Opinion Article

On the Requirement for a Transition from Positivism to Post-positivism in Science and Education due to the Quantum Mechanical Implications

Abstract

Advances in quantum physics in the first quarter of the twentieth century dramatically influenced perspectives on the scientific and philosophical issues. The paper discusses why a shift towards post-positivism in philosophy of science is necessary from a novel perspective considering the basic principles of quantum physics and its implications. Concerning the realities about the limitations in observation and evaluation in scientific results, we need to question the meanings of objectivity, truth and therefore present knowledge base, resulting in a re-alignment of *ontological*, *epistemological* and *methodological* aspects regarding the philosophy of research. Parallel analysis of the quantum mechanical and post-positivist approaches foresights *relativist* and *critical realist* views in philosophical aspects. It is proposed that the right way to get close to the truth and enhance our knowledge is to have overall perspectives of post-positivism that matches well with the basic principles of modern physics in most aspects. It suggested that this new approach would be an appropriate pattern in the conduction of higher education, proposing *interdisciplinary, constructive* and *active learning* rather than an imposing way in a traditional fashion.

Introduction

Transformation of knowledge, during the two important stages of learning process—*education* and *research*—results in continuous development of science and technology (see also Steinke 1994 and Sadler-Smith, 1996). As a result, advancement in science and technology reinforces scientists to modify or entirely change the *philosophical, epistemological* and *methodological approaches* in these stages. Undoubtedly advances in modern physics have been of great importance in the evolvement of philosophy of science. Our worldviews in the beginning of the twentieth century were dramatically characterized by new perspectives of physics such as *the Planck radiation law* (see for instance Pyle, 1985), *Bohr's atomic model* (see for instance Willden, 2001) and eventually developed *the band theory of solids* (see for instance Blakemore 1989), entirely changing the imaginations on the *atomic* and *electromagnetic nature* of the universe (Kragh, 2002). Some new ideas and perspectives towards physical phenomena were so successfully introduced and developed up to the mid-century that the birth of *quantum physics* provided great insights to scientists who could hardly ever imagine a better understanding of the microscopic nature and therefore matter as a whole.

Towards the end of the nineteenth century, some physicists started to think that most of the issues underlying the topic were totally understood, and rest of physics would only involve some modifications in details since revolutionary discoveries of classical physics such as Oersted's discovery of electromagnetic relations (1820) followed by Ampere's (1826) and Faraday's (1831) Laws of *electromagnetism* for the generation of the electric energy, eventually construction of *classical electromagnetic theory* by Maxwell (1850), and finally Thomson's (1896) *discovery of electrons*. However, some modern theories and experiments of great scientists such as Planck, Einstein, Bohr, de Broglie, Heisenberg, Schrödinger and Born proved that their predecessors could ever be so much wrong as we might be now. It is right to say that the quantum mechanics is also an incomplete science evolved itself from *Schrödinger's and Dirac's formalism* to the *quantum electrodynamics* (QED) of Feynman, more general view of quantum mechanics combining *quantum field theory* (QFT) with the *special relativity*, and will possibly be evolved to much novel ones and so on.

Success of the above mentioned physicists was to have a deep knowledge of what had been achieved in the past and to have *critical perspective* of what was happening at the time without ignoring a single detail even in an anomalous manner. Faraday (Özdemir, 2015) possessed a great success in postulating the *electromagnetic induction*, which later on resulted in many important applications such as *electric generators and engines*, because he did not ignoring five seconds of impact during his lifelong experiments.

Novel perspectives and achievements of modern physics such as Planck's (1900) explanation of *the black body radiation*, Einstein's (1905) *photoelectric phenomena and relativity theories* (Penrose 2009), and *Heisenberg's Uncertainty principal* (1925) have ultimately led to a transition of philosophy of science from *positivism* to *post-positivism* after mid-twentieth century. This entailed scientists to realign their *epistemology* and *methodology* in research and education, which has eventually led to new methods of education in theoretical and practical manner (Warwick & Stephenson, 2002).

