**`'EUREKA!'**

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**Philip McNamee** assesses the current state of insightful problem solving research in psychology and looks to control theory as an approach that offers a new explanation.

**Despite the phenomenon of insight being investigated since Archimedes ran through the streets of Syracuse naked screaming 'Eureka!' psychology still lacks a consensus as to how it happens and why. Perceptual Control Theory is a new scientific development that sees insight as the product of 'reorganisation'. Not unlike the ideas put forward by the Gestaltists of the early 20th Century, could reorganisation and PCT offer a unitary framework for the current explanations of insight…**

"The Eureka Moment" origins are most famously attributed to the Greek philosopher Archimedes, who suddenly gained the solution to a particularly taxing problem (how to ascertain how much gold was in the unusually shaped crown of the King) when he submerged himself in a bath of water and realised that the volume of water displaced was equal to the submerged volume of his body (Shanker, 1995). There was such a sudden 'flash of insight' that he was said to have ran through the streets of Syracuse naked proclaiming "heure 'ka heure 'ka"!" (Greek for 'I Have found it'). The idea of sudden insight has been part of anecdotes explaining major findings throughout scientific history including Newton's discovery of gravitational law (Sandkuhler & Bhattacharya, 2008) and Kekulé's discovery of the ring structure of benzene (Rothenburg, 1995) and although the veracity of such stories is questionable, the experience of sudden insight, the 'aha! moment' of suddenly and unpredictably becoming aware of the solution to a taxing problem is common to us all (Sandkuhler et al, 2008). But despite insight gaining much attention in the history of psychological research, the underlying mechanisms of such a process remain mysterious (Bowden, Jung-Beeman, Fleck & Kounios, 2005) and no current explanation seems to be able to explain it completely.

This article sets out to assess the current state of research into insight, and see how historically the 'eureka experience' has been investigated and explained. The essay will then look to control theory as a way of explaining 'the eureka moment', namely Perceptual Control Theory (PCT), which makes some novel predictions about the mysterious processes of insight.

Insight was first brought to the attention of psychology by the Gestalt school in the early twentieth century. Wolfgang Köhler (1887-1967) was the main contributor to the domain of problem solving within Gestalt circles. He was particularly interested in sudden restructurings of knowledge and used chimpanzees as his test subjects to see the solution process in action. In his classic experiments Köhler (1925) placed bananas out of reach of the chimps, either outside their cage or hung up on a wire above their heads, and waited for them to use the objects placed around them, sticks and boxes, in a novel way to reach the treat. The chimpanzees displayed repeated but unsuccessful attempts to reach the banana until an observable change occurred, and the ape was able to use the tool successfully to obtain the banana (Dominowski & Dallob, 1995). This sudden change in behaviour was concluded to be a moment of 'insight'. Linked to the Gestalt theory of perception, Köhler believed that insight occurred when the chimps visualized the problem mentally in a new way, restructured the problem elements as a whole and came up with a sudden and un expected "complete method of solution", that was not produced from prior experience (Köhler, 1925, p 217). Restructuring became the key to insightful problem-solving, a process in which the solver must ignore their original perceptions and see the requirements of the problem in a new way (Ohlsson, 1984). It was argued that the problem situation exists as an organized whole structure, rather than a collection of connected parts, and restructuring causes this representation to be viewed in a new light. However Köhler (1925) was explicit that insight was only a product of problem solving and could therefore could not explain how it worked.

This idea of restructuring, although considered, was never incorporated into mainstream cognitive theories of problem solving when they started to emerge in the 1970's.

*Searching* for solutions, in an information processing system was seen as the key to successful problem solving (Newell & Simon, 1972). The inability to objectively measure concepts like the restructuring process, or the fixation one has on a certain problem representation (Dominowski, 1981; Durso, Rea & Dayton, 1984) were seen as reasons why these phenomena had to be ignored. It was only much later in the development of cognitive psychology that researchers and theorists began to come back to the original ideas of the Gestaltists (Luo & Knoblich, 2007).

