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EPISTEMOLOGICAL AND HISTORICAL STUDIES OF PHYSICS CONCEPTS FOR SCIENCE TEACHING

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Submitted to the International Conference
"The History and Philosophy of Science and School Science Teaching"
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ABSTRACT

Theoretical aspects and applications of a research program in physics teaching will be presented. An epistemological framework has been developed in parallel with historical case studies on fundamental concepts and theories of physics. Energy and entropy and the first two laws of thermodynamics make up one topic: the original contexts were analysed with twofold emphasis, the understanding of physical meanings and their historical construction. Students' ideas on the subject were surveyed and used to set up synoptical networks which are used to establish dialogical interactions in the classroom. The studies were also applied to the planning of a science exhibition for the general public,

where the relationship of the evolution of scientific thought with the transformation of man's activities in society is illustrated.

Introduction

The work presented here is one of several lines of research being developed in the Graduate Course on Physics Science Teaching. This course was established jointly by the Institute of Physics and the School of Education of the University of São Paulo in 1973.

The work proceeds along three lines: epistemological, as anlysis of the process of the construction of scientific knowledge; historical, as case studies of the origin and evolution of scientific concepts and theories; educacional, as application to classrom teacher–student interaction and to planning of scientific exhibitions.

The program profits from a multidisciplinary collaboration among several areas and universities[1].

Epistemological Framework

Studying the origins of the concepts and theories of Physics and considering the deep influence of the mechanical philosophy in science and in general thought we were led to examine Newton's conceptions and his powerful epistemology of "Reason and Experiment", of passive and active Principles, showing the path of analysis and synthesis to the general Laws of Nature. The Laws "by which the Things themselves are form'd"; do not consist in occult qualities, "their Truth appearing to us by Phaenomena, though their Causes be not yet discover'd...For these are manifest Qualities, and their Causes only are occult..."

(I. Newton, 1704).

The contact with Newton's thought and with recent historians' interpretations, (Dobbs, 75, Westfall, 71) gave directions to our analysis of the meaning of physical concepts and the understanding of their historical evolution. Furthermore, the originality and completeness of his conceptualization, the complexity of elements in the creation of the concept of Force, gave support for a clearer understanding of the distinction between the historical construction of scientific knowledge and every day reasoning about science. It enhanced the new rationality that was implanted in the XVIIth Century. "Newton...modifying orthodox mechanism allowed it to rise above itself to the more sophisticated level of modern science" (Dobbs, 1975).

The epistemological analysis of this rationality has an underlying principle: knowledge — expressed by language, symbols, gestures, relations in a logical and dynamical structure of meanings — does not reside inside our minds only, but, in a dialectical way, it consists of the capture of an exterior reality, an appropriation performed inside the social context (Bakhtin, 1929/1981, Vygotsky, 1934/1962).

The elements chosen to implement a consistent framework to think the construction of scientific knowledge are: the process of discovery–creation of concepts and theories; the object of a theory, its constance and transformation throught the perception of new phenomena and the realization of new syntheses; the truth and the limits of a scientific theory; the understanding in science in relation to reality, natural and social; the fragmented quotidian knowledge and the consistent, axiomatic theories built through historical process (Bohm, 1964; Heller, 1970; Langevin, 1938; Schenberg 1984; Paty, 1988).

Historical Studies

Several historical studies have been developed as dissertations for Master's degree[2]. Looking for early meanings, focussing the ambiguities at the conceptual frontiers of the physical theories, seems to be a way to complement the understanding, both of some scientific meanings and of the complexity of its construction. The adjustment of knowledge to the world (nature and social reality) goes as circular processes of reciprocal influences. As we follow the original papers and the historian's analyses, the scientific order of reasoning seems irregular, discontinuous, sometimes incongruent — till a new synthesis is accomplished (Kuhn, 1959; Bohm, 1964).

Our interpretations are not meant to be original or definitive. Rather, they are exercises of re–creation or ways to understand the concepts, taking advantage of the fact that focussing the historical moments of change allows new links with reality to be formed. They will be different links for each participant in the work, following his own personal history of interactions, inside and outside of school (Hamburger, 1989).