Present knowledge base is a result of learning and represents individuals' worldviews. As Coll and Taylor (2001) stated "individuals' worldviews constructs *paradigms*, which are some combinations of basic beliefs, concerning ultimate or first principles." It is personally interpreted that paradigms are intellectual developments involving the essence of philosophy of science such as *ontology*, *epistemology* and *methodology*. Paradigms can change in course of time, because science is always potentially in the edge of revolution as also stated by Williams (1982). From the author's point of view, science is continuously evolving itself since its nature consists of proofs and refutations. As stated by Pickstone (2001), the ways of knowing are based on the ways of production.

This paper discusses how and why advances in physics have in due course led to a transformation in the philosophy of science and learning, and therefore in education. The way of thinking in post-positivism will be combined to the ideas in quantum physics. In connection with this, one suggests that the difference between positivism and post-positivism can well be understood when we analyze the conflicting views between classical physics and quantum physics.

Basics of Quantum Theory

Deterministic views of classical theory initially started to scrunch with the requirement of statistics in especially thermodynamic phenomenon when the repetition of the same event and the multiplicity of different events are the case. Consequently it is obvious that multiple recurrences of one particular phenomenon in many microscopic and macroscopic events may not have ended up with the same results. The first comprehensive theory was initiated with the *Maxwell-Boltzmann Statistics* (1871), evaluating the possible ensembles of an isolated thermodynamic system with particular values of a continuous energy range.

Planck in 1900 introduced the term *quanta* by explaining quantum behavior of thermal or blackbody radiation. According to classical belief thermal radiation should have been infinite when the temperature of metals continually increased. However Planck's quantum theory suggested that electromagnetic radiation could be dispersed by energy quanta of E=h x ν called *photons* where E is energy of photon with ν frequency and h the Planck constant. This was the first theory, which was suggesting that something with no mass (like a photon) could have energy (Tekeli et. al., 1999). It was combining energy and frequency concerned with particle and wave behavior, respectively (for further reading, see also Einstein and Infeld foreword by Isaacson, 2007).

This was eventually led to a well-known fact called as *wave-particle dilemma* as follows: When Planck mathematically formulated the semi-classical *black body* or more generally known as the *thermal radiation* problem in 1900, he was not quite aware of the fact that this invention was going to revolutionize physics towards a new type of version of it—*Quantum Physics*—without which today's globalization would not have been possible (Loudon, 2000). In 1905, Einstein showed that a photon could act as particle when it is illuminated to a metal surface. He demonstrated that photon energy could be converted to kinetic energy of electrons. Bohr's atomic model in 1913 generalized the idea of *quantized electronic energy levels* in an atom that can be changed by either emission or absorption of photons. This was the first modern model for atomic nature (Thornton and Rex, 2002). Contrariwise, de Broglie suggested the wave nature of electrons in 1923. This burdens electrons with a wave parameter called the *de Broglie wavelength* (de Broglie, 1970), resulting in an important term "*matter wave*". This summarized controversy between a photon as a particle of light and the matter wave of each quantum system caused the wave-particle dilemma in quantum physics.

In fact, this dilemma was formulized by Schrödinger in 1925 with a fundamental equation named after his name in which every quantum mechanical system needs to have a waveform (Bransden and Joachain, 1990). This formulation established a new type of mechanics called *wave mechanics* that differs from the *Newton mechanics*. Basic differentiation comes from the fact that wave mechanics calculates the accompanying wave functions for individual quantum systems that indicate the probabilities of quantum mechanical species where they may be situated in space, as shown by Born in 1926. However the Newton mechanics can determine the exact positions.

We would not like to be misunderstood by the readers with a wrong idea that the Newton mechanics is more comprehensive than the quantum mechanics just because the former is more deterministic. The latter is a result of experimental facts that is more explanatory and appropriate for us to understand microscopic world and macroscopic world as a whole. Predictions of quantum mechanics are also valid in macroscopic world. However they reduce to Newton mechanics so that the application of them is dispensable. A detailed discussion on how quantum mechanical implications construct the macroscopic phenomenon in real world is given in the philosophical section.

