The Kochen-Specker theorem and the role of the observer in quantum physics

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The Kochen-Specker theorem (see for example Kochen & Specker, 1975) is a "no go" theorem in physics which was mathematically proved by John Bell in 1966 and by Simon Kochen and Ernst Specker in 1967. It conclusively demonstrates that it is impossible that quantum mechanical observables represent objectively observable "elements of physical reality". More specifically, the theorem falsifies those hidden variable theories that stipulate that elements of physical reality are independent of the way in which they are measured (i.e. they are not independent of the measurement device used to measure them and are therefore inherently contextual). That is, the outcome of an experiment depends on how the experiment is designed and executed. Specifically. the theorem proves mathematically that two basic assumptions of hidden variable theories of quantum mechanics are logically inconsistent: 1) that all hidden variables corresponding to quantum mechanical observables have definite values at any given point in time 2) that the values of those variables are intrinsic and independent of the device used to measure them. The inconsistency is based on the noncommutativity of quantum mechanical observables. In colloquial language this means that the outcome of an experiments depends crucially on how we observe things. There is no outcome independent of the choice of measurement. That is, the features of the system we observe do not exist a priori to measuring them (Zeilinger, 2012). As Anton Zeilinger put it in an excellent interview: "What we perceive as reality now depends on our earlier decision what to measure which is a very deep message about the nature of reality and our part in the whole universe. We are not just passive observers" (Zeilinger, 2012). This statement connects psychology and physics (which is indicative of the deeper relevance of Gustav Fechner's "psychophysics" discussed earlier). The interdependence between the observer and the observed is known as the observer problem in quantum mechanics and its pertinence for psychology has been discussed in previous sections. In his epistemological discussions with Einstein, Niels Bohr explicitly emphasised the role of free choice on part of the observer: "...our possibility of handling the measuring instruments allow us only to make a choice between the different complementary types of phenomena we want to study" (Bohr, 1996). More recently, Rosenblum and Kuttner disagreed with Einstein when they stated that "Quantum theory thus denies the existence of a physically real world independent of its observations" (Rosenblum & Kuttner, 2011, p. 7). Einstein is known to have said that he does not believe that the moon only exists when it is observed (Germann, 2015a; Stone, 2013), a statement which epitomizes the widely held belief in an objectively existing reality. However, Einstein's ontological stance has now been conclusively experimentally falsified (e.g., Aspelmeyer & Zeilinger, 2008; Bouwmeester et al., 1997; Giustina et al., 2015; Gröblacher et al., 2007; Handsteiner et al., 2017). The deep and far reaching implications of the measurement problem cannot be simply ignored. Some physicists argue that the measurement problem is merely a "philosophical profundity" (they use the phraseology in a derogative way) and that the problem is in reality no problem. This is the "shut up and calculate" ethos advocated by a significant proportion of physicists (Kaiser, 2014; Tegmark, 2007). However, as Daniel Dennett rightly pointed out: "There is no such thing as philosophy-free science; there is only science whose philosophical baggage is taken on board without examination." (Dennett, 1995). An argument which prohibits systematic thinking and the quest for understanding should concern every scientifically minded cogniser. Replies to the advice to simply ignore the foundational conceptual issues associated with the observer-problem have been articulated as follows: "Shut up and let me think!" (Echenique-Robba, 2013). It has been argued that "layers of protection against rational inquiry" have a religious undertone. For instance, Richard Dawkins criticised religion on the following grounds: "What worries me about religion is that it teaches people to be satisfied with not understanding." (Dawkins, 1996) Contrast this with Feynman well known statement that nobody understands quantum physics and that one should not try — otherwise bad and scary things will happen to you! "On the other hand, I think I can safely say that nobody understands quantum mechanics. So do not take the lecture too seriously, feeling that you really have to he does not believe that the moon only exists when it is observed (Germann, 2015a; Stone, 2013), a statement which epitomizes the widely held belief in an objectively existing reality. However, Einstein's ontological stance has now been conclusively experimentally falsified (e.g., Aspelmeyer & Zeilinger, 2008; Bouwmeester et al., 1997; Giustina et al., 2015; Gröblacher et al., 2007; Handsteiner et al., 2017). The deep and far reaching implications of the measurement problem cannot be simply ignored. Some physicists argue that the measurement problem is merely a "philosophical profundity" (they use the phraseology in a derogative way) and that the problem is in reality no problem. This is the "shut up and calculate" ethos advocated by a significant proportion of physicists (Kaiser, 2014; Tegmark, 2007). 