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Utilizing History and Philosophy of Science (HPS) to Teach Physics: The Case of Electromagnetic Theory

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Here the paper provides a historical and philosophical analysis of the development of electromagnetic theory in physics teaching for the benefit of scientific literacy. The analysis is described by the paradigms offered by Kuhn. A number of scientists' work in electromagnetic theory which is embedded in the tension between engaging in revolutionary science and normal science provides an insight into how scientific work is thought to proceed. The work of revolutionary scientists: Faraday and Maxwell, who were pivotal in developing the understanding of electromagnetic radiation. A group of scientists now known as the Maxwellians were integral to refining and clarifying Maxwell's theory. By realizing these things, the students will become inspired and reinforced in resolve to understand the richness of scientific discovery.

Keywords: History and philosophy of science, Kuhn's theory of paradigms, science education.

INTRODUCTION

History and philosophy of science (HPS) have been implemented in science teaching for a long time. A lot of educators have discussed the need to use HPS in order to understand science and to develop scientific literacy. Thagard (2011) states his view on the reasons why people concerned with science education should be interested in the history and philosophy of science. First, the history of science provides valuable background about the origins of the concepts and theories that science educators aim to convey to new generations of students. Second, the philosophy of science can contribute insights about the structure and growth of scientific knowledge through penetrating discussions of methodology and norms of inference.

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Third, history and philosophy of science can potentially help to address questions about why scientific ideas are often so hard to communicate to the general population. Sherratt (1982), reviewing British science curriculum in the first half of the 20th century, mentioned the following benefits of using HPS: (a) demonstration of humanistic and cultural aspects of science, (b) teaching about the nature and methods of science and (c) prevention of over-specialization by a sterilized focused solely on the latest products, instruction. In addition, a great benefit, especially for teachers, was specified – intellectual enrichment through awareness of the legitimacy of alternative views and interpretations in science. The latter occurs in today's students as it did in science's historical past.

Harvard Project Physics Course (HPPC), developed under Rutherford, Holton and Watson, is perhaps the best-known project heavily loaded with HPS contents. This feature was justified by a need to produce a physics course with a humanistic orientation, attracting and motivating a wider range of students to study physics, in the way others study history and literature (Brush, 1989). Assessment showed that in response to such instruction, students improved their attitudes to physics

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State of the literature

- The preliminary studies showed positive outcomes to use history and philosophy of science in order t o understand science concept and to develop scien tific literacy.
- This method will help students make sense out of historical facts and reach tentative conclusions on what was really happening to the scientists involve d during the time period being studied.
- Although various benefits for teaching and learnin g history and philosophy of science have been poi nted out, the status of its implementation is rather deficient.

Contribution of this paper to the literature

- This study provides a historical and philosophical analysis of the development of electromagnetic the ory in university physics teaching.
- The development of electromagnetic theory is esp ecially interesting for teaching because it can show the reasons for paradigm shifts in research commu nities.
- By realizing these things, the physics students will become inspired and reinforced in resolve to unde rstand the richness of development of electromagn etic theory.

(Welch & Walberg, 1972). Many of them were surprised to find historical-philosophical aspects of physics knowledge, which contrasted their image of physics as being strictly formal ("mathematical") and rigid theoretical construction. Niaz et al. (2002) have shown how history and philosophy of science can facilitate freshman students' conceptual understanding of atomic structure (based on the models of Thomson, Rutherford, and Bohr). Control group students received instruction in the traditional manner, whereas the experimental group students anticipated in six classroom sessions that involved arguments, counterarguments, and discussions within a HPS perspective. Results obtained showed that 37% of the experimental group students and 5% of the control group provided conceptual responses, and the difference was statistically significant.

Although various benefits for teaching and learning history and philosophy of science have been pointed out, the status of its implementation is rather deficient (Monk & Osborne, 1997). HIPST (History and Philosophy in Science Teaching, 2008–2010) is a European project focusing on more effective strategies of development and implementation of HPS into science teaching (Höttecke, Henke & Riess, 2012). There are 10 partners from 8 European countries (Germany, Greece, Hungary, Israel, Italy, Poland, Portugal, and UK). A detailed account on guiding ideas, objectives, framework, and management structure of HIPST has been introduced elsewhere. The project specifically aims at the development of teaching and learning material for learning scientific content as well as learning about epistemology, processes and contexts of science.