On the other hand, Heisenberg in 1925 highlighted an important reality in quantum physics—*uncertainty principle* (Fujikawa, 2012): Let us first state that this is a most unconventional aspect of quantum physics or microscopic nature that differs from classical physics or macroscopic nature. However we should not forget the fact that microscopic world is the elementary components of the macroscopic environment. As a matter of fact, motions of species in physics can be characterized by the two basic parameters of a physical event. Basic parameters are;

1 Position (where something is)
2 Velocity or more specifically momentum (momentum=(mass) x (velocity))

In classical theory, i.e., in the Newton mechanics or from the macroscopic perspective, we can measure these two quantities more or less very precisely, no questioning really where something is and what its momentum is. However in quantum mechanics or from the microscopic perspective this precision that we can measure things in hundred percent is out of reality or not valid any more. Let us suppose a particle such as an electron has a momentum **p** and a position **x**. Position and momentum couple or correspondingly energy and time, the basic quantities of a physical event, must have uncertainties delta(**x**) and delta(**p**) or corresponding uncertainties in energy and time; delta(**E**) and delta(**t**), respectively. In one type of experiment or theory, if one can measure or calculate the former correctly one has to give up the latter. In between there always exist possibilities of uncertainties in both, even in a perfect experiment. Sizes of uncertainties are not independent, they are related by delta(**p**) x delta(**x**) > (h = Planck's constant). So for instance if we can measure **x** exactly, the uncertainty in **p** (delta(**p**)) must be infinite, in order to keep the product constant.

These uncertainties lead to many strange things: for example in a quantum mechanical world, we cannot predict where a particle will be with 100% certainty. We can only speak in terms of probabilities. We can say that an electron will be at one location with a 95% probability, but there will be a 5% probability that it will be somewhere else. No one can make an exact interpretation on this kind of uncertainty whether this is a natural way that the universe works or this is due to an artifact that whenever we make a measurement we must interfere with the system that is measured. Whatever it is, it is a fact that it happens. We have to live with this reality. On the other hand, this is a real controversy that disproves a positivist, realistic approach towards a scientific phenomenon and this behavior of microscopic nature completely breaks down the deterministic view of philosophy of science—positivism. Later in 1954 as Einstein stated, "it is difficult to attach a precise meaning to the term scientific truth" (Coll & Taylor 2001). A unique interpretation of uncertainty principal by Penrose (2011) is also given in the references.

In order to deliver the right, it is consequently acknowledged that the statistical mechanics has enriched the methodological aspects of modern physics. However one would like to underline the fact that quantum mechanical approach of modern physics is already a sophisticated statistical method, since the quantum mechanics is based on uncertainties and probabilities. Therefore discussing the aspects of modern physics using the quantum mechanical arguments in this study also includes the statistical mechanics.

Although quantum physics involves some novel and very sophisticated theories and principles, this has not caused a complete break with the past. For instance, the Newton mechanics still concretely stands in the macroscopic world or Faraday's *induction law* still underlies the basis of producing electricity. Quantum mechanics is so comprehensive that its principles can be reduced to *classical* Newton mechanics in some special conditions where classical phenomena can satisfactorily be applied. This is in general called the *Bohr Correspondence Principal* (see for example Bransden and Joachain, 1990). For example, the *Fermi-Dirac statistics* of modern physics that is applied to microscopic phenomena of *fermions* is reduced to classical

Maxwell-Boltzmann statistics, which can quite happily be applied to the systems in *classical regime*, such as *ideal gas* (see for example Kittel, 1969).

We can summarize the basic unconventional phenomena of quantum physics that haven't been noticed in classical physics, as follows:

a) Quantum behavior of electromagnetic radiation (light as photons, Planck, 1900)
b) Particle behavior of photons (photoelectric effect, Einstein, 1905) and wave nature of electrons (de Broglie, 1923), resulting in wave-particle dilemma
c) Uncertainty principle (Heisenberg, 1925)
d) Accompanying wave functions for quantum mechanical species (wave mechanics, Schrödinger, 1925) and absolute square of wave functions as probabilities (Born, 1926).