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Do not keep saying to yourself, if you can possible avoid it, “But how can it be like that?” because you will get ‘down the drain’, into a blind alley from which nobody has escaped. Nobody knows how it can be like that.” (Feynman 1964) The blind acceptance of “that just how nature is” has been adopted by generations of students. This has been compared to the “education” (i.e., operant conditioning) of children who are brought up in a traditional family and who are told by their parents to “shut up and obey” when they are still undeveloped and obedient to authority (Echenique-Robba, 2013). The anti-rationalistic argument against deeper cogitations on the interpretation of quantum mechanics takes many forms. For instance: “Don’t work on this if you ever want to own a house” or “understanding is just being Newtonian” or “whys are the unscientific business of philosophy” (but see Echenique-Robba, 2013). We argue that psychology plays a crucial role in understanding the conceptual basis of QM and particularly the observer-effect. Further, we propose that a deeper understanding of consciousness (discussed in the subsequent section) and embodied cognition will help to clean up the “conceptual mess” (Echenique-Robba, 2013) which underpins QM. From an embodied/grounded cognition perspective, our inability to “understand” QM (e.g., concepts like superposition) might be based on a lack of appropriate sensorimotor representations which are usually acquired in early phases of development (in the Piagetian stage model sensorimotor learning and development usually takes places in a critical period which ranges from birth to about age two (Piaget, 1952)). From this perspective, the lack of somatically anchored “primary metaphors” (Lakoff, 1987, 1994; Lakoff & Núñez, 1998) which are required to represent central QM principles is responsible for our inability to “grasp” (i.e., embody) the conceptual basis of QM (currently QM is “ametaphorical”). According to the grounded cognition framework, thought is fundamentally rooted in neuronal representations associated with the perceptual and motor systems (rather than being amodal and symbolic (Barsalou, 2008)). Therefore, the systematic development of appropriate somatic representations might help humans to cognitively represent QM principles in an embodied fashion, thereby enabling a genuine understanding of seemingly paradoxical concepts via symbol grounding (cf. Gomatam, 2009). Moreover, neurogenesis, neuroplasticity, and synaptoplasticity appear to play a pivotal role in acquiring novel concepts. Therefore, certain neurochemical substances which facilitate neuroplasticity and neurogenesis are important candidates in this context. For instance, it has been shown that the nonselective 5-HT2A agonist psilocybin (O-phosphoryl-4-hydroxy-N,N-dimethyltryptamine (Hofmann, Frey, Ott, Petrzilka, & Troxler, 1958; Hofmann et al., 1959)) induces neurogenesis in the hippocampus of rats, specifically in area CA1 (Catlow, Song, Paredes, Kirstein, & Sanchez-Ramos, 2013). The hippocampus crucial for various forms of learning (Manns & Squire, 2001) and learning induces long term potentiation in the hippocampus, specifically in CA1 (Whitlock, Heynen, Shuler, & Bear, 2006) which is interesting in the context of psilocybin induced neurogenesis as these regions overlap. Moreover, functional connectivity analysis using arterial spin labelling perfusion and blood-oxygen level-dependent fMRI showed that psilocybin (and potentially related tryptaminergic compounds) alters the connectivity patterns in the brain's rich-club architecture (key connector hubs) (Carhart-Harris et al., 2012). Specifically, it facilitates more global communication between brain regions which are normally disconnected, thereby enabling a state of "unconstrained cognition" which might be beneficial for a deeper understanding of complex problems (i.e., cognitive flexibility, divergent thinking, creative ideation, perspectival plurality, etc.). Interestingly, synaesthesia (Hubbard, 2007; J. Ward, 2013), i.e., cross-modal associations, can be neurochemically induced in a relatively reliable fashion. Novel cross-modal association between perceptual modalities might be very helpful for developing new insights into the persistent measurement problem in QM. Recall the Lockean associationism discussed in Chapter 1 in the context of synesthetic experiences: Nihil est in intellectu quod non prius fuerit in sensu (There is nothing in the intellect/understanding that was not earlier in the senses). To highlight the importance of the measurement problem for science in general, the first Newton medal awardee Anton Zeilinger explicitly states that it is not refined to the quantum domain but it is also applicable to macro phenomena (Zeilinger, 2012). Moreover, the problem is not only relevant for physics but particularly for psychology and the neurosciences. From a (currently purely theoretical) material reductionist point of view, psychology is fully reducible to its neural substrates which in turn are composed of matter which is ultimately governed by quantum mechanical principles. Following this hierarchical (syllogistic) argument, psychology is ultimately based on quantum physics. Considered from a broader perspective, the measurement problem is pertinent for the scientific method in general because it concerns the process of objectivity of measurements. That is, science can no longer claim detached objectivity (e.g., Pan, Bouwmeester, Daniell, Weinfurter, & Zeilinger, 2000) because experimental findings are significantly irreconcilable with the metaphysical and primarily taken-for-granted assumption of local-realism (Santos, 2016) which underlies much of contemporary scientific theorising. The measurement problem has to integrate the observer as a causal force which crucially influences the outcome of measurements. That is the observer shapes physical reality in a way which needs to be explained by physics and psychology. As we argued previously in the context of psychophysical/introspective measurements, we are not just passively recording but actively creating physical/psychological observables. In this context it has been argued that physics faces its final frontier – consciousness