There still remain opposing accounts in the research field as to how insight works. Some researchers argue that insight constitutes its own, unique mechanism of problem solving, whereas others argue that it uses the same processes as all other types of problem solving but is perceived as different due to a high level of emotional intensity (i.e. it is epiphenomenal (Jung-Beeman, Bowden, Haberman et al, 2004)). Although there are many variations and theories within this, these two views account for the majority of insight explanations. However all these theories are based on evidence that many argue is fundamentally flawed. Insight research is synonymous with methodological weaknesses and low test validity. The actual 'insight problems' themselves are perhaps the most criticised aspect stemming from the fact that there is no classification system (Weisberg, 1995). Dominowski and Dallob (1995) argued that it is not enough to allow insight problems to be defined as those solved by insight, because there is a tendency to be trapped in an argument of circularity. Insight problems are those solved by insight, and insight is apparent from the reaction to insight problems. Insight problems often vary so much between studies that it becomes difficult to compare findings, meaning evidence cannot be generalised (Weisberg, 1995).

The most recent and contemporary approach to insight research has been the use of neuroimaging methods. There has been a popular move from behavioural methods to the more applied use of neuroscientific tools, such as fMRI and EEg (Kounios & Beeman, 2009), to investigate which brain areas are implicated in gaining that sudden realisation. Despite the advances in technology and the broad consensus that the right hemisphere plays a significant role in insight (Kounios, Fleck, Green et al, 2008), the literature is yet to define what insight actually is, and what the reasons are it is accompanied by such a thrilling comprehension. Cognitive neuroscientists have argued that the representation of the correct solution is activated at a subconscious level and the 'eureka moment' is a product of conscious retrieval (Kounios et al, 2008).

Yet research is still to explain why this is. Why is the solution kept in the subconscious, what would be the advantage or rationale for such a process? Additionally neuroimaging studies are plagued by the same methodological flaws their behavioural measure counterparts had before them. Using such methods divorces the neural process from the intrinsically linked subjective feelings that always accompany insightful solving (Metcalfe & Wiebe, 1987). There still exists an ongoing debate on the underlying mechanisms associated with insight; one school argues restructuring is conscious and controlled with the other arguing it is an automatic and subconscious process (Sandkuhler & Bhattacharya, 2008).

What seems to be lacking therefore is a universal, and agreed upon definition of what insight is, along with a parsimonious explanation of the 'aha!' moment. What is needed is a new perspective that can take the consensus findings we currently have, such as the phenomenological experience associated with insight (Sternberg & Davidson, 1995), the inability to predict when insight will be used (Metcalfe & Wiebe, 1987) and the role of the unconscious (Bowden & Jung-Beeman, 2003), and find a theory that can explain all aspects of the elusive 'eureka moment'.

Perceptual Control Theory (PCT; Powers, 1973) is a self-regulatory model that does just that. Although relatively unknown in mainstream psychology, PCT has been developing since the 1960's. It is a theory of purpose, based on the idea that behaviour is a means to an end, a contextually modifiable output that is adapted in response to our perceptual inputs. PCT states that all behaviour is the product of an organised and ordered set of control systems, and tries to harmonize the seemingly dichotomous ideas of the mechanistic nature of behaviour and inner subjective purposes and goals (Powers, 1973). As people, we set goals and try to achieve these goals through a process of *control*. We are not mere stimulus-response creatures, subject to environmental forces (Cziko, 2000) rather our actions and purposes affect the environment around us, which in turn affects our behaviour. We are constantly trying to control our perceptions of the environment to achieve goals, and we do this by changing our behaviours. In Powers' own words "what an organism senses affects what it does and what it does affects what it senses." (Powers, 1973, pg. 41).

