed. Nancy Nercessian's exploration of the significant parallels between Kuhn's theory of scientific knowledge, perception and learning, on one hand, and research findings in cognitive science, on the other, clarifies some of the epistemological concerns generated by conceptual changes in the sciences which Kuhn emphasised in *The Structure*.[29] She focused on the problems of conceptual change from three interrelated perspectives, namely, the nature of the representation of a conceptual structure, the processes of learning a conceptual structure and the processes of creating new conceptual structure. On the issue of concept representation, Kuhn had argued that scientists learn paradigms largely by thoroughly exploring and exploiting the problem-solving potentials embedded in the exemplary problems of their specialties during normal science. Nercessian, taking Kuhn's argument further, explains that people (including scientists) mostly do not represent concepts by means of sets of necessary and sufficient conditions.[30] Rather, they do so for both natural and artificial objects by prototypical examples. It follows that category memberhip is a function of similarity and dissimilarity to the features of the prototype. Moreover, concepts have a graded structure; some instances of a given concept are better examples of the original concept. The instances also exhibit different degrees of dissmilarities to instances of other concepts to which the object could otherwise mistakenly have been assigned. Kuhn's favourite example of ducks, geese and swans discussed earlier is appropriate here. Swans may be erroneously classified as geese; yet instances of the category 'swan' are more similar to instances of the category 'goose' than they are to instances of the category 'dog'.

Kuhn deals with the problem of perception and concept representation by claiming that the phenomenal world to which the naming procedure of science is applicable must contain "natural families," that is, non-intersecting sets of entities. Additionally, it must allow for empty spaces between the families to be differentiated after neural processing by the percipient. During normal science, the world-constitutive activity made possible by the accepted paradigm proceeds incrementally and cumulatively, and existing perceptual patterns and their associated cues become increasingly entrenched. At some point which cannot be logically specified in advance for all concrete or conceivable cases, stubborn anomalies threaten the incremental progress characteristic of normal science, and therewith the entrenched patterns and cues. Consequently, scientific revolutions invariably occasion changes in the existing world-constituutive relations which "...are both learned through and constitutive of perceptual experience. When the representations through which we understand the world change, the world-constitutive similarities and differences that are the focal points of learning and problem solving change."[31] Kuhn's change of focus from perception to the lexicon of science which we alluded to earlier, according to Nercessian, is due mainly to two interconnected reasons: (a) his desire to explicate how scientific communities are the producers and validators of scientific knowledge and how they transmit paradigns in the course of reseaerch, and (b) because of the need for him to enlarge upon the vexed problems of incommensurability and partial communication arising from revolutions. The two reasons are connected: unravelling the nature of the linkage between perception and conceptual change is key to understanding incommensurability and, by implication, the nature of inter-theoretic communication after the occurrence of a revolution. Kuhn suggests that the lexicon of a scientific community generates variable beliefs and expectations about the aspect of nature investigated by its members, depending on particular scientist's experience and learning. However, what members of the community share in common, as Nercessian intimates, is a lexical structure, and differences in lexical structure lead to incommensurability. Different lexical structures entail different kind- relations which, in turn, constitute different realities. Typical examples include the transitions from Ptolemaic astronomy to the Copernican, the phlogiston theory to Lavoisier's oxygen theory, Lamarckism to Darwinism, and from Newtonian physics to the Einsteinian, etc.

As we have already pointed out, Kuhn holds that for conceptual change to occur, the human neural mechanism which processes stimuli must be reprogrammed when exposed to novel similarity and dissimilarity relations, and must sort perceptions into similarity classes such that they are separated in perceptual space.[32] Some research results in cognitive development have vindicated Kuhn on this issue.[33] In a nutshell, these researches establish the existence of an in-born representational system in humans through which the brain limits the way objects are individuated and trackad through time and space. In the infant, the basic process is restricted to tracking for individual objects, not kinds. As the child grows older and begins to learn the language of her community, information about features of objects necessary for kind identification begins to play a role in the learning process. The identification of individuals and of kinds relies on perception, although, naturally, the system for kind identification is built on the earlier system for identifying individuals. As Nercessian correctly observed, the cognitive framework begins with individuation and later identifies objects as kinds. Thus, there are good reasons for believing in the existence of an innate, perception-based, mechanism in humans that embodies a no-overlap principle for tracking and individuation. The mechanism provides the foundation for a more advanced system which uses highly abstract features (such as the type required in science) that enable discrimination to keep track of kinds and incorporates a no-overlap principle also. Its development is a function of language-mediated maturation and learning processes. In Kuhn's theory the notion of "kind" is such that will populate the world as well as categorise a pre-existing population. Furthermore, the advanced cognitive system should be reprogrammable in order to pick out the new kinds generated by a scientific revolution.