Philosophical Aspects

Let us have a look at the definitions of ontology, epistemology and methodology which are the main constituents of philosophy of science and paradigms, in order to understand why philosophical approaches have to change while science is advancing or evolving itself. The question as to what is the form or nature of reality or what is there that can be known is referred to as *ontology* (Coll & Taylor, 2001). *Epistemology* is simply the philosophy of knowledge or of how we come to know (Hofer and Pintrich 2004, and Trochim 2000). *Methodology* is a set of tools involving methods and techniques that enable us to get information in more practical manner. In general a particular scientific research has to involve these three important issues, which are continuously affected by scientific innovations. Methodological approaches of a particular topic is very much dependent upon the views regarding the ontological and epistemological questions. For example, according to Coll and Taylor (2001), "those subscribing to realist ontology and objectivist epistemology rely on inquiry that is experimental and manipulative, in which questions and hypotheses are stated and are evaluated by empirical testing. In this approach careful control of experimental conditions is necessary to prevent outcomes being subject to extraneous influences." This is more likely to be a positivist approach, proposing that what science deals with is that what can be directly observed and measured. This is in a sense true approach if everything was directly observable and measurable as in classical physicists' mentality.

Now, let me return to quantum mechanics and attempt to discuss what are the new aspects that quantum mechanical approach has brought and that differ from classical ones (for further reading see also Murdoch, 1989). As far as the ontological aspects are concerned in quantum physics, we cannot establish the form of species whether they are *abstracts* as waves or *concretes* as particles before the laboratory experience. Abstract forms of species may turn out as concrete ones after a particular experiment or the opposite. I propose that this reality in quantum physics invokes the *relativist ontology* whilst classical physics is based on the *realist ontology*. *Einstein's relativity theory* also supports this assumption for modern science. I recon the discussion above proposes a required transition from positivist to post-positivist view of the world. According to positivist view, the research components are totally definite as observed even by a preliminary examination. However, as in the Heisenberg uncertainty principle, quantum mechanics has produced evidences and conflicting views in contrast to the realist ontology of positivism.

One can speculate that the predictions of quantum physics are only valid for the ontological issues in the teeny objects of microscopic world such as atoms, molecules and elementary particles, and the outcomes of these predictions cannot be applied to the macroscopic issues in the real world. In fact they are equally valid for the ontology in the real macroscopic world (Vedral, 2011).

Let us now explain this important matter with a few examples of the implications of quantum mechanics in the real world. These examples are so stunning that every tiny bits of microscopic quantum phenomenon are integrated and built up in a macroscopic object or body. First of all let us start with one of the most incredible birds, robins. It has been determined by Wiltschkos (1972) that robins, when they migrate to warmer Mediterranean costs, escaping from the harsh winter conditions of Scandinavia, seem to be able to detect one hundredth of very small fluctuations in the orientations of the Earth's magnetic field via a process called "*quantum entanglement*" (Gauger et. al., 2011) that even Einstein skipped by referring it as "spooky". The birds' somehow built a sort of biological compass, "the quantum sixth sense" that seems to be an excellent indication for one of the strangest features of quantum mechanics. This extraordinary phenomenon was first pointed out with a thought experiment of Einstein and his colleagues Podolsky and Rosen in 1935 as a paradox called "*EPR paradox*", however it was eventually proved to be a reality (Freedman and Clauser, 1972 and Blaylock, 2010). It describes how two separate and isolated particles have instantaneous connections via a weird quantum link. In the case of robins, the best explanation is that the spin entanglement of electrons occurs within a protein in the bird's eyes due to the Earth's magnetic field, and that makes the entangled electron pairs highly sensitive to direction variations of the Earth's magnetic field, allowing the bird to "sense" which direction it should migrate. The amazing discovery eventually led to the development of "quantum biology".

Another important implication of a different quantum phenomena is the "*quantum tunneling*" (a kind of quantum teleportation) of enzymes (Carlo 2012) inside the living cells, accelerating the chemical processes so that it would otherwise take much more time than lifetimes of the livings and therefore life wouldn't have been possible without this quantum process.

On the other hand, one of the most tangible applications of quantum physics is the *quantum computing* that make direct use of quantum mechanical phenomena, such as superposition and entanglement, to perform fast and efficient acquisition and process on data (Gershenfeld and Chuang, 1998).

As seen from these examples taken from the real life, maybe all of the quantum behavior are not only applied in the microscopic world but also in bigger objects such as the birds' eyes and living cells, surprising the most scientists who believed that the quantum laws are only valid at microscopic scale.

