The Many Worlds of Quantum Mechanics : A Pedagogical Conundrum

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Abstract: The measurement problem in quantum mechanics has been a cause of much puzzlement over the years. The very idea of having two different versions of reality for the same system has been a cause for much interest. Often quantum mechanics text books follow the 'shut up and calculate' paradigm. This denies the opportunity for the common student to understand the consequence of one of the most elegant and beautiful aspects of science. The state of the art textbooks give a purely algebraic, perfunctory and monotonous approach where the real consequence of the system is not fully appreciated. A good reason for this is the considerable deviation of the quantum mechanical process from the commonsensical idea of truth, reality and reason. We tend to look at the world in a materialistic, deterministic, causal and objectivistic way. We tend not to accept a world of contradictions. A quantum measurement is essentially an amalgamation of contradictions, mystery and duality. It encompasses an implicit dependence on subjectivity and contradicts with causality as we know it. We look at the world as in the present. But a quantum mechanical measurement is a prediction of the future influenced by the observer or the measurer. This offers a philosophical and pedagogical conundrum. It poses a challenge on not just how our perception of the world might change in addition to providing a big challenge on how to take this to the student. The most common text book interpretation of quantum mechanics has been the Copenhagen Interpretation suggests the 'collapse of the wave function' as a mechanism of transition between duality. But a more bizarre yet elegant theory called the Many Worlds Interpretation has been catching up very quickly; it stands for the split of the universe when we make a quantum mechanical measurement. This adds up to the problem in taking up a mysterious and paradoxical subject like quantum mechanics, as it is, to the student. How do you tell the ordinary student, this is how the constituents of the world behave ?.

Keywords: Many Worlds Interpretation, Copenhagen Interpretation, Reductionism, Positivism, Duality.

1.Introduction

The very basic idea of education is to imbibe into the student, the idea of a imaginative outlook on life (or nature) to be imparted into the mind of the students, rather than the mere perfunctory transmission of a set of instructions to the students **(Barrow & Woods, 2006; Ozoliņš, 2013)**. This perception of education is more relevant to a subject like quantum mechanics, where students have often struggled because of their difficulty to relate the physical reality with the concepts defining quantum mechanics, thereby following a 'shut up and calculate' paradigm **(Baily & Finkelstein, 2010)**. A direct offshoot of this mindset is the popularity of the Copenhagen Interpretation of quantum mechanics **(Stapp, 1972)** .

The concept of the Copenhagen Interpretation seems quite out of the ordinary to the average student. When you make the measurement of an atomic constituent, you measure an attribute of that electron, say position x, you get a probability to find that electron at that given position. Now the electron will evolve in time in that position, in a deterministic way. But once again, if you measure the electron in a different position, say y, you will get a probability for the electron to be in that position. This is a result of a barrier imposed by the uncertainty **(Busch et al., 2007)** principle, you can not measure the position and momentum of a subatomic particle simultaneously. There is a duality between a deterministic measurement (wave) and a probabilistic measurement (particle), also known as the wave-particle duality. In this way we fail to understand the nature of the electron prior to the measurement, in addition to the fact that the system evolves according to our measurement. If you take away the role of the measurer, you know nothing about the state of the electron prior to the measurement. Propounding practicality to the system, it has been suggested that the incertitude is due to the limitations of the measuring apparatus **(Bohr, 1935)**. This is nothing like what a student would encounter in his deterministic world of classical physics. The fact that the observer creates the reality and that is what we know about it is hard to reconcile with the practical world around him. The student will find it extremely difficult to understand the fact that one might not be ever able to find out the current state of the atom without the measurement itself influencing it. Upon measurement the same entity can be seen as either a particle or a wave and in order to 'completely' understand the microphysics of the system under consideration, we must take into consolidation, both the wave and the particle nature of it, known as the complementarity principle **(Wootters & Zurek, 1979)**. Reality to the average student is singular and is not self-contradicting in any manner. But Quantum mechanics violates it, making it a very difficult concept to imbibe.

