UNDER PEER REVIEW

Opinion Article

Advances in Modern Physics:
Transition from Positivism to Post-positivism
in Education and Research

Abstract

Advances in quantum physics in the first quarter of the twentieth century dramatically influenced perspectives on the scientific and philosophical issues. In this paper, I discuss why a shift towards post-positivism in philosophy of science is necessary from a novel perspective considering the basic principles of quantum physics. Concerning the realities about the *limitations* in observation and evaluation in scientific results 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. *Parallel analyses* of the *quantum mechanical* and *post-positivist* approaches foresight *relativist* and *critical realist* views in philosophical aspects. 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. I suggest that this new approach would be a good pattern in conduction of higher education, proposing *interdisciplinary, constructive* and *active* learning rather than an *imposing way* in a *classical* fashion.

Introduction

Transformation of knowledge, during the two important stages of learning process—*education* and *research*—results in continuous development of science and technology. As a result, advancement in science and technology reinforces mankind 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 as the imaginations on the *atomic* and *electromagnetic nature* of the universe changed (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 mankind who could hardly ever imagine a better understanding of the microscopic nature and therefore matter as a whole.

While, 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, some modern theories and experiments of great scientists such as Planck, Einstein, Bohr, de Broglie, Heizenberg, Schrödinger and Born proved that their predecessors could ever be so much wrong as we might be now. Success of the above mentioned physisists was to have a *deep knowledge* of what had been done 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. Fraday postulated the electromagnetic induction (1831) which later on resulted in many impotant applications such as electric generators and engins (Özdemir, 2015) , bec ause he didn't ignore 5 seconds of phenomena during his lifelong experiments.

Novel perspectives and achievements of modern physics have ultimately led to a transition of

UNDER PEER REVIEW

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." I interpret paradigms as *intellectual tradition* involving every aspects of philosophy of science such as *ontology*, *epistemology* and *methodology*. Paradigms change because, according to Williams (1982), science is always potentially in the edge of revolution. From my 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.

In this paper, I intend to discuss 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, I suggest 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

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 continuously 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 futher reading, see also Einstein and Infeld forworded by Isaacson, 2007).

This eventually led to *wave-particle dilemma* as follows: 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 this idea that energy levels of electrons in an atom could be changed by either emission or absorption of photons. This was an early quantum mechanical model for atomic nature. In contrast, de Broglie eventually suggested the wave nature of electrons in 1923. This was putting on electrons a wave parameter called the *de Broglie wavelength*. As a matter of fact Schrödinger in 1925 formulized that every quantum mechanical system had to have a waveform by an equation called after his name. 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 foresights accompanying wave functions to every particle system and that, as invoked by Born in 1926, the wave functions indicate probabilities of quantum mechanical species where they may be situated in space, although the Newton mechanics can determine the exact positions. I would not like to cause a misunderstanding of readers towards an idea that the Newton mechanics is more comprehensive than the quantum mechanics just because

UNDER PEER REVIEW

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.

In fact, Heizenberg in 1925 highlighted an important reality in quantum physics—uncertainty principle: Let me 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).

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 *Bhor 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 *Boltzmann statistics,* which can quite happily be applied to the systems in *classical regime,* such as *ideal gas*

UNDER PEER REVIEW

(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 (Heizenberg, 1925)
d) Accompanying wave functions for quantum mechanical species (wave mechanics, Schrödinger, 1925) and wave function as probability (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 (Trochim 2002). *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 Heizenberg uncertainty principle, quantum mechanics has produced evidences and conflicting views in contrast to the realist ontology of positivism.

