Experiments for an innovative approach to physics

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Resumo: *O estudo de caso refere-se à apresentação para graduados em física e matemática de uma "metodologia" inovadora para a Física. A metodologia tem o intuito de unificar diferentes capítulos da Física ao nível fenomenológico e ao nível explicativo. É inevitável discutir epistemologicamente a relação fenômeno/experimento/teoria, e, também, é importante propor uma metodologia didática baseada na interatividade de forma a estimular os estudantes-professores para problemas específicos, para suas dúvidas e enganos. A metodologia foi estudada como uma atividade em cursos para professores (atualização). Foi experimentado com grupos de graduados em Física e Matemática em três anos sucessivos. A meta é melhorar a ciência que é ensinada, através de uma metarreflexão do conteúdo de ciência e das práticas de laboratórios tidas no decorrer do curso universitário. São discutidas a conveniência didática de experiências e a análise de eletrodomésticos tecnológicos. A metodologia pedagógica é guiada por alguns temas principais que são discutidos de uma maneira espiralada (atividade construtiva e mudança conceitual, o papel dos experimentos na ciência e na educação da ciência, o uso da energia como conceito explicativo, a função de resposta, o uso da transformada de Fourier).*

Palavras chaves: *Metodologia didática, educação científica, experimentos*

Abstract: *The case study concerns the presentation to graduates in physics and mathematics of an innovative approach to physics. The approach is aimed at unifying different chapters of physics both at the phenomenological level and at the explanatory level. It is unavoidable to discuss the epistemological issue of the relation phenomena/experiment/theory and it is also important to propose a didactical methodology based on interactivity in order to stimulate the* *students-teachers to explicit problems, doubts, misunderstandings. The innovative approach has been studied as an activity in courses for teachers. It has been experimented with groups of young graduates in physics and mathematics in three successive years. The goal is to improve science teaching through metareflection on the science content and labwork practice learned in the university course. The appropriateness of didactical experiments and analysis of technological appliances are made. The teaching approach is guided by some leading themes which are explicitly communicated and discussed in a spiral approach (constructive activity and conceptual change, the role of experiments in science and in science education, the use of energy as an explicative concept, the response function, the use of Fourier transforms).*

Key words: *Didactical methodology, science education, experiments*

1. The "case" of the case study

The case study concerns the presentation to graduates in physics and mathematics of an innovative approach to physics. The approach (see Appendix 1 for the salient features) is aimed at unifying different chapters of physics both at the phenomenological level and at the explanatory level.

Many sessions are required for exploring the experimental behavior and for the discussion of the theoretical frame. Therefore the case study concerns a didactical presentation extended in time in which it is difficult to evaluate the importance of a particular element, experiment or of a specific section.

We decided to overcome this difficulty by comparing three presentations of the approach which differed in the order of the sessions and in part of the phenomena and objects used in the practical part of the course.

The aim of the case is then to evaluate the acceptance of the approach at the cognitive level (understanding) at the epistemological level (plausibility) and at the application level (utility).

Since the approach is aimed at a unification at the descriptive level of different phenomena (VICENTINI, 1995; VICENTINI and WANDERLINGH,1997) the demonstration of the phenomena is necessary unless the phenomena are part of everyday experience.

Since the approach is aimed at a new theoretical perspective (WANDERLINGH, 1992; 1996; 1997) it is unavoidable to discuss the epistemological issue of the relation phenomena/experiment/theory.

Since it is an innovative approach by a team of teachers, it is important that all the team shares the conviction of the validity of the approach. It is also important that the team shares the importance of a didactical methodology based on interactivity in order to stimulate the students-teachers to explicit problems, doubts, misunderstandings.

Since the approach is framed in a thermodynamic scheme a basic knowledge of generalized thermodynamics is required. As the university courses in physics and mathematics restrict the presentation to classical TD (that is, Thermostatics for fluid systems) it has been necessary to dedicate some sessions to this field of study in all three presentations.