The topic of electromagnetic theory is fertile because it relates to various epistemological and philosophical concepts. Its history is strongly linked to the relationships between science, technology and social-economic problems. The historical conceptual development of electromagnetic theory is especially interesting for teaching because it can show the reasons for paradigm shifts in research communities, based on a progression moving from phenomenological observations to qualitative and then mathematical models and laws, in an increasing process of abstraction. This historical progression can assist learning progression and challenge students' alternative ideas.

KUHN'S THEORY OF PARADIGMS

Thomas Kuhn is one of the most influential historian and philosopher of science of the twentieth century. His book The Structure of Scientific Revolutions is well-known descriptions of how progress in science occurs have influenced a number of diverse disciplines and is the most widely read book ever written in this field (Kuhn, 1970).

Paradigms have been referred to in The Structure as universally recognized concrete scientific achievements, with a twofold function. They establish, inspire and foster particular coherent scientific traditions, and they issue patterns and models of scientific research. Paradigms are open-ended and are subject to further articulation and specification in the course of normal science, that is itself a puzzle-solving activity induced by the paradigms. During that period, scientists do not handle "genuine" problems. Instead they build their competence, working with paradigmatically provided projects, the puzzles, which are formulated in the concepts and language of the paradigms. Assembling the solutions, which is guaranteed by the paradigms, is a mopping-up operation. Rather than investigating and revealing the world, the scientists test their ingenuity and skills, increasing the accuracy and scope of the paradigms either in theory or in their match with the world. Musgrave (1980) discusses Kuhn and some of his concepts, says: According to Kuhn's conception, the scientific community engages in 'normal research' for relatively long periods between short bouts of 'extraordinary research.' During normal periods there is consensus on the guiding principles of research (the paradigm), a consensus reinforced by the dogmatic style of scientific education. Rive paradigms are not taught, their intervention is discouraged, and controversy over fundamentals ceases. Instead, the scientific community concentrates on 'puzzle-solving,' on forcing nature to fit the paradigm to which it is committed. If nature is stubborn and a scientist fails to solve his puzzle, then he is blamed, not the paradigm. Only in 'extraordinary' periods, when rival paradigms compete, do unsolved puzzles or 'anomalies' turn into critical arguments against paradigms. But such periods are short-lived—soon consensus emerges on a new paradigm, and the scientific community devotes itself once again to normal science.

In the domain of education, Kuhn's ideas are pervasive in numerous contemporary science education reform documents. The theoretical work of Kuhn offers a powerful tool for the classroom: introduction of the idea of extraordinary science and normal science. And the work of scientists in electromagnetic radiation theory appears to follow the patterns Kuhn claimed would exist- a period of extraordinary inquiry, followed by normalization.

DEVELOPMENT OF ELECTROMAGNETIC THEORY

We are going to study about the scientists who had great effects on the theory and the field of electromagnetic Wave in chronological order. The work of revolutionary scientists: Faraday and Maxwell, who were pivotal in developing the understanding of electromagnetic theory. Faraday provided the scientific foundation for Maxwell. Maxwell followed with a mathematical theoretical underpinning and extension of Faraday's discovery. A group of scientists now known as the Maxwellians were integral to refining and clarifying Maxwell's theory which enabled later experimentally proved Maxwell's theoretical extension demonstrated the existence of electromagnetic radiation by Hertz and development of wireless telegraphy by Marconi.

Faraday (1791-1867)

Faraday began his research on electromagnetism as a laboratory assistant aiding in Humphrey Davy's experiment on the magnetic effects produced by electricity. But the catalyst for his own impendent research in electromagnetism came when his friend Richard Phillips asked him to write an account of the origins and developments within electromagnetism over its roughly two-year history as a recognized scientific domain. In order to write an adequately-informed history, Faraday replicated the experiments leading to Oersted's initial discovery. The resulting work-is the "Historical Sketch of Electro-magnetism". Perhaps the best characterization of this work is that it was an extensive review of the state of electromagnetism in its infancy as a science.

After hearing of Oersted's announcements that electric current in a wire produces magnetic fields and further experiments and theoretical expositions of Ampere, Faraday was convinced that he could reverse the Oersted's experiment, that is, magnetism can produce an electric current. Faraday's paper in Quarterly Journal of Science in September 1821 entitled On Some New Electro-Magnetical Motions and on the Theory of Magnetism, read: After the great men who have already experimented on the subject, I should have left doubtful that anything I could do could be new or possess an interest, but that the experiments seem to me to reconcile considerably the opposite opinions that are entertained on it.