Our analysis of perception and concept learning and representation points to the conclusion that perception of similarities and dissimilarities in science is not purely a perceptual process. Instead, it is a larger, paradigm-determined, process of pattern recognition that involves schemas (schemata) and analogies through which scientists obtain reliable but fallible knowledge of the world.[34] A schema (schemata) is a context-dependent mental framework for organising knowledge by creating a matrix of related concepts, whereas the use of an analogy involves applying a pattern already in the repertoire to a different or novel situation. A schema resembles Kuhn's concept of disciplinary matrix or paradigm, except that in the former symbolic generalisations are not necessary, whereas in the latter they play an indispensable role in the cognitive machinery of a scientific discipline.[35]

Howard Margolis' engaging account of cognition, which has a strong Kuhnian flavour, establishes that schemas and analogies are integral to perception.[36] Margolis reduces thinking and judgment in general to pattern-recognition, and his theory emphasises the role of perception in scientific knowledge, due to the fact that pattern recognition is grounded in preception. His concept of *P*-cognition, anchored on the uphill-consolidation-downhill discovery schema, applies to sequences of orderly arrangement of the features of anything (including, of course, learned perception of similarities and dissimilarities) in a given situation, the recognition of which is prompted by cues in the context. Indeed, his general discovery schema for the appearance and spread of a radically new idea bears a striking resemblance to the normal science-crisis-extraordinary science typology developed by Kuhn, in that the uphill/consolidation phase is akin to normal science, while the downhill period approximates to crisis and extraordinary science. He explains that the uphill phase of a discovery terminates when the discoverer sees the new idea as conflicting with what he had previously taken for granted, yet somehow believable, in contrast to previous occasions on which he or others caught a glimpse of the idea seen in a way that appeared implausible or narrow or like some minor variant of a familiar notion. Consolidation begins from that point and reaches its zenith when the discoverer feels strongly that he knows that his idea is correct. Afterwards, the downhill phase commences: it consists of polishing and supplementing the arguments that might persuade others to accept the novel idea.

A creature, says Margolis, can learn a new thing by copying what someone else is doing, and can discover something new on its own. But in general, copying and discovery cannot be sharply distinguished. Both depend on drawing from patterns already stored in one's cognitive repertoire, except that in the latter situation (discovery) one uses existing patterns in a new context that, (perhaps only fleetingly, by fruitful misperception) looks like a familiar pattern. This mode of acquiring knowledge is complemented with routinized learning, which is dominated by following a stereotype, as is the case during normal science, and training, through which a person is prompted to different kinds of behaviour such that what is produced eventually is a more elaborate pattern (or set of patterns) than one would have managed if presented with the whole thing at once. Both humans and animals share this form of knowledge. The distinctively human element in the process is learning that involves consciously trying to learn, which provides the psychological foundation for scientific knowledge. Evolution appears to favour more efficient, reliable, automatic systems to locate, choose and sequence whatever patterns that have been stored in the repertoire previously.[38] Margolis' reasoning about cognition in general, if interpreted specifically within the backdrop of Kuhn's theory, implies that scientists imbibe and exploit, during research, intricate mathematically-structured networks of priming and inhibiting relations among cues and patterns. Hence, a scientific revolution will occasion turbulence in, and disruption of, entrenched priming and inhibitory networks.