2. Context

2.1. General information

The innovative approach has been studied as an activity in courses for teachers. It has been experimented with groups of young graduates in physics and mathematics in three successive years. The graduates had followed traditional courses in physics and traditional laboratory courses. The mathematics graduates did not have any practical experience in laboratory.

The experimental courses were held in afternoon sessions of two hours each (during the day the participants were involved in teaching activities in the school). The number of participants was 20 in the first trial, 17 in the second, 18 in the third.

2.2. Goals - intended outcomes

The goal is to improve science teaching through metareflection on the science content and labwork practice learned in the university course. The appropriateness of didactical experiments and analysis of technological appliances to the choice and sequence of contents are a main issues.

2.3. Teaching approach

The teaching approach is guided by some leading themes which are explicitly communicated and discussed in a spiral approach. The leading themes are:

a) Learning as a constructive activity and conceptual change; comments about it are interpreted in the various sessions. Different kinds of questionnaires have been used and discussed. The problem of conceptual change from their previous understanding to the new approach is explicitly discussed.

b) The role of experiments in science and in science education. Technology as an empirical referent of theoretical argumentations; starting from a possible view of the role of experiments in science the analysis of their understanding of it compared with a possible philosophical description, various experimental demonstrations and the technology derived from scientific knowledge are used to comment on the issue.

c) The unification of different physics chapters in the phenomenological description (response function) and in the use of energy as an explicative concept; the unification is first used at the descriptive level of different phenomena showing explicitly, recalling and comparing the different cases. Written material is also given for study.

d) The complementary approach by which many phenomena may be described: that is the space and time domain on one hand, and the frequency domain on the other. The use of Fourier transforms.

3. Research questions

3.1. Basic assumptions and long term research program

The scheme of Figure 3.1 (ALBANESE and VICENTINI, 1997a, ALBANESE, DANHONI NEVES and VICENTINI, 1997a) presents in a synthetical form the frame of understanding the role of experimental work. It has been used during the presentations as a methodological tool on which to place the various experimental situations.

Of particular importance for the case study is the step from observation to the empirical law level (or primary model), and the indication that technology besides experiment, may be considered a check of the validity of empirical laws and theories (secondary model).

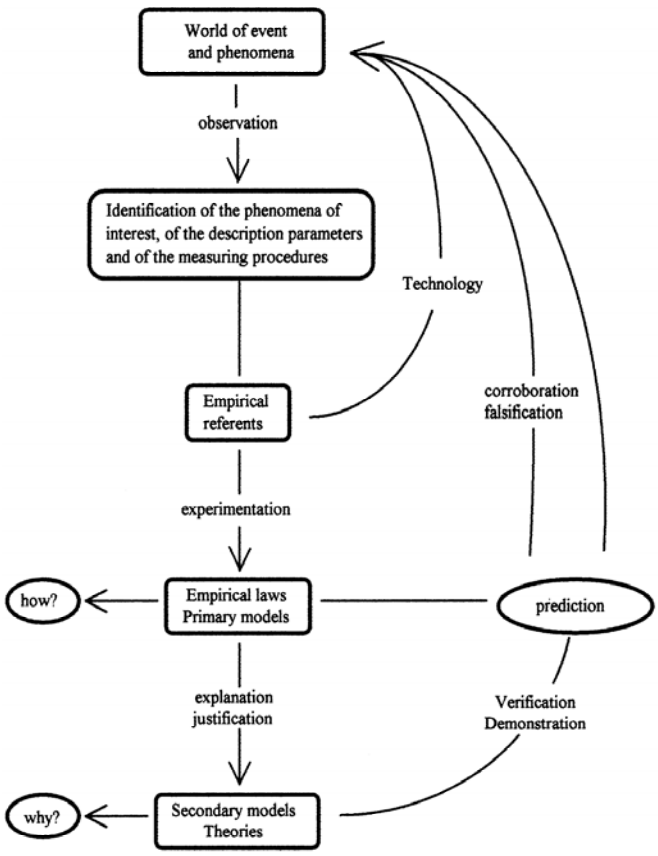

Figure 3.1: A schematic representation of the paradigmatic context in experimental sciences.