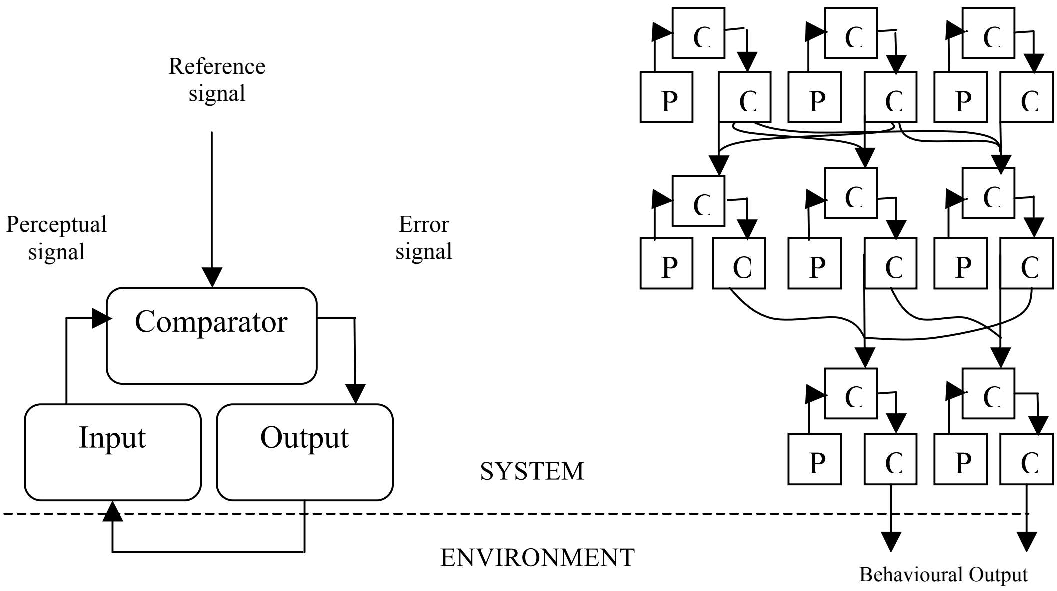


**Figure 1.** *A diagram of a single control system and how it organises within a hierarchy. For simplicity only the directional effects of the outputs are shown.*

All behaviours are completed in order to limit the discrepancies between our intentions and incoming perceptions (Powers, 1973). There is a process of comparison between the things we perceive, and the things we are achieving. If our behaviour is not reaching our goals then our behaviour must be adapted in some way in order for this to happen. Our behaviour is seen as a closed loop, a cycle of perceptions, comparison, behavioural outputs, changing environment, incoming perceptions and so forth. This *negative feedback* into the control system is essential to keep our systems up to date and adaptive. There are thousands of these control systems each controlling something different, from high level concepts like personality and wellbeing to low level concepts such as intensity and sensation (Cziko, 1995). This hierarchy enables the higher level control systems to feed down into the lower level systems and thus the organism stays controlled and in order. The *reference level* (goal in engineering terminology) of any lower level system is set by the output of the next higher order control system (as can be seen in Figure 1). These control systems are evident in both living beings, such as the homeostatic system within our bodies (Powers, 1973), and non-living things, like a household thermostat (Carey, 2008).

This fundamental framework can be and has been adapted and applied to a plethora of different phenomena and explains them succinctly and objectively. Fields as diverse as biology, robotics, marketing and literature have all had PCT applied to them in some form. In terms of problem solving, PCT would predict that the 'eureka moment' is a product of *reorganisation*. Reorganisation, which is very similar to the Gestaltian idea of restructuring, is a fundamental part of the hierarchy of control systems and is instigated when a control system consistently fails to achieve its goal. This is known as *intrinsic error*, and a high level of such error will result in reorganisation of the systems in order to reduce it. It is assumed in the model that only through reorganisation can the basic set of operations and control systems be modified, and through this process we are able to alter our behavioural output (Powers, 1973). It must be noted, however that there is only a change in organisational parameters which in turn enables the production of new behaviour. Reorganisation does not produce specific behaviours, rather changes the parameters for potential behaviour. Goals previously unattainable can now be accomplished (Powers, 1973).

Reorganisation will cease to take place when the error is deemed to be reduced to a significant level. This means that many cycles of reorganisation may take place before the correct configuration of control systems is completed, or on the other hand a correct reorganisation may never be reached. This is because the whole process is random and under no volitional control, it is simply a product of error detection and reduction (Marken & Powers, 1989).