Margolis used his *P*-cognition theory to reanalyse and reinterpret Tychonic and Copernican systems, and the transition from Ptolemaic astronomy to Copernican astronomy. He explains that the transition from an entrenched way of seeing the world (Aristotelian or Ptolemaic) to a new way of seeing (Copernican) is an interaction among social (not atomistic) individuals who talk to one another, and among whom the new pattern recognition matrix has emerged as something people are interested in discussing. The puzzle here for Margolis, re-echoing Kuhn, is to see how, within a community of people with comparable educational qualifications, and all sharing basic cognitive processes common to the species, some see things in a new way that ultimately proves to be compellingly superior to the old view, and others could not see things that way. Kuhn claims that reception of a "new way of seeing" depends on how deeply entrenched existing mode of seeing is in the mind of the scientist – the more deeply entrenched the more difficult it is for the scientist to come to terms with the novel way of seeing. Margolis agrees, but went beyond Kuhn by suggesting that a scientist can comfortably apply different theories (Newton's and Einstein's say), in response to the research problems she is dealing with. He explains, in this regard, that:

> Such switches ...reflect essentially the same fluency-enhancing/inhibiting of competing patterns and priming of complementary patterns that occur with more routine activities like comprehending ordinary language. In science, after a Kuhnian paradigm shift – but not during the transition for that individual – someone who has come to see things in a new way will be fluently capable of talking the language of the old view... .[39]

The major insight that emerges from Margolis' analysis of cognition, especially as it relates to the role of perception in the acquisition of scientific knowledge, is that perception, like thinking in general, is based on the a-logical, a-rational, processes of pattern recognition through which scientists systematically learn important things about the phenomenal world by adapting and tuning patterns they already know to new situations. As a result, Margolis rejects the algorithmic model of human cognition, because it just cannot explain satisfactorily the basic elements of concept formation, representation and learning which are central to a well-grounded philosophy of science.

IMPLICATIONS IN UNDERSTANDING THE NATURE OF SCIENTIFIC KNOWLEDGE

It should be clear by now that Kuhn captured an essential but hitherto neglected feature of the knowledge-acquisition process vouchsafed by scientific research. It is even more remarkable that, against the "received wisdom" in the philosophy of science, he maintained, among other things, that there is a mechanism for processing perceptual data which does not depend on explicit rules and definitions. Therefore, Kuhn's theory is a challenging alternative to the strong rationalist programme in the philosophy of science, and makes a good case for interdisciplinary approach in tackling major problems in the subject.

As already indicated, correspondence rules are rare in scientific literature. Thus, even after discussing with scientists, it will be hard to discover any set of rules that guide specific traditions of research. The difficulty is akin to the sort of problems someone would encounter if asked to state or define what all games or planets have in common, for example. It is not that some "rules of the game of empirical science", as Popper described the type of methodological prescriptions he proposed, cannot be abstracted from close examination of selected traditions of scientific research. The point is that working scientists do not rely on definitions and rules, because the heuristic power of theories (paradigms or disciplinary matrices) and skills already acquired from professional training and practice provide adequate guidance for research. Moreover, the nature of education in the sciences is such that practitioners learn concepts, laws and theories ‘‘from a historically and pedagogically prior unit that displays them with and through their applications.’’[40]

An aaccepted scientific theory is always presented and explained with concrete applications to a selected range of natural phenomena which are documented in science textbooks and technical journals. Thus, when a student learns a theory in her field, the process necessarily involves the study of its applications, including exercises in problem-solving both with pencil and paper or with equipment in the laboratory, as the case may be. In this way, she acquires the skills she will need for effective research. Now, the fact that scientific research can be done without any set of fully articulated methodological rules, that scientists rely more on disciplinary matrices germane to their fields than on algorithms of research, may help explain why, according to Kuhn, all the branches of science seen together as a whole resemble a ramshackle edifice with little coherence among its various parts.[41] More specifically, a broad section of the scientific community may share explicit rules when such rules are available, but not models and exemplars. An extended remark from Kuhn is apposite in this regard:

> An investigator who hoped to learn something about what scientists took the atomic theory to be asked a distinguished physicist and an eminent chemist whether a single atom of helium was or was not a molecule. Both answered without hesitation. But their answers were not the same. For the chemist, the atom of helium was a molecule because it behaved like one with respect to the kinetic theory of gases. For the physicist, on the other hand, the helium atom was not a molecule because it displayed no molecular spectrum. Presumably both men were talking of the same particle, but they were viewing it through their own research training and practice. Their experience in problem-solving told them what a molecule must be. Undoubtedly their experiences had had much in common, but they did not, in this case, tell the two specialists the same thing.[42]

Perception of similarity relationships made possible by scientific education and consolidated during professional practice is a key cognitive process that reinforces the tradition-bound social nature of science. Furthermore, cognitive skills acquired from studying exemplary problems and problem-solutions of science become increasingly entrenched as students learn laws and formulas, and how to recognize which law fits which problem, by studying exemplars. It is through this process that students absorb the cognitive achievements of their fields.