Let us now extend the philosophical discussion with a few arguments on the some fundamental aspects of quantum mechanics between Einstein and other well-known founders of quantum philosophy such as Heisenberg, Bohr and Dirac. Basically Heisenberg noted that there is an unusual relation between the precision of two basic quantities of physics; position and momentum. If we measure the position in precise, we have to give up measuring the momentum in a certain accuracy and vice versa. The basic differentiation between the two philosophical views that Einstein and others believed is that whether this uncertainty is a natural way that the universe works or it is an artifact that appears when measuring these quantities (Penrose 2011). Einstein who said the sentence "God does not play dice with the universe" never believed that the uncertainty is natural (see also Natarajan, 2008). If it is not natural we can explain it with a following argument: Observation of a microscopic object is limited with the wavelength of observing light. Reducing the wavelength of the incident light increases the precision of the position but also increase the light energy and therefore reduce the precision of velocity, resulting in more uncertainty in momentum.

However, Heisenberg postulated the uncertainty principal like a fundamental law of universe and the lowest product of uncertainties in position and momentum is in the order of the Planck constant which is a universal constant coming from very early creation of universe; supposedly the Big Bang. The conflict between Einstein and Heisenberg was finalized by Copenhagen interpretation of Bohr's Institute, postulating that we have to recognize this uncertainty without looking at it as natural or an artificial (Murdoch, 1989). It was further developed by Dirac who said; "Shut up and calculate!", following his great quantum mechanical formalism and Feynman's *Quantum Field Theory*, all based on the famous the uncertainty principal.

I personally believe that this is an uncertainty given to human beings by God. I in a way agree with Einstein that "nothing is uncertain for God" but I also agree with Heisenberg that "everything is uncertain for us".

Following the discussion above, as far as the epistemological and methodological aspects are concerned, we cannot perform ideal experiments or establish ideal theories that uncover the truth contrarily to objectivist classical view of physics. However we can only perform experiments and establish theories that may approach the truth. Since approaching is an infinite process, we cannot know how close we have reached the truth at a time. This is a true assumption from just a post-positivist perspective while positivists believe that the measured or observed values by an appropriate method are totally definite and correct way to reach the truth (Nevvajai, 2000). In contrast to quantum physics, classical physicists could judge and come to conclusions with their measured or observed values in a positivist way, because all the parameters of physical phenomena are correctly measurable and observable. However this is not true from the perspective of quantum physics. What positivists or classical physicists did not criticize or ask themselves is; "what is measurable and observable and to what extend?" As a matter of fact, the answer to this question should be *nothing* in hundred percent. The discussions on the philosophy of quantum physics and post-positivism must be built on this particular point in epistemology and methodology of modern sciences.

The firs principal alternative to *objectivism* could be seen as *subjectivism*, which supports that there is no external reality but findings of an inquiry are produced by the observer. However this is controversial with the post-positivist worldview, proffering *critical realism* instead of subjectivism in epistemological and methodological issues. A critical realist believes that there is a reality independent of our thinking about which science can study (Trochim 2000). While positivism strongly insists on realism, post-positivism is rather chary, supporting the philosophy of *critical realism*.

Post-positivists think that all observations could have a possibility of having misinterpretation, misunderstanding and error and that all theory can be improved. As Trochim (2000) stated, "where the positivist believed that the goal of science was to uncover the truth, the post-positivist critical realist believes that the goal of science is to hold steadfastly to the goal of getting it right about reality, even though we can never achieve the goal." Therefore objectivity in post-positivism is right approach from a broader perspective including a more comprehensive spectrum of most scientific views, although positivism believes that the objectivity of individual scientist extracts the true information about reality, no matter what their paradigms are. Post-positivism indicates the fact that no individual can see the world perfectly as it really is. Philosophy of quantum physics is based on many parameters with uncertainties and probabilities and that also supports an objectivity of this kind in the epistemological and methodological approaches. Perhaps unfortunately or fortunately, the universe does not look like what we see with our eyes.