(H. Stapp, 2007). For instance, the “von Neumann–Wigner interpretation”, also described as “consciousness causes collapse” of Ψ, postulates that consciousness is an essential factor in quantum measurements. Von Neumann uses the term “subjective perception” (J. Von Neumann, 1955) which is closely related to the complementarity of psychophysics discussed previously. In his seminal paper “Quantum theory and the role of mind in nature”, Henry Stapp argues: “From the point of view of the mathematics of quantum theory it makes no sense to treat a measuring device as intrinsically different from the collection of atomic constituents that make it up. A device is just another part of the physical universe... Moreover, the conscious thoughts of a human observer ought to be causally connected most directly and immediately to what is happening in his brain, not to what is happening out at some measuring device... Our bodies and brains thus become...parts of the quantum mechanically described physical universe. Treating the entire physical universe in this unified way provides a conceptually simple and logically coherent theoretical foundation...”(H. P. Stapp, 2001). According to Stapp, two factors seem to be involved in any measurement: the observer (the one who is asking the question) and the observed (i.e., matter/nature). However, according to Stapp (who was a collaborator of Werner Heisenberg), quantum theory transcendents this dualistic dichotomy between epistemology and ontology because it was realized that the only “thing” that really existed is knowledge. That is, ontology is always defined by epistemology which is primary. In simple terms, knowledge (a faculty of the human mind) is primary and matter secondary (i.e., Stapp argues for “the primacy of consciousness”). In a sense, quantum physics addressed a quintessential and long-standing philosophical problem, namely how epistemology and ontology interact and interrelate to each other. Thereby, quantum physics overcomes this dualistic notion inherited from western philosophy (e.g., the Cartesian split) and merges the dualistic concepts into one integrated whole. Following this line of thought, our beliefs about reality have to be fundamentally revised and reconceptualised. Our perspective on the relation between self and reality will never be the same. At this point it should be emphasized that physics is still in its infancy, even though it is one of the oldest and by far the most established science. Notwithstanding, current physics only deals with baryonic matter172. Cosmologists estimate that baryonic matter constitutes only $\approx 4\%$ of the universe. The remaining 96% consist of dark matter and dark energy (Olive, 2010; Sahni, 2005). These numbers show us very clearly how limited our state of knowledge with regards to the fundamental ontology of the universe really is.173 Psychology is a much younger than physics and therefore “epistemological humility” is a virtue which needs to be adopted by every scientist sincerely interested in the advancement of science and knowledge (a “matter”174 of scientific integrity).

Footnotes

172 A baryon is a composite subatomic particle made up of several elementary particles (i.e., three kinds of quarks). 173 A fitting analogy can be drawn between our nescience concerning dark matter/energy in cosmology and the un-

conscious in psychology. These limitations might be epistemological in nature. Evolution has not equipped us humans to understand the vastness of the universe or the intricate workings of the psyche. Our neocortical structures evolved mainly to ensure survival in our immediate environment. That is, hand eye coordination, fight or flight responses, mating behaviour, etc. Questions concerning the nature of reality might just be too complex for our cognitive systems. What does an ant know about computers? With regards to consciousness a more fitting effigy might be: What does a fish know about water. That is, there are perhaps non-negotiable epistemological limitation which deterministically delimit the human gnostic horizon. 174 From a cognitive linguistic point of view, it is interesting to note that the English language is extremely biased towards a materialistic worldview. Idioms and conceptual metaphors convey the