Faraday's 1831 discovery states: The movement of a magnet in a coil of wire induces a current flow in the wire. This descriptive statement launched one of the greatest and beneficial discoveries made by man. In the introductory paragraph of Faraday's read paper before the Royal Society of England, he said: It appeared very extraordinary, that as every electric current was accompanied by a corresponding intensity of magnetic action at right angles to the current, good conductors of electricity, when placed within the sphere of this action, should not have any current induced in them, or some sensible effect produced equivalent in force to such a current. These considerations with their consequence, the hope of obtaining electricity from ordinary magnetism, have stimulated me at various times, to investigate experimentally the inductive effect of electric currents.

In around 1845, Faraday was challenging the prevailing paradigm that electromagnetic phenomena were the result of direct action at a distance of electrical particles and proposed that they were caused by strains in an electromagnetic field that filled the surrounding space (Faraday, 1846). This was known as field theory. He proposed the widely used method for visualizing magnetic fields. We can trace in space the lines one obtains following the direction of the compass needle, he called them lines of force, the term field lines is now more commonly used. But the ideas were still far from being accepted when Maxwell under Kelvin's guidance, began to study Faraday's ideas and work. Faraday successfully led us a unified theoretical understanding of the phenomenon of electromagnetism. In Maxwell's own word "Faraday is, and must always remain, the father of that enlarged science of electromagnetism." We turn, then, to Maxwell.

Maxwell (1831-1879)

In 1855, Maxwell was a twenty four years old scientist at the beginning of his lifelong research on electricity and magnetism. Faraday's Experimental Researches in Electricity was published in three volumes in 1844, 1847 and 1855. After reading Faraday's papers, Maxwell produced the major work on electricity and magnetism, On Faraday's Lines of Force followed by On Physical Lines of Force in 1861. A Dynamical Theory of the Electromagnetic Field was received in October 27, 1864, and read by Maxwell in December 8, 1864 at the Royal Society of London. An abstract was printed in the Proceedings of the Royal Society of London. In this abstract no mathematical equations are reported. The full paper appeared in the Philosophical Transactions of The Royal Society of London (Maxwell, 1865). A common denominator in all the stages of Maxwell's work was his commitment to the field interpretation of the electromagnetic phenomena. This is not to say that his view of what "field" meant was static but rather that it evolved and was polished with time.

Maxwell developed mathematical equations in his famous treatise. The equations confirmed Faraday's earlier experiments on electrical inductance which stated that a changing electrical field induced a changing magnetic field, which in turn induced a changing electric field. Most importantly, Maxwell's equations predicted the existence of electromagnetic waves. Ten years after Maxwell's death in 1879, Hertz experimentally confirmed the existence of the electro-magnetic waves predicted by Maxwell. Maxwell once publicly acknowledged his scientific debt to Faraday, and in the seven page preface to Maxwell's, 500 page Treatise on Electricity and Magnetism, he says that his major task was to convert Faraday's physical ideas into mathematical form, and hence to make them more widely accessible. Asimov(1996) said about Maxwell's equations: in considering the implications of his equations, Maxwell found that a changing electric field had to induce a changing magnetic field, which in turn had to induce a changing electric field, and so on; the two leap-frogged, so to speak, and the field progressed outward in all directions.

In fact, Maxwell's Treatise had a more complex derivation of thirteen equations rather than the four equations generally mentioned. Heaviside is the scientist who simplified the thirteen equations to four equations. The found this long list and argued that a more compact set of equations involving only the electric and magnetic forces and fluxes would be clearer and more useful, particularly in the treatment of electromagnetic propagation and energy flow. Maxwell's four equations were thus synopsized as follows: 1.Unlike charges attract each other; like charges repel (also called Coulomb's Law). 2. There are no single, isolated magnetic poles (if there is a north pole, there will be an equivalent south pole). 3. Electrical currents can cause magnetic fields. 4. Changing magnetic fields can cause electrical currents.

Maxwell's treatise based on Faraday's earlier work replaced action at a distance with the newly emerged field theory. In this we have an excellent example of a paradigm shift as described by Kuhn. After Maxwell's work, his theory was refined between 1879 and 1894 by a group of scientists who are known as the "Maxwellians". Their works contributed to the clarification of many concepts that had been introduced by Maxwell.