The Copenhagen Interpretation suggests the wave as a superposition of several other waves or particles and the probabilities a measure of the proportion of the amount of each observable (say position) in the 'complete' wave. When you measure a particular attribute, the entire wave function collapses to what you have just measured (it gives a probabilistic result of course). But the collapse of the wave function seems to be an ad-hoc narrative. Another interpretation of the multiple realities is the Many Worlds Interpretation which argues that upon every quantum mechanical measurement a new world is created, every 'reality' has its own separate world for itself **(Dewitt & Graham, 2016)**. Although the Many Worlds Interpretation has not reached the level of text book acceptance, the theory is quickly catching up. Quantum mechanics is a theory replete with several paradoxes and interpretations **(Karuppath, 2010)**, we will not attempt to go into the details of such an elaborate subject. But there are considerable proponents of the Many Worlds Interpretation who argue that such paradoxes are dealt with in a better way in the Many Worlds Interpretation, which include quantum entanglement, quantum computing and interaction free measurement etc. **("Rapid Solution of Problems by Quantum Computation," 1992; Santanam et al., 2011, pp. 231–239; Tipler, 2012; Vaidman, 1994)**. We dedicate this paper to the task of identifying the difficulty in teaching the Many Worlds Interpretation in contrast with the state of the art Copenhagen Interpretation and the importance of considering metaphysical, philosophical and neuroscientific aspects needed to understand the microphysics of the quantum world better, concepts which may not have received enough of a consideration in existing literature like **(Baily & Finkelstein, 2010; Garritz, 2013)**.

2.Classical And Quantum probabilities.

The idea of probabilities in quantum mechanics is very strange to the student. Quantum mechanical probabilities can not be seen without juxtaposition with wave particle duality. In a typical probability exercise as the average student would see it, would be a typical question: Consider a bag with 10 blue balls and 10 red balls, 'what is the probability of getting a blue ball ?' would be the typical question, as is a usual norm of probability in academia. But a quantum mechanical analog of this would be that the bag is a wave function in which there is a definite proportion of blue and red balls, initially. If you measure a red ball you will get a probability of getting a red ball. Now if you let the system as it is, without disturbing it, it would give a bag (wave function) which entirely contains red balls. Instead if you had measured blue balls, you would have received a probability for the bag having a probability of being in a 'blue ball' state. And do not disturb, it will evolve in such a way that all its balls are blue. Infact, further, as is established in the Copenhagen Interpretation the wave function in its most generic form can live in a superposition of several states. This means that , if you are once again going to measure the purely red or the purely blue bag (wave function), you are going to get a probability of some other color like blue, green etc. This student is not ready for any such thing as the Copenhagen Interpretation, not according to his usual training. Up until high school there is no training attributed to handle this kind of a methodology. The 'shut up and calculate' norm in quantum mechanics, which may have resulted in our lack of full fledged understanding of the 'quantum world' may very well be a direct result of the difference in the very idea of probability in quantum mechanics and classical physics or the mathematics associated with it .

In the Many Worlds Interpretation the probability of the outcome is the number of worlds with that particular outcome or state **(Putnam, 2005)** . Let us retake the previous example, if a bag contains 10 red balls and 10 blue balls, the probability of getting a red ball will be 0.5. That is the proportion of worlds which contain red balls. Instead of the collapsing wave function we have a splitting of the worlds. Thus the probability in the Copenhagen Interpretation is epistemological (knowledge), the probability in the Many Worlds Interpretation is an attempt to make it ontological (existence). In either case, Merely saying that quantum mechanics is probabilistic may not show the full complexity of the science, the probabilities are in fact fundamentally different from what the student will usually encounter. It may require a completely different educational mindset.

3.The Multiplicity Of The Universe

The universe is ontologically a singular ubiquitous entity that comprises all of the known existence. The idea of the Universe, its infinite existence and expansion has been a very fundamental aspect of physics and education. The idea of either the universe splitting or all of us living in a superposition of several universes is not a concept which may be easily assimilated by the student. The human mind often tends to accept and assimilate the the world around them and try to connect whatever they learn academically with the world or life they are a part of **(Barrow & Woods, 2006; Ozoliņš, 2013).** In that case the acceptability or understanding of multiple universes is going to be difficult.