As far as the epistemological and methodological aspects are concerned, we cannot perform ideal

UNDER PEER REVIEW

experiments or establish ideal theories that uncover the truth in contrast 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 although 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, because all the parameters of physical phenomena are correctly measurable and observable, classical physicists could judge and come to conclusions with their measured or observed values in a positivist way. However this is not true of quantum physics. What positivists or classical physicists did not criticize or ask themselves is; "*what is measurable and observable and to what degree?*" As a matter of fact, the answer to this question should have been *nothing* in hundred percent. The discussion of philosophy of quantum physics and post-positivism must be based upon 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 in contrast with post-positivist view of the world, proposing *critical realism* in epistemological and methodological approaches. A critical realist believes that there is a reality independent of our thinking about it that science can study (Trochim 2002). While positivism is realism, post-positivism is a 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 all the time. As Trochim (2002) 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, if not all but most scientific views, although positivism believes that the objectivity of individual scientist abstracts the true information about reality, no matter what their intellectual traditions are. Post-positivism indicates the fact that no individual can see the world perfectly as it really is. Philosophy of quantum physics is based upon the uncertainty principal of Heizenberg 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 be post-positivists or not, they led to great changes in our views upon 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.

Educational Aspects

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

UNDER PEER REVIEW

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-ladenness 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 between 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 trough 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 whose views are critical realism as led by the leading scientists of modern physics.

UNDER PEER REVIEW

Conclusions

I discuss 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 *classical* fashion.

References

Bransden, B. H. and Joachain, C. J. (1990), *Introduction to Quantum Mechanics,* Longman Scientific & Technical, Essex.

Coll, Richard I. & Taylor, Neil T.G. (2001). Using constructivism to inform tertiary chemistry pedagogy. *Chemistry Education: Research and Practice in Europe, 2*(3), 215-226.

Einstain, A. and Infeld, L., foreworded by Isaacson, W. (2007), *The Evolution of Physics,* A Touchstone Book published by Simon and Schuster, New York, London, Sydney, Toronto.

James, E. Eijkelhof, H. Olson, J. Raizen, S. & Saeaz, M. (1997). Innovations in science, mathematics and technology education. *J. Curriculum Studies, 29*(4), 471-483.

Kittel, Charles (1969). *Thermal Physics.* New York, London, Sydney, Toronto: John Wiley & Sons, Inc.

Kragh, H. (2002). *Quantum generations: A history of physics in the twentieth century,* Princeton University Press.

Murdoch, D. (1989), *Neils Bhor's Philosophy of Physics,* Cambridge University Press, Cambridge.

Nevvajai, Igor D. (2000). How is it possible to conceive of being in science? *Proceedings Conf. on Metaphysics for the Third Millennium,* Rome, Italy. Available: http://www.philosophy.ru/library/nevvajai/conceive.html.

Noe, K. (2001). The rise and fall of positivism: From a viewpoint of the philosophy of science. *Sociological Theory and Methods, 16*(1), 3-17.

Özdemir, Y. (2015). *Leaders of Science; Bilime Yön Verenler (in Turkish).* Ankara: Nobel

Yayın.

Pickstone, J. V. (2001). *Ways of Knowing,* Manchester University Press, Manchester.

Said, Abdul A. (1996). Other ways of knowing: Discovering peace and conflict resolution. Available: http://www.american.edu/academic.depts/acainst/cgp/article1.htm.

Tekeli, S. Kahya, E. Dosay, M. Demir, R. Topdemir, Hüseyin G. Unat, Y. & Aydın, Ayten K. (1999). *Introduction to History of Science; Bilim Tarihine Giriş (in Turkish).* Ankara: Nobel Yayın.

Trochim, William M.K. (2002). The research methods knowledge base: Positivism and post-positivism. Available: http://trochim.human.cornell.edu/kb/positvsm.htm.

van der Molen, Henk J. (Ed.). (2001). *Virtual University? Educational Environment of the Future.* London: Portland Press.

Warwick, Paul & Stephenson, Philip (2002). Reconstructing science in education: insights and strategies for making it more meaningful. *Cambridge Journal of Education, 32*(2), 143-151.

Williams, Pearce L. (1982). *Criticism and the growth of knowledge.* Cambridge University Press Cambridge, London, New York.