Kuhn has been criticized for positing a theory of science with unacceptable relativistic undertones, based on his critique of the traditional concept of objectivity in science.[43] However, his major ideas, particularly the theory of group-licensed perception of similarity which allows members of a scientific community to reach a consensus on a number of basic ontological commitments as well as on the methods by which research activities and their results will be judged has, in the words of Barry Barnes "...played a major part in clearing the path for more promising lines of thought" in the philosophy of science."[44] Science has become so professionalised, according to Kuhn, that members of a given scientific community provide the only audience and judge of the knowledge-claims within that community. Mature science is an esoteric, isolated, and largely self-contained enterprise for specialists. For Popper, Paul Feyerabend and other philosophers who dislike it, increasing specialisation is a danger to science. That may be true, especially if it leads to a preponderance of narrow-minded scientism among scientists. Nevertheless, specialisation is the price we have to pay for the cognitive power arising from detailed systematic investigation of the phenomenal world grounded on the cognitive efficacy of perception of similarity relationships between problems and standard exemplars in different scientific communities.

It is clear that scientists have access to the phenomenal world through the theory or paradigm that guides their research. The paradigm produces entrenched networks of cues and patterns in the form of similarity and dissimilarity relations embedded in the cognitive repertoire of members of the scientific community. Hence, Kuhn's problem of incommensurability as an aftermath of scientific revolutions centres on the entrenched similarity/dissimilarity relations, and can be usefully reformulated as the question of how a scientist gets from knowing P to an altered cognitive state of knowing P and Q which conflict in some areas, "in the sense of being able to use them in the way that people who know how to use them do use them."[45] Kuhn, in his analysis of revolutions as changes of worldview, underscored the problem of translating the lexicon of an existing theory into the lexicon of a new theory. But he overstates the difficulty by not taking into consideration the fact that contemporary physicists conduct research using Einstein's relativity theory and still routinely apply Newtonian physics whenever it is necessary to do so. Such a physicist sees a Newtonian problem as just a Newtonian problem, not as a special case of Einsteinian situation which might create unnecessary complications for solving non-relativistic problems. In general, scientists can work with two inconsistent theories quite comfortably: a scientist who now perceives the world differently through the lens of a new theory will be capable of operating fluently with the lexicon of the old theory which she had already absorbed previously, especially when it is convenient for expository or polemical purposes, just like the speaker of two different natural languages. This ability is based on the subliminal fluency-enhancing inhibition of competing patterns and priming of complementary patterns similar to what happens when a bilinguist effortlessly switches from one language to the next.[46]

CONCLUSION

Kuhn provided a general characterisation of the constitution of the phenomenal world investigated by scientists in his analysis of the dynamic processes through which individual members of a given scientific community gain access to the phenomenal world. Unlike hard-core rationalists, Kuhn explored the complex interactions of language, perception, education and subjective factors in the acquisition of scientific knowledge. In his account, the network of perceived similarity and dissimilarity relations serves as the foundation for organising the phenomenal world and the language used in describing that very world. Kuhn argues that different scientists may identify the referents of terms in different ways: what they have in common, if communication is to succeed, is not the criteria by which members of a category are identified but rather the pattern of similarity/difference relations, or shared taxonomic structure, which those criteria provide. The pattern binds them together cognitively as researchers in the same field, and it does not require that scientists give the same answer to the question: similar with respect to what?