The big problem with the Many Worlds Interpretation is the very empirical emptiness of the theory. It does violate the very idea of scientific empiricism, of experimentally proven facts. Modern science does emphasize a very big importance on experimentally accepted facts. The proponents of the Many Worlds Interpretation have never come forward with a solution to experimentally prove the existence of many worlds. If there are indeed multiple or parallel worlds is quantum mechanical measurement a portal to open into a new world? If it is a portal, can we go into that world ?. These are natural questions which will arise, when we live in a world of experimentally accepted facts. But this issue is not limited to the Many Worlds Interpretation alone. Even in the collapsible wave function model of the Copenhagen Interpretation there is no experimental proof or a noteworthy nature or mechanism of a collapse happening. If some curious student may ask, why should it be a collapse, why not something else ?, the answer is still an open question. Open questions in physics are usually at a higher level, it is unusual that a foundational or fundamental subject like quantum mechanics, has open or unanswered questions in its first principles itself.

4.Basic Philosophical Contradictions

The modern norm of education, which has its sound foundations on scientific empiricism, a subject like quantum mechanics, whichever interpretation which one may choose, leads to a challenge of making it acceptable to highly materialistically trained students. In a poll conducted among students of quantum mechanics , it has been shown that the 'realist' and 'agnostic' interpretations were quite popular among the students **(Baily & Finkelstein, 2010)**.

The realist interpretation is the argument in favor of incompleteness of quantum mechanics **(Einstein et al., 1935)**. But the Copenhagen Interpretation regards the quantum mechanical wave function to be complete which has made its way into text books. The agnostic interpretation is also popular which suggests that understanding these open questions are beyond our ability. This can be justified in a scientific way when we go with the fact that measurement or state of the art experimental set up prevents us from understanding the exact mechanism of quantum mechanics **(Bohr, 1935)** . But if one suggests that they will forever remain beyond human ability and quantum mechanics only serves the purpose of experimental validity **(Baily & Finkelstein, 2009)**, that would be an opportunity missed to learn more about the atomic world. After all, isn't science a quest for the truth? . The current mindset among many students verging on the 'shut up and calculate' paradigm might not lead to scientific progress when they do not have a desire to pursue the truth or the unknown.

One good reason why students may have a proclivity towards the realist interpretation of quantum mechanics , even going against the typical textbook, could be the principle of reductionism which has deep roots in classical physics or our everyday lives. Reductionism is an idea that every phenomenon in the universe can be deduced to a set of fundamental laws of physics **(Meyer-Ortmanns, 2015)**. But quantum mechanics can not be treated explicitly as a set of laws, but rather a statistical and observational result which has resulted in a great but limited understanding of the atomic world. This is primarily a contradiction with the usual world of physics and common sense, on which the entire pedagogic curriculum may be based on.

The basis for accepting a theory or idea as scientifically correct is experimental proof and falsifiability **(Keuth & Popper, 2013)**. The collapsibility of the wave function, the exact process and mechanism is not dealt with in the Copenhagen Interpretation. The uncertainty principle provides a barrier which may hinder us in the falsifiability of such a proposition. The same non-falsifiability exists about the Many Worlds Interpretation as well. If there are multiple worlds, 'can we access them ?' or 'will there be any tangible proof for the existence of such multiple worlds?'. There must also be an option of falsifiability. The absence of falsifiability raises an important question on the ontological acceptability of such arguments, both in the case of Copenhagen Interpretation and the Many Worlds Interpretation. Pedagogically, most of the things which we call as science are the ones we accept on the basis of experiments and falsifiability. Quantum mechanics thus becomes a 'weird' science for the students. While quantum mechanics strongly bases it on the basis of experimental results, the interpretations of the results may not be necessarily based on empiricism. Quantum mechanics is a purely statistical result or a consequence of the inability of experiments or perhaps human perception to understand what goes behind the scenes. In Spite of this, the subject forms one of the main pillars of physics, and may have resulted in considerable productivity in recent times. It is strange to note that it has so many philosophical or conceptual contradictions, which make the subject at loggerheads with the largely classical physics based curriculum across the world.