The leading physicists of early twentieth century whether they were post-positivists or not, they led to great changes in our views about the universe, and their ideas and views undoubtedly reinforced us to reconsider the philosophy of science and the methods of education. Today reflection of these views upon science, technology and education continuously advances our knowledge. Both in modern physics and post-positivism, extending the critical questions may raise answers that could result in new types of physics and philosophy of science. Future may be re-formed with these new ideas as it has been presently done by the implications of quantum mechanics.

Educational Aspects

We discussed the supporting views of quantum physics for post-positivism as philosophy of science. In this section let us raise a question as to "what are the educational aspects that post-positivism foresights?"

Noe (2001) summarizes the transition from positivism to post-positivism as follows: **"**The positivistic method stemmed from the spirit of experimental philosophy which promoted the scientific revolution. It was this period that the classical positivism emerged and social sciences began to introduce the positivistic method. In the twentieth century, the *Vienna Circle* tried to realize the methodological unification between natural sciences and social sciences under the slogan of unified science. But their radical reductionism which aimed to assimilate social sciences to natural sciences trying to introduce unified language of physics was suffered a setback as a result. After that the trend of post-positivism made an important alteration in understanding positivistic method by proposing new theses of the theory-leadenness of observations, the impossibility of crucial experiments and so on. According to them, the relation between natural sciences and social sciences must be reconsidered not as hierarchy, but as pluralistic co-existence.**"**

This in fact proposes not a separation of the two kinds of sciences (social and natural sciences) but need of both sciences in most aspects. For example, when the modern universities in Turkey were first established in the years 1930-1960, positivistic views were so dominant that the social and natural science curricula had totally different kinds of infrastructure. Today the need for exchanges of information has been recognized in higher education. As a result, more and more interdisciplinary programs are developed in our individual departments. Nowadays, for instance, physics graduates can find more jobs in projects of different fields rather than in their own fields.

As James et al (1997) suggested, "The traditional boundaries of the separate sciences do not accord with contemporary experience; and wider public understanding and interest in science is most likely to be developed through an integrated approach." This kind of *globalization* in science requires *lifelong* and continuously *constructing learning* in most aspects of sciences (van der Molen, 2001). As a result of post-positivist new thinking, Said (1996) points out the importance of achieving *global understanding* and explains the process of approaching the truth as follows; "we sift from the truth of reason to the truth of images, from the truth of images to the truth of intuition, from the truth of intuition to the truth of feeling and from the truth of feeling to the truth of pattern. We shift from truth to truth. Each one of us possesses a little piece of truth. Total knowing requires as an in-gathering of pieces of truth."

Most post-positivists are also *constructivists* in pedagogical terms, because in a post-positivist view of the world the truth is an external reality that we try to approach and therefore learning about a certain issue can never be complete but construct our experiences. Accepting constructivist beliefs about the nature of truth and knowledge loads us as university professors with completely different mission in teaching methodologies of science, in comparison to conventional positivist approaches in education, which proposes that scientific knowledge can entirely be transmitted to the learner. Under constructivism, the teacher holds a totally different role; that of a facilitator rather than transmitter of knowledge (Coll and Taylor, 2001), involving students in an active way in the learning process. Teachers' attitude of this kind in university education would trace a kind of idea in students' mind that the knowledge they receive is not a concrete block of information that cannot be changed or constructed but, nevertheless, it can be modified, added up and even completely changed. Therefore such higher education will produce individuals who can set up their own paradigms in terms of epistemology and methodology, and whose views are critical realism as followed by the leading scientists of modern physics.

Conclusions

It is discussed why the transition of philosophy of science from positivistic to post-positivistic approaches is necessary from a novel perspective considering the basic principles of quantum physics. Concerning the realities about the *limitations* of observation and evaluation in modern sciences leads us to question the meanings of objectivity, truth and therefore present knowledge base, resulting in a re-alignment of ontological, epistemological and methodological aspects regarding the philosophy of research. Since post-positivism foresights a relativist and critical realist approach towards the principal issues (ontology, epistemology and methodology) of the philosophy of science, I propose that the right way to get close to the truth and enhance our knowledge is to have overall perspectives of post-positivism that matches well with the advancement of modern physics in most aspects. My critical feelings suggest that this new approach would be a good pattern in receiving a right higher education, proposing *interdisciplinary, constructive* and *active learning* rather than an imposing *way* in a traditional fashion.

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