Although it can be argued that very little modern science involves sense perception of evidence, this is only true if we exclude perception carried out with instruments. In highly advanced sciences such as physics, chemistry and astronomy, most theories are formulated mathematically. But because scientists aim to invent theories that explain the phenomenal world, they apply group-licensed cognitive tools to deduce empirically decidable consequences from accepted theories. The extremely challenging task of deriving testable consequences from scientific theories has been admirably discussed by Kuhn.[47] Suffice it to say that the effort to match theory with experimental findings provides an important entry point for observation and measurement with the help of sophisticated equipment, activities that necessarily involve perception.[48]

The key point that emerges from our analysis is that perception of similarity and dissimilarity relations between instances of concepts and the prototypical exemplars in a scientific communities is crucial in scientific cognition of reality. Learned perception of similarity is central to the stimuli- or data-processing mechanisms through which scientists perceive the world of their research-engagement, and it is reprogrammed whenever a revolution occurs. In his classic work, *The Structure of Scientific Revolutions*, Kuhn presents a nuanced, thought-provoking, account of scientific revolutions. In it the problematic concomitants of paradigm-shifts in science such as changes in world-view, partial communication across the revolutionary divide and the techniques of persuasion which convert the "die hards" to the new way of seeing were boldly discussed. Some of his fomulations on these topics have an unmistakable anti-realist flavour.[49] It is not surprising, therefore, that critics have labelled him a relativist, for espousing what Dudley Shapere called "the presupposition theory of meaning" and incommensurability.[50] Kuhn's observation that scientists already deeply committed to existing theory are usually reluctant to jettison it for a new one contradicts the widely-accepted notion that scientists are open-minded men and women guided by logic and evidence in their work. In view of the entrenched habits of thought rooted in group-licensed perception of similarity and conservatism of scientific research, such behavior is understandable. Because the theory-nature link forged by the older theory depended largely on primitive learned perception of similarity relationships deeply internalized in the course of professional education and successful research practice, methodological criteria such as the ones stipulated by positivists and falsificationists cannot, on their own, compel a scientist to see things from a new perspective. According to Kuhn neural reprogramming is necessary for the transition to the "new way of seeing", due to the fact that the cognitive shift from one theory to another cannot be made one step at a time, forced by logic or neutral observational experience alone. Like the gestalt switch, it must occur, for each member of the scientific community where the revolution has taken place, partly as a–logical, a-rational displacement of an existing cognitive pattern or pattern recognition schema by another. Thus, the assimilation of radical theoretical change by scientists oftentimes involves a conversion process (or what Margolis described as a contagion).

Kuhn's "linguistic turn" which stresses the role of scientific lexicon in scientific cognition of reality was an integral part of his effort to articulate a viable theory of perception in science that would attenuate the anti-realist flavour of his initial formulations in *The Structure.* Yet, he still insisted that "the ways of being-in-the-world which a lexicon provides are not candidates for true/false."[51] His initial, implausible, extreme position on incommensurability which suggests that scientists find it extremely difficult to operate fluently with two different theories is inaccurate. Admittedly, there are physicists found it difficult initially to assimilate the theory of relativity after years of successful research within the Newtonian research program. But like the language-learning process, some of their colleagues make the transition faster, and eventually most became very proficient in using both theories to solve research problem as appropriate. Kuhn wrongly extrapolated the gestalt character of paradigm-shift as experienced by a scientist to cover the entire scientific community, without making allowance for variability in the innate and learned capacity in scientists to switch from one theoretical framework to another, and for the possibility that some scientists turn out to have a deeper understanding of new theories – and , as a result, extend the range of application of the theories far beyond its initial domain - than their colleagues who invented them in the first place. At any rate, we believe that despite the uneasiness which the use of a religious metaphor such as conversion might cause in some philosophers of science, Kuhn's analysis of the puzzling features of scientific revolution and its aftermaths invites thoughtful reanalysis different from the distorted and hostile interpretations gven to it by John Watkins, Karl Popper and Imre Lakatos.[52] At any rate, on several occasions respected scientists and philosophers such as Albert Einstein and Ortega y Gasset, to mention just a few, also used religious metaphors to describe scientists` and their work – y Gasset in fact calls scientists the monks of modern times.

ENDNOTES

[1]M. Bunge, ed. (1967), *Quantum Theory and Reality*, Berlin; Springer-Verlag. See also A. Fine (1999), "The Natural Ontological Attitude," R. Boyd, P. Gasper & J. J. Trout (eds.), *The Philosophy of Science*, Cambridge Mass.: A Bradford Book, 261-278.