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**The Rubin's Vase Illusion**
The Rubin's vase illusion is a well known and well cited example of an optical illusion and has been used to argue a wide range of theories. In this case it can be used as an example of reorganisation in practice. Insight has been shown to be pervasive in all human cognition, not just problem solving (Sternberg & Davidson, 1995) and as such can occur in perception too. Imagine, as a naive being, you look at the Rubin's vase for the first time and see the standard white vase in the positive space of the image. Somebody then tells you that it is possible also to perceive two faces staring directly at each other in the negative space.
You don't see it at first. You try but just don't see the alternate image. But then, suddenly, 'Eureka!' you see the two symmetrical faces. And now you are able to switch between two perceptions of the same picture: the vase and the faces. Subtle reorganisation of the image, blind variation of the different elements of the picture enabled a second representation of the original picture to become possible. Once the reorganisation is complete and the new perception comes to consciousness, two separate control systems are then formed in the hierarchy: one to control the perception of the positive space, and one to control the perception of the negative space. These control systems were only possible because of the reorganisation of the original perceptual inputs, changing connections in the original perception in order to create a new control system and a new perception.

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Although there remains little evidence for reorganisation as a concept, one seminal study has shown the efficient and dynamic nature of random selection and retention. Marken & Powers (1989) showed that reliance on random variations is not a crude and inefficient method to achieve goals but can be seen as a dynamic goal seeking process. They did this by studying the behaviour of a single cell E.coli bacterium. This cell uses trial-and-error changes of direction in response to the perception of the concentration of attractants in its environment. A computer model based on the closed loop philosophy of PCT was created, whereby the bacterium would make its way up concentration gradients of attractants and down gradients of repellents, all the while only able to change direction using a random tumble in space. The model showed that the virtual bacterium could find the source of food quickly by just using random changes of direction; in fact the model E. coli was as 70% efficient as a straight line would have been. Such a model highlights the importance and applicability of the simplicity of random selection, which is after all the basis of such scientific staples as evolution (Cziko, 1995).

The idea of blind variation and retention has been being applied to the investigation of insight before (Simonton, 1999) but PCT is the most explicit in its application of the framework. Such a concept is also backed up by other theories, like the 'deliberation without attention' hypothesis (Dijksterhuis, 2004) that states that complex, multi-faceted decisions are better left to the unconscious. And despite reorganisation being a seemingly novel way of explaining insight the model has strong relations to other ideas. It is very similar to the Gestaltian idea of restructuring (Ohlsson, 1984) which has been accepted by insight researchers more and more in recent times (Luo & Knoblich, 2007). It accounts for why insight is accompanied by such strong subjective feelings (Metcalfe & Wiebe, 1987) and finally it provides explanation that can be backed by rigorous operationalised definitions (Powers, 1973). Reorganisation can be explained in a detailed and mechanistic way with it being an intrinsic and fundamental part of the model. Therefore the sudden and subjective 'eureka moment' felt by people is not viewed as a disparate response but rather a fundamental part of the process. The 'Aha!' moment is not because we reached the answer, but rather the feeling that comes with successful reorganisation, the reconfiguration of the control systems into such a way that the solution becomes attainable.

Insight is a phenomenon that is an extremely popular research subject in psychology but yet after almost a century of research there is still no clear explanation as to the processes involved (Shanker, 1995). PCT can be seen as a new approach to this mysterious process, with a fresh pair of theoretical eyes. Of course there still remain common problems. Insight still lacks a definition, and the many names ascribed to the phenomena (insight, the eureka moment, the 'Aha!' moment, illumination, intuition) do not help. There also needs to be a change in the assumptions about insight, namely that insight problems do not automatically produce insight. Until these problems have been ironed out any explanation, including a PCT perspective will be open to criticism. However the predictions put forward in this article offer some interesting suggestions about how 'the eureka moment' comes about whilst still encompassing the main points of the cognitive account. What PCT lacks is evidence that can back up the predictions of the model. A wider understanding and acceptance of the theory as a whole will hopefully lead to wider research and application.

Maybe the demystification of 'the eureka moment' is closer than we think.

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