Educacional Applications

For application in the classroom, a dialogical student–teacher interaction is proposed, through the development of synoptical networks

containing the knowledge expressed by the class (Fleshner, 1970; Hamburger, 1988; Kubli, 1979).

In a scientific Exhibition panels and experiments were designed and built in the case of thermodynamics[3].

EXAMPLE: STUDIES AND APPLICATIONS ON THE ORIGINS OF THE CONCEPTS OF ENERGY AND ENTROPY AND THE CONSTITUTION OF THE FIRST TWO LAWS OF THERMODYNAMICS.

Historical Synthesis

The main ideas developed are briefly presented, following the synthesis made for the Exhibition.

The first Panel, called **The Path of Fire**, summarises the basic epistemological idea. The contents of the panels are the following.

— Thinking about Fire. The question is to understand the difference that exists between the fire that burns spontaneously in the forest, and the fire that exists between two stones and is produced with a purpose. We look for the moments where ***action*** is simultaneous with ***thought*** in comprehension of a new possibility of interaction with the world, natural and social. When Man grasped, captured, the fire that existed between two stones, he transformed himself and generated new ways of living (Wallon, 1942). The new act of making fire, from that moment on, would be shown, beyond the action itself, an intention: to heat, to roast, to boil water. We think that, not only the ways of making fire but also the intentions that lead to these actions, change throughout history.

– The theory of exchange of ***phlogisticon*** in the XVIIIth century, led and gave support to the great development of chemical reactions. The comprehension of combustion as a chemical reaction with the gas oxygen led to the use of a simpler principle for the path of fire. A subtle fluid, not necessarily massive, buth with definite interactions with the material constituents of matter, the ***caloric***, is now the cause of heat.

Carnot saw the flow of caloric ***from a hot to a cold body*** as the motive power of fire and discovered–created the efficient ideal "machines fitted to develop that power". ..."The production of motive power is then due, in ***steam machines***, not to an actual consumption of caloric, but to its transportation from a warm body to a cold body" (Carnot, 1824 in Kestin, 1976).

– Carnot also saw the existence of a ***limit for the production of work from heat***, which, in a steam machine, is given by the existence of the cold source.

–"The general and philosophical acception of the words "***perpetual motion***" should include not only a motion susceptible of indefinitely continuing itself after a first impulse received, but the action of an apparatus, of any construction whatever, capable of creating motive power in unlimited quantity...Such a creation is entirely contrary to ideas now accepted, to the laws of mechanics and sound physics" (Carnot, 1824 in Kestin, 1976).

The above quotation contains already the meanings of the ***first and the second Laws of Thermodynamics***.

– Clausius determined the mathematical value of this limit and

clarified its physical meaning discovering–creating the concept of entropy, i.e., the ***transformability*** of a system that goes from one temperature to another.

"...if the quantity of heat Q passes from a body whose temperature is t_1 into another whose temperature t_2, the equivalent value of this transformation is

$$Q\left[\frac{1}{T_2}-\frac{1}{T_1}\right],$$

where T is a function of the temperature (t)...(Clausius, 1862 in Kestin, 1976).

For the analysis of the origin of the concept of energy and its conservation law, we used T.S. Kuhn's article "Energy Conservation as an example of Simultaneous Discovery" (Kuhn, 59) and articles by Mayer and Joule. We came to an understanding of how and "Why, in the years 1830 to 1850, did so many of the experiments and concepts required for a full statement of energy conservation lie so close to the surface of scientific consciousness?"

– We also show that, during the short period, when the concept of energy was emerging in the formulation of scientists, at the same time, the physical meaning was being constructed in the ***transformations*** that were happening at the beginning of the XIXth century–technical, social, political, conceptual, mathematical and many others. The "availability of ***conversion processes***" one of the three factors selected as determinants by Kuhn, can be understood in the words of Faraday, in 1834, on the "Relations of Chemical Affinity, Electricity, Magnetism, and other powers of Matter": "We cannot say that any one (of these powers) is the cause of the others, but only that all are connected and due to one common cause. He gave nine experimental demonstrations of "the production of any one (power) from another, or conversion of one into another" (Kuhn, 1959). Several of these conversion processes are shown in the Exhibition along with the Panels.