[2]A. J. Ayer, ed. (1959), *Logical Positivism*, New York, The Free Press; K. R. Popper (1959), *The Logic of Scientific Discovery*, London: Hutchinson; W. Newton-Smith (1981), *The Rationality of Science*, Boston: Routledge & Kegan Paul; A. I. Tauber (1997), *Science And The Quest For Reality*, London: Macmillan Press Ltd. & C. Norris, (2000), *Minding the Gap: Epistemology and Philosophy of Science in the Two Traditions*, Amherst: University of Massachusetts Press.

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[4]P. Bridgman (1999), "The Operational Character of Scientific Concepts," R. Boyd, P. Gasper & J. D. Trout (eds.), *The Philosophy of Science*, op. cit., 57-70.

[5]Kuhn, T.S. (1977), *The Essential Tension*, Chicago: The University of Chicago Press, 297-308. Also consult W. Newton-Smith (1978), "The underdetermination of theory by data," *Proceedings of the Aristotelian Society, s*upplementary vol. 52; H. M. Collins (1985), *Changing Order: Reputation and Induction in Scientific Practice*, London: Sage.

[6]S. Blackburn (2005), *Oxford Dictionary of Philosophy*, Oxford: Oxford University Press.

[7]B. deGelder (1989), "Granny, the Naked Emperor and the Second Cognitive Revolution,"*The Cognitive Turn*, S. Fuller, M. DeMey, T. Shinn & S. Woolgar (eds.), Dordrecht: Kluwer.

[8]*The Essential Tension*, op. cit., 266-292.

[9]N. Nercessian (2003), "Kuhn, Conceptual Change and Cognitive Science," T. Nickles (ed.), *Thomas Kuhn*, Cambridge: Cambridge University Press, 178-203.

[10]H. Andersen, X. Chen & P. Barker (1996), "Kuhn's Mature Philosophy of Science and Cognitive Psychology," *Philosophical Psychology*, vol. 9, 347-363; H. Andersen & N. Nercessian (2000), "Normic Concepts, Frames and Conceptual Change," *Philosophy of Science*, vol. 67, 224-241: H. Margolis (1987), *Patterns, Thinking, and Cognition :A Theory of Judgment*, Chicago; The University of Chicago Press. The papers in Fuller, S., M. DeMey, T. Shinn, & S. Woolgar, eds., (already cited) also dealt with similar themes.

[11]T. Kuhn (1997), "The Road Since Structure," A. I. Tauber, (ed.), *Science And the Quest For Reality*, Hampshire: Macmillan, 231-248.

[12]R. Carnap (1936 & 1937), "Testability and Meaning," *Philosophy of Science,* vols. 3 & 4.

[13]D. Hull (1973), "Reduction in genetics: doing the impossible," P. Suppes (ed.), *Logic, Methodology and Philosophy of Science, vol. 4.*

[14]Kuhn, T.S. (1977), *The Essential Tension*, 308.

[15]R. L. Gregory (1966), *Eye and Brain*, New York: McGraw Hill Book, Co.; D. M. MacKay (1991), *Behind the Eye*, Oxford: Basil Blackwell.

[16]R. J. Sternberg, R.J. (2003), *Cognitive Psychology*, Australia: Thomson. See also H. A. Gleitman, J. Fridlund, & D. Reisberg (2004), *Psychology*, New York: W. W. Norton & Co.

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[19]G. H. Bower & E. R. Hilgard, (1986), *Theories of Learning*, New Delhi: Prentice-Hall.

[20]Kuhn, *The Essential Tension*, op. cit., 172-173.

[21]Ibid., 131.

[22]M. Polanyi (1964), *Personal Knowledge: Towards a Post-Critical Philosophy*, New York: Harper & Row Publishers, 49-65.

[23]L. Wittgenstein (1968), *Philosophical Investigations,* G.E.M. Anscombe (trans.), Oxford: Basil Blackwell.

[24]See R. N. Giere ed. (1992), *Cognitive Models of Science: Minnesota Studies in the Philosophy of Science*, Minneapolis: University of Minnesota Press, vol. 15. L. Magnani, N. J. Nercessian, & P. Thagard, eds. (1999), *Model-Based Reasoning in Scientific Discovery*, New York: Kluwer/Plenum.

[25]P. Hoyningen-Huene (1993), Re*constructing Scientific Revolutions*, Chicago : University of Chicago Press.