5.Consciousness In Quantum Mechanics

What the Copenhagen and Many Worlds Interpretation fail to do is keep the 'consciousness' of the observer away from the result of the measurement. Consciousness has been in general unacceptable in physics yet has found its way into quantum mechanics **(Achuthan et al., 2009; N. K. Karuppath & Panajikunnath, 2010)**. In both the interpretations that we have considered, there is an implicit element of subjectivity. Science is an objective paradigm as the usual classical physics narrative goes. Measurement by the observer influencing the result of the observation is counter intuitive and brings subjectivity into physics. For the Copenhagen Interpretation the change in the quantum state is marked by the change registered in the consciousness of the observer **(Shimony, 1963)**. While in the Many Worlds Interpretation the consciousness has an equally big role to play, because the consciousness of the observer along with his observation of a quantum mechanical system results in the splitting of the universe. In any case metaphysics or consciousness is not a subject which is a part of a typical physics student's curriculum.

The idea of consciousness can have two major consequences, it may either prompt the learner to seek refuge in realism or materialism or one may develop an impression that, since consciousness plays a role, it may be that there may be limitations in understanding what one can understand fully about the quantum or atomic world. Such a dogmatic approach could be counterproductive to science in general and quantum mechanics in specific. As a spin-off, consider the study of the intricacies of the nervous system which may provide clues to our capabilities or perhaps even limitations towards better understanding of quantum mechanics **(De & Pal, 2005)**. In order to critically analyze the role of consciousness in quantum mechanics it is important that an interdisciplinary approach inclusive of metaphysics or even neuroscience be made a part of the physics curriculum.

6.Discussion and Conclusion

There is an essential need to take into consideration contradictions in the picture of studying quantum mechanics. The education system does not focus on studying other interpretations of quantum mechanics other than the Copenhagen Interpretation. From the study in **(Baily & Finkelstein, 2010)** it is clear that the primary focus of academia is on the Copenhagen Interpretation in spite of all its issues. The alternate Many Worlds Interpretation or other interpretations of quantum mechanics are not taught to the students. While there is active research in considering alternative interpretations of quantum mechanics, one must acknowledge the need for including other interpretations in the understanding of quantum mechanics. There is no importance given to understanding how our minds or the brain has an effect in understanding the limitations or capabilities of quantum mechanics. We believe the student must be exposed to all possible considerations in the study of quantum mechanics rather than the 'shut up and calculate' methodology, where the Copenhagen Interpretation is considered sacrosanct. Alternate philosophical viewpoints are also not provided to the students. This evinces a bottle neck in the systemic methodology of education in nurturing potential researchers towards understanding the microphysics of the atomic world. Historically quantum mechanics is replete with criticism, arguments and controversies, and hence an argumentative discussion of quantum mechanics in the classroom has been suggested **(Garritz, 2013)**.

The training of students in thought experiments may play a significant role in understanding and developing the subject much better. Both the Copenhagen Interpretation and the Many Worlds interpretations among a plethora of other ground breaking concepts in physics are a result of such thought experiments. The natural tendency of the student or any learner per say will be the natural commonsensical intuitive attempt at connection with the real world. Why should reality be different at the atomic level contradicting the world we live in ?. This tendency can lead to a lack of connection on part of the student with the subject. To understand this better let us consider a simple thought experiment. Imagine you are a quantum particle, under the Copenhagen Interpretation, you will live in a superposition of several states and depending upon the observer's measurement, one of your states will be noted and associated with a probability (after the collapse of 'your' complete wave function) . On the other hand in the Many Worlds Interpretation, you will have multiple versions of yourself living in multiple universes, and the measurer will measure you in any one of all those possible worlds. The probability here will be a measure of the number of worlds in which you have carried out one particular action (that can be seen as a 'state' in quantum mechanical terms). In a very naive view this can seem very intuitive to the student, much more than the Copenhagen Interpretation. We do not intend to make an attempt to compare the Copenhagen Interpretation or the Many Worlds Interpretation, in terms of success in veridacity or acceptability. We would rather suggest that quantum mechanics textbooks contain a chapter dedicated to the 'Interpretations of Quantum Mechanics', with considerable emphasis on other interpretations, philosophy, metaphysics and neuro-scientific aspects. Interdisciplinary learning, imaginative learning are the stepping stones in building a bridge in solving the problems at the microphysical scale.

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