The learning assumptions of the group may be placed in a constructive learning model: the conceptual scheme that an individual constructs for understandings has its roots in the experiences of everyday life and is strongly influenced by the interaction with phenomena. The communication of theoretical schemes by the social community will be accepted only if it is judged plausible, useful, understandable (HEWSON, 1981).

The main points of the sequence we are proposing may be synthesized, as far as contents are concerned in:

a) showing the analogy between different equilibrium phenomenologies; generalized equations of state as empirical laws that may be interpreted as static response functions;

b) showing the analogy between different phenomenological processes: generalized kinematics, response (memory) function description;

c) energy and entropy as conceptual organizers.

The broad research question is then related to the difficulties in understanding and accepting the plausibility and usefulness, of the scheme by persons used to the traditional presentation of physics (that considers in separate chapters: mechanics, thermodynamics, electromagnetism) and who have received information on the relation theory/experiments by the traditional didactical organization of theoretical lectures and laboratory exercises (that is only in an implicit form).

3.2. Specific research questions

a) What are the problems for understanding and for accepting the plausibility and usefulness of a presentation of the contents of physics that is different from the traditional presentation?

b) How the analysis of appropriate experimental and technological situation may help the teaching practice?

4. Research design

4.1. General design

The research project consists of:

a) a first presentation of the approach to a group of young graduates with the evaluation of the sequence of the arguments presented, the time duration and the appropriateness of experimental demonstrations;

b) the confrontation with a second presentation to a new group of young graduates;

c) the confrontation with a third presentation to a new group of young graduates.

The comparison among the three presentations is shown in Table 1 and the list of the experiments used is given in Table 2. The total time for the presentations increases from 16 hours to 26 hours.

1^{st} **presentation** (16 hours)
• From classical thermodynamics of fluids to process TD of general systems (12 hours) • Generalized kinematics (2 hours) • Response function (2 hours) • Experiments presented: *a*, *b*, *c*, *d*, *e*
2^{nd}**presentation** (20 hours)
• Generalized kinematics with experiments *a* and *b*, introduction of the response function algorithm at a qualitative level (2 hours) • Acoustics experiments *f, g, h* with the formal treatment of Fourier analysis (4 hours) • Optics experiments *i, j, l* with the formal treatment of Fourier analysis in the space domain (4 hours) • Electricity experiment *e* with the formal treatment of Fourier transform and response function (4 hours) • Equilibrium situations: equations of state and static response (fluids, solids, electric and magnetic materials). Connecting known information in a unified scheme (2 hours) • Non equilibrium thermodynamics and response function (2 hours) • Energy/entropy and memory function (2 hours)
3^{rd}**presentation** (26 hours)
Same as 2^{nd} with the changes: *a)* A first session is dedicated to the role of experiments in physics and the introduction of a “cause-effect-response” scheme for the description of experimental activity (2 hours) *b)* The session on equilibrium is anticipated as a second session with the use of the static response function. *c)* In optics the response function has been applied for filters also in the time domain. Experiments *m* (2 more hours) *d)* Analysis of technical applications. Experiments *o* (2 hours)

Table 1

The experiments were presented in different forms:

• as demonstrations aimed at defining the descriptive variables and measurements procedures (experiments *a, b, c* in particular);

• as group work with a computer on line aimed at determining quantitatively the phenomenological behavior (experiments *d, e, g, j*);

• as demonstrations aimed at the discussion of the response of the optical filters (experiments *i, k*);

• as qualitative group work aimed at defining the descriptive variables (experiment f);

• as group work aimed at the qualitative analysis of technological apparatus (experiment m);

• as group work with measurement (experiments h, l).