Maxwellians

Maxwell's ideas and equations were expanded, modified, and made understandable after his death, mainly by the efforts of FitzGerald (1851-1901), Lodge (1851-1940) and Heaviside (1850-1925). They were christened as "The Maxwellians". This group was later joined by Hertz who had conducted the famous experimental demonstration of the existence of electromagnetic waves and by Marconi who developed the wireless telegraph.

Heaviside (1850-1925)

Heaviside left school when he was sixteen years old; however, self-study overcame gaps in his formal education. He began his career as a telegrapher and to find a way to improve signaling along submarine cables which by 1866 were being laid on the ocean floor across the Atlantic. He turned to Maxwell's treatise, though he said much of its mathematics was then far above his head. Hunt (1991) said virtually everything Heaviside published after 1882 concerned the elaboration and application of Maxwell's theory. That year seems appropriate from which to date Heaviside's emergence as a public exponent of Maxwell's theory and his designation as a 'Maxwellian". In 1879, Heaviside published his work in the magazine "Electrician" on the "Sensitiveness of the Wheatstone Bridge". Thus he took his place as one of the acknowledged authorities on the subject.

FitzGerald (1851-1901)

FitzGerald was well educated compared to the other Maxwellians. He attended Trinity College in Dublin and named Erasmus Smith's Professor of Natural and Experimental Philosophy. FitzGerald turned to the study of Maxwell's Field theory while trying to prove a mathematical theory of James MacCullagh, a mathematician, and Trinity College graduate. MacCullagh's work was in optics and as Hunt(1991) described it, MacCullagh "made the potential energy of an element of the ether proportional to the square of its absolute rotation or curl. MacCullagh's theory was not held in high esteem in the scientific community and FitzGerald set about trying to lend credence to MacCullagh's work. FitzGerald was of the opinion that Maxwell's work confirmed MacCullagh's theory.

Lodge (1851-1940)

Lodge broke away from his father's business, enrolled at University College London, and earned his doctor of science degree in 1877. After reading Maxwell's treatise in 1876, Lodge wrote two papers for the Philosophical Magazine describing a mechanical model he had devised to simulate electrical phenomena based on Maxwell's principles. His work was on radio communication and especially equipment for achieving syntony, the ability to tune the transmitting and receiving circuits to the same wavelength to assure privacy and secrecy of communication. This was an important aspect of radio communication. Marconi developed such a tuning system and studied Lodge's syntony equipment.

Hertz (1857-1894)

Hertz took the position of Professor of Physics and Director of the Physics Institute as successor to Rudolf Clausius (1822–1888). He was fresh from his triumphs in Karlsruhe, where he had proved in a series of elegant experiments that the long-wavelength electromagnetic waves implicit in Maxwell's theory existed. He also had been able to demonstrate convincingly that these waves had all the well-known properties of light waves – reflection, refraction, interference, polarization. Almost immediately Hertz became the superstar of the physics community, not merely in Germany but throughout the world of science. The object of these experiments was to test the fundamental hypotheses of the Faraday-Maxwell theory, and the results of the experiments are the confirmation of the fundamental hypotheses of this theory. As state earlier, Hertz was one of at least four scientists later known as "the Maxwellians" although he was not initially part of the group. The maxwellians had explored and refined Maxwell's theory and partially anticipated Hertz's discoveries. Their work provided some of the basis and impetus for Hertz's work.

Marconi (1874-1937)

Marconi was born in 1874 in Bologna, Italy. After reading of Hertz's experiments in demonstrating the existence of electromagnetic radiation aroused great interest of Marconi, he turned his mind toward wireless. He commenced his experiments on wireless telegraphy in 1894, the same year as the death of Hertz. In 1895, Marconi succeeded in transmitting wireless radio signals across a room inside his home. And seven years later (1894), transatlantic signals transmitted from Marconi's engineers and technicians in England were received across the Atlantic Ocean by Marconi at his radio station in Canada, a distance of about 2000 miles. Marconi as a normal scientist was in attempting to put into practice the extraordinary theoretical work of Faraday and Maxwell.