– We point out a important issue of the XIXth century, the value of work. We may see the two first laws of thermodynamics as laws of ***equivalence of heat and work***. Joule establishes the ***mechanical equivalence of heat*** by the experimental realization of the Law of Conservation of Energy. The second law gives the ***limit*** for the possibility of ***transformation*** of all the heat given to a body into work. ***Energy and entropy are then always associated.*** We represent them as two faces of the same coin, in a reference also to the simultaneous growth of importance of money in the XIXth century.

Finally other meanings for entropy are indicated as giving the direction of ***evolution*** of a system.

Quotidian Knowledge

The social dissemination of the theory's potentialities – it's use in the development of technology, it's connection with new ways of thinking, it's teaching in schools – make it reach us as an inner part of our quotidian life. In that situation, the students, even in lower grades

of school, have some acquaintance with the concepts (Hamburger & Sousa Lima, 1989).

The network shown below was built from the surveys in classes of 10th grade of public high schools in São Paulo (Bliss, 1983; Aurani, 86; Higa, 88). The words were extracted from written answers to the question: "Please tell me in what situations you use the concept of energy and what are the meanings of that word". It can be seen that practically all the elements of the scientific theory are presented, as a synthesis of the knowledge of the class as a whole. At the individual level the knowledge is disorganized and fragmented.

- ENERGY
  - PHYSICS
    - FORCE
      - SYNONYM
      - DISTINCT
    - FORMS
      - HEAT
      - KINETICS
      - POTENCIAL
      - SOLAR
      - CHEMICAL
      - MECHANICAL
      - NUCLEAR
      - ELECTRIC
      - LUMINOUS
    - CONSERVATION
    - TRANSFORMATION
    - CAN BE STORED
    - SOURCES
      - WOOD
      - COAL
      - GASOLINE
      - FOOD
  - OTHER MEANINGS
    - EFFORT
    - MUSCULAR FORCE
    - POWER
    - PHYSICAL RESISTENCE
    - WILL TO DO SOMETHING
    - FIRMINESS
    - DISPOSITION
    - REPREHENSION
    - VITALITY
    - MENTAL
    - HUMAN BODY

The teacher can use this network in several ways:

1. to establish a link with the student's thought, through the work involved in making the questions and in analysing the answers; 2. to show to the class, who originated it, so that the students recognize their expressions; 3. to present to the students the scientific knowledge as built historically by the scientists in the context of the past, and reaching today's applications; 4. to reorganize the meanings appearing in the network as a coherent whole, as shown, for instance, in textbooks.

The scientific exhibition aims to show the whole meaning comprised by the scientific theories. At the same time, specially trained students explain the exhibit to the visitors, in order to disclose the meaning of the applications, which are closer to their own knowledge. It also illustrates a coherent concomitance between the evolution of scientific thought and the transformation of mankind's pratical activities.

NOTES

[1]Collaboration between the Physics Institute and other Departments: Linguistics (DeLemos, C., Univ. Campinas), Psychology (Almeida, A., Sousa Lima, E., Univ. S.Paulo), History of Science (Dantes, M.A., Univ. S.Paulo), Phylosophy of Science (Da Costa, N., Univ. S.Paulo, Paty, M., Univ. S.Paulo and Paris VII, CNRS).

[2]Dissertations by Rodrigues, I.G. (1988), Abramof, P.G. (1989), Higa, T.T. (1988), Aurani, K.M. (1986), Albuquerque, I.F.M. (1988).

[3]The Scientific Exhibition, called "Waves, Fields and Particles",

also shows demonstrations experiments with Eletromagnetic Phenomenae, Superconductivity at high temperature, and Panels on Evolution of the Universe, of Earth and of Life in Earth. It is part of the Program "Science and Education" of the University of São Paulo.

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