[26]T. S. Kuhn (1990), "Dubbing and Redubbing: The Vulnerability of Rigid Designation," C. W. Savage (ed.), *Minnesota Studies in the Philosophy of Science*, Minnesota: University of Minnesota Press. He reiterated the shift in focus in "The Road Since Structure" (already cited).

[27]Hoyningen-Huene, Re*constructing Scientific Revolutions*, op. cit., 103.

[28]Ibid., 123-124.

[29]N. Nercessian (2003), "Kuhn, Conceptual Change and Cognitive Science" (already cited). See also X. Chen, H. Andersen, & P. Barker (1998), "Kuhn's Theory of Scientific Revolutionsand Cognitive Psychology," *Philosophical Psychology*, vol. 11, 5-28.

[30]See H. Andersen & N. Nercessian (2000), "Normic Concepts, Frames and Conceptual Change" cited above.

[31]Nercessian, "Kuhn, Conceptual Change and Cognitive Science, op. cit., 184.

[32]T. S. Kuhn (1970), *The Structure of Scientific Revolutions* (2nd ed.), Chicago: Chicago University Press

[33]E. S. Spelke, A. Philips & A. L. Woodward (1995), "Spatio-Temporal Continuity, Smoothness of Motion and Object Identity in Infancy," *British Journal of Developmental Psychology*, vol. 13.

[34]See F. C. Bartlett, *Remembering: A Study in Experimental and Social Psychology*, Cambridge, Eng.: Cambridge University Press; M. Hesse (1966) *Models and Analogies in Science*, Notre Dame: University of Notre Dame Press; D. Rumelhart (1981), *Schemata*, New Jersey: Erlbaum Associates; Thorndyke, P.W. (1984) "Applications of schema theory to cognitive research," Anderson, J.R. & Kosslyn ,S.M. (eds.), *Tutorials in Learning and Memory*, San Francisco: Freeman; Brewer, W F. (1999), The MIT Encyclopedia of the Cognitive Sciences, R A. Wilson & F.C Keil (eds.), Cambridge, MA: MIT Press.

[35]M. Masterman (1970), "The Nature of a Paradigm," *Criticism and the Growth of Knowledge* (already cited).

[36]Margolis, *Patterns, Thinking, and Cognition*, op. cit., 113-114.

[37]Ibid., 172-173.

[38]Ibid., p. 125. See, in addition, H. Plotkin (1994), *Darwinian Machines and the Nature of Knowledge*, London: Penguin Books.

[39]Ibid., 127.

[40]Kuhn, *The Structure of Scientific Revolutions*, op. cit., 46.

[41]Ibid., 49.

[42]Ibid., 50-51.

[43]For detailed analysis consult Lakatos & Musgrave, *Criticism and the Growth of Knowledge (*already cited); G. Gutting ed., (1980), *Paradigms and Revolutions*, Notre Dame, Indiana: University of Notre Dame Press; T. R. Machan (2004), *Objectivity: Recovering Determinate Reality in Philosophy*, *Science and Everyday Life*, Aldershot, Hampshire: Ashgate Publishing Ltd.

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[45]Margolis, *Patterns, Thinking, and Cognition :A Theory of Judgment*, op. cit., 126.

[46]Hull, “Reduction in genetics: doing the impossible,” (already cited).

[47]Kuhn, *The Essential Tension*, op. cit., 111-135.

[48]I. Hacking (1994), Representing and Intervening, Cambridge: Cambridge University Press.

[49]Kuhn, *The Structure of Scientific Revolutions*, op. cit.,111-135.

[50]Shapere, D. (1992), “Meaning and Scientific Change,” I. Hacking (ed.), *Scientific Revolutions*, Oxford: Oxford University Press, 37.

[51]Kuhn, “The Road since Structure,” op. cit., 244.

[52]*Criticism and the Growth of Knowledge* (already cited), is a comprehensive discussion of the leading theories of Thomas Kuhn. It is the fourth volume of the Proceedings of the 1965 International Colloquium in the Philosophy of Science held at Bedford College, Regent’s Park, London, from 11 to 17 July 1965. The book contains, apart from Margaret Masterman’s paper,

critical articles on Kuhn's philosophy of science, and his replies to the criticisms. Of course, Kuhn has modified some of earlier views on the various issues raised in the work.

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