PARADIGMS IN THE DEVELOPMENT OF ELECTROMAGNETIC RADIATION

The two competing paradigms on electromagnetic radiation emerged in the mid 1850s. Scientists who adhered to each of the theories defended their positions until irrefutable proof of the correctness of the field theory caused the abandonment of the action at a distance theory. By Kuhn's definition, one must conclude that a paradigm shift and a scientific revolution were raking place when the action at a distance theory was replaced by field theory. Kuhn's concept of normal science is that it strives to bring theory and fact into closer agreement. Its object is to solve a puzzle for whose very existence the validity of the paradigm must be assumed. The research worker is a solver of puzzles, and only in passing, a tester of paradigms. So Heaviside, FitzFerald, Lodge, Hertz and Marconi were engaged in normal science as they tested various aspects of Maxwell's theory. Hertz especially was working on the proof of the theory. Marconi developed Maxwell's theory into a workable and usable communication system. The normal scientists were working on the poof and not the theory.

DISCUSSION

The use of historical examples is warranted because there is evidence in science education that many problems faced by students in understanding physics concepts are similar to those that had to be overcome by early scientists as they developed a new physical idea. An ontological analysis of the early scientists' ideas during instruction might help students to understand the ontology of the early conceptions compared to the ontology of the modern scientific ones. Including the historical and philosophical aspects of science in science courses is one of the key recommendations derived from science teaching research studies (de Castro & de Carvalho 1995; Matthews, 1994). History and philosophy of science are considered, at the least, as subjects that provide ideas for activities which students find interesting and problematic.

Theoretical support for the use of HPS in education came from the development of the theory of learning, an implementation of the philosophical constructivism (Staver, 1998). Thus, a simple, but profound, idea which stated that understanding of the world is determined by knowledge already possessed at each stage of development received a sound theoretical elaboration ("theory-laden" nature of reasoning used by scientists (Hanson, 1958) and "p-prims" based reasoning of the science learner (DiSessa, 1993)). The new vision of education made valid, and essential, alternative conceptions ("misconceptions") held by the students, as well as their ideas, beliefs, and epistemological commitments prior and during the formal learning (Nersessian, 1989; Galili, 1996). Educational importance was asserted to present science as an interplay of competing ideas, instead of the indoctrination of unique and correct theories. It was realized that instruction restricted to the "end of line" knowledge, could be the way to "educate" a computer, but does not work well with regard to humans. Recent research in science education has drawn attention to the importance of alternative interpretations, rivalries, and conflicts in scientific progress (McComas, Almazroa & Clough, 1998; Niaz, 2001).

Examining the status of the history of science in education, it has become clear that reflective thinking may not differ from other perspectives in education: it might be possible to incorporate principles of reflective thinking with historical perspectives. This method will help students make sense out of historical facts and reach tentative conclusions on what was really happening to the scientists involved during the time period being studied. Under this method students analyze provided information and gather other information to aid in their analysis. They then must support their generalizations and defend or abandon them when new evidence is found. Students thus become active and involved learners utilizing information from all sources as material to prove or disapprove hypotheses and to throw light on problems. All of the above developments argue that science teaching and learning needs to be more contextual, that science needs to be seen in its historical, philosophical, and intellectual context. That after stressing 'hands on science' we need to stress 'minds on science' (Matthews, 1989). There is little doubt that science teachers who know something of the history and philosophy of their subject can enliven their classroom presentations, and bring more coherence to the structure of their programmes, and then the quality of teaching and learning must be improved.

CONCLUSION

This study outlines the work of Faraday, Maxwell and Maxwellians on the development of electromagnetic radiation. Their work parallels discussions by Kuhn on the social, personal and scientific background necessary for a paradigm shift and a scientific revolution to occur. The paradigm shift started when Faraday made electrical discoveries and assumptions that started a paradigm shift in motion from the prevailing paradigm of action at a distance. The emerging field theory postulated that magnetic lines of force and electrical current were mutually interlocked and when set in motion by a change in the magnetic field or the motion of a conductor in a magnetic field, or flow of current in a conductor, an electromagnetic radiation was generated. Maxwell mathematically proved this theoretical assumption in a 500 page treatise and Maxwellians were integral to refining and clarifying Maxwell's theory which enabled later experimentally proved Maxwell's theoretical extension demonstrated the existence of electromagnetic radiation by Hertz and development of wireless telegraphy by Marconi. Kuhn's concept of scientific revolution and normal science as described by Kuhn was effect. By realizing these things, the science students will become inspired and reinforced in resolve to understand the richness of scientific discovery.

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