Experiments	
a)	Fluid flow between communicating vessels
b)	Motion of containers with different fillings along a semicircular vertical guide (ALBANESE, 1996)
c)	Pendulums
d)	Approach to thermal equilibrium through partitions made of materials with different thermal conductivity
e)	Discharge of a condenser on an RL circuit and RLC circuits
f)	Production of sound (diapason, musical instruments)
g)	Spectral analysis of sound via computer
h)	Sound intensity measurements with phonometers
i)	Optical diffraction phenomena (ALBANESE and DANHONI NEVES, 1997; 1998)
j)	Filtering in computer elaboration of images
k)	Additive color synthesis experiments
l)	Wavelengths measurements of different light sources (laser, overhead projector)
m)	Analysis of technical applications

Table 2

As may be seen from the two tables the first presentation differed substantially from the other two in the sequence, in the number of experiments and was shorter in duration.

In fact it had been organized with the principal focus on the improvement of the knowledge of thermodynamics from what usually learned in a general course toward non equilibrium thermodynamics and the “response function” approach. However, we had to register a partial failure in the sense that we observed an increased knowledge of thermodynamics but a strong resistance to the new approach.

Criticisms were explicited concerning the mathematical difficulties and it became clear to us that we were facing a case of conceptual change analogous to what observed with students in face of newtonian mechanics. Here, in fact, the role of naive physics conceptual structure (which resists to newtonian mechanics for the seemingly major applicability to everyday phenomenology) was played by the newtonian conceptual structure to which teachers were used from their learning as students and form their teaching experience (ALBANESE, DANHONI NEVES and VICENTINI, 1997b; 1998).

The point on the mathematical difficulties connected with the integral formulation of the response function algorithm, for us of comparable difficulty with the differential equations formalism hidden in the "magic" formula, $F = ma$, pointed in this direction.

We then decided to change the approach with three major changes:

a) to start the course from the response function algorithm in a simplified form;

b) to declare the importance of learning the new mathematical algorithms of the response function and of Fourier transforms;

c) to discuss technological applications.

4.2. Monitoring the activities

In order to evaluate the understanding and the acceptance of the plausibility and utility of the new approach we need to compare the initial state of knowledge with the final situation.

The definition of the initial state is aimed also at identifying conceptual and epistemological obstacles to understanding.

The monitoring tools used are shown in Table 3.

For the initial profile of the participants
• conceptual maps about theory/models/experiments • conceptual maps of their knowledge in thermodynamics • analysis of secondary schools official programs • explanation of the functioning of technical applications (moka, TV, pressure cooker, xerox machine, refrigerator, compact disc reader, microwave oven, microphone, video/audio magnetophones, radio)
In course monitoring
• video recording of some session and crossed observation
Final evaluation
• Choice of the argument for the didactical proposal • Report on their learning • Organization of the didactical proposal

Table 3. Monitoring tools

Initial state

The participants to the course were, in all presentations, a mix of mathematics and physics graduates.

In the selection procedure we had decided to mix the physics graduates (with more knowledge in physics and at least three courses on laboratory) with the mathematics graduates (with only a two years course on general physics, no experimental activity but, of course, more knowledge in mathematics) hoping that the different competence level in physics and mathematics would help pair interaction.

In all the presentations we used the same monitoring tools for defining the initial profile of the participants. The results being comparable we will give a summary of the three investigations.

Work group activities (with separate groups for the mathematicians and the physicists) were used to obtain information on the initial knowledge in physics (the conceptual map of thermodynamics), the explanation of technical applications and the role of experiment in science (the conceptual maps on "experiment").

The initial conceptual maps on TD are restricted to the thermostatics of fluid systems in the classical formulation with, eventually, some microscopic concepts.

In the analysis of the official program all declare a basic knowledge of mechanics, thermodynamics, electromagnetism and optics. Mathematicians declare problems for aspects of modern physics but also on the phenomenology.

The categorization of the technical applications posed problems for both group: the categories "thermal engine, electromagnetic apparatus, optical apparatus, ... " were used but not defined. No one doubts in placing "Moka", pressure cooker, frigidaire, electric oven in the category "thermal engines" but other applications pose problems.

The explanation of the functioning of three applications of their choices leads to the choice of moka (not always correct), electric oven, pressure cooker, frigidaire. Physicists, on the average, show a better competence in the explanation but one sees, in general, a lack of understanding of the connection of the technological artifacts with what learned in the physics course. This conclusion is not surprising at all as the organization of the general physics courses in Italy focuses more the theoretical frame than the applications in technology.

The role of experiment (as shown in the conceptual maps of Figures 4.1 and 4.2 as typical example) is seen as a step between "observation" and "models-theories" with more attention to measuring procedures for the physicists and more attention to the mathematical aspects for the mathematicians.

In course monitoring - The monitoring was aimed at the evaluation of the level of attention and interest of the participants. It was made mainly by the use of video recording of some sessions and the participation of all the four activity leaders to each session (one or two leading the session, the others two observing its development).

From the observations, checked by a qualitative analysis of the video registrations, we could ascertain in all session a high level of attention with a good quality of the discussion.

Final evaluation - As a final evaluation three probes were used:

a) We asked the participants to choose, as the work group requested for the conclusion of the course, among a set of options all aimed at pursuing the content organization presented by us or to choose the option of critically excluding its didactical validity.

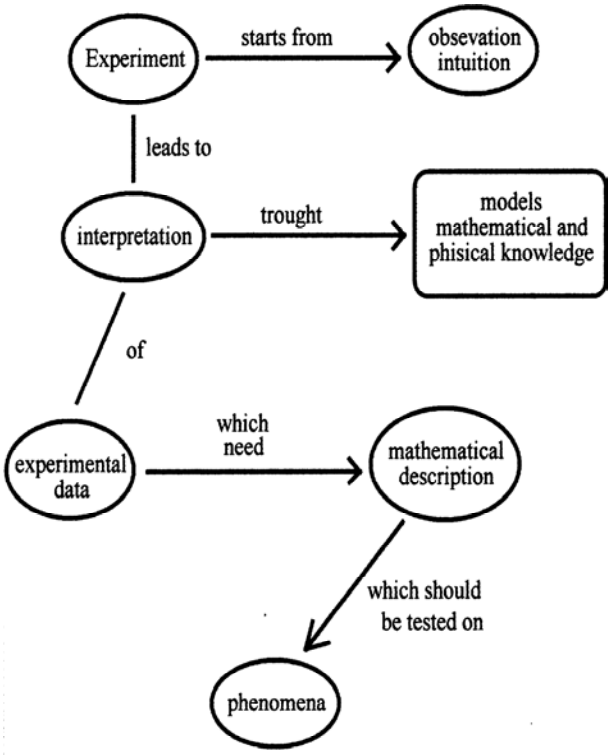

Figure 4.1: Mathematicians

b) It was also requested to prepare a scheme of the presentation, in any form they choose (conceptual map, short essay, block diagram, ...). The scheme should have the aim of communicating to us what they thought to have learned.

c) The organization of the didactical proposals by the groups.

We will discuss the final evaluation probes separately for the three presentations in the next section.

5. Results

We will discuss the results with attention to the three components: understanding, plausibility, utility for the successive presentations.

5.1. First presentation (January-October 1995)

Probe a) All participants rejected the use of the response function approach by deciding to focus their work on more traditional sequences.

The reasons for rejecting the approach, explicited in a very lively final discussion, were, on one side, due to a strong belief in the didactical validity of teaching mechanics in the traditional newtonian scheme (which lead to the necessity of introducing "force" before "energy") and, on the other, attributed to presumed major mathematical difficulties in the new approach. One participant, while extremely

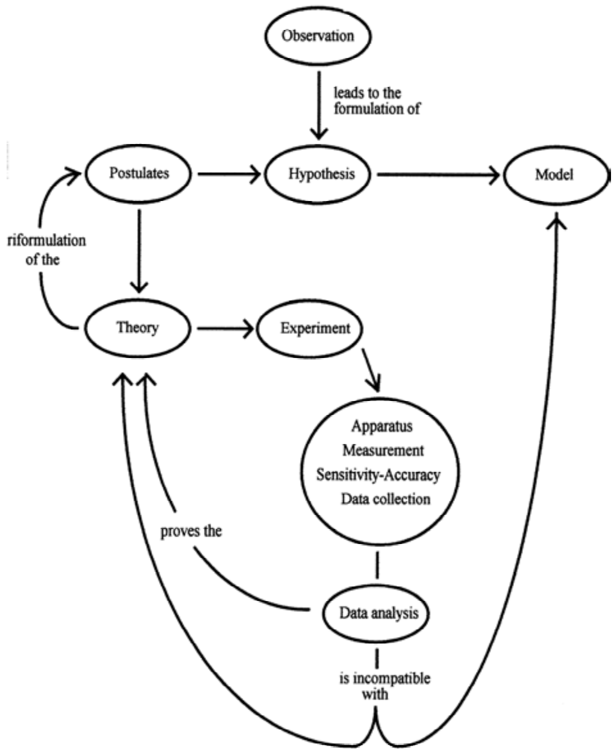

Figure 4.2: Physicists

critical also on the teaching approach used (he gave good suggestions for a better presentation), decided for a follow up in the second presentation.

Probe b) All participants choose to communicate their increased knowledge in TD by preparing conceptual maps. The maps produced included concepts related to the generalization to various systems (electric, solid, magnetic) and to process thermodynamics near equilibrium.

Conclusions: The presentation was unable to convey reasons for accepting the plausibility of the response function scheme. No epistemological obstacle was found for increasing thermodynamics knowledge while the traditional knowledge of mechanics as separate from thermodynamics acted as a strong epistemological obstacle toward the new approach.

5.2. Second presentation (January-October 1996)

Probe a) No one choose to critically exclude the approach, and five groups worked on optics, acoustics, waves, thermodynamics, mathematics. The participant that was following the course for the second time was now so convinced and enthusiastic that he choose to investigate in depth the mathematical difficulties (were we more convincing or more time is needed?). In the third presentation he joined us in the teaching team.

Probe b) The schemes given seemed very scholastic, as if the participants had seen our request more as an evaluation of their learning than as an evaluation of our approach. Thus we were very perplexed on their meaning notwithstanding the fact in all the essays "unification of different chapters, response function, Fourier transforms" were mentioned.

Probe c) It came then as a surprise to see all the works were indeed focused on pursuing the approach with a good integration of the contents, the use of the formalism, the introduction of experimental activity and the questions raised for the development of the work.

However, the analysis of the proposals developed by the participants showed that the usefulness of the response function formalism was not clear (see Appendix 2).

Conclusions: The presentation reached the aim of the understanding and accepting the plausibility of the approach but failed on the communication of the utility.

5.3. Third presentation (January-October 1997)

Probe a) Again no one choose to critically exclude the approach and five groups worked on mechanics, optics, acoustics, thermodynamics, electricity.

Probe b) It was not requested explicitly, but it was suggested to include some considerations in the didactical proposal. An example of considerations that prove the understanding is given in Appendix 2.

Prove c) Not all groups were able to use the scheme but some did.

In Appendix 3 we report the organization to the proposals which seem to prove the acceptance of the utility of the scheme.

Conclusions

The comparison between the first and the other two presentations on the organizational level (more experiments, more time and a particular focus on technology) and the results seems to lead to the conclusion that:

a) for understanding a new approach a variety of experimental situations explicitly discussed in relation to models and theories more than on measurements procedures is a necessary factor;

b) for accepting the plausibility of a new approach in confrontation with a traditional one the habit to the traditional approach may act as an epistemological obstacle (in a parallel situation to the obstacle that naive schemes pose to students). Again exposing a variety of experimental situations is a necessary factor but they need to be presented as examples of the relation theory/experiments/models more than focused on measurement procedures;

c) for accepting the utility of a new approach its relevance for technological applications should be stressed. May be this is a particular for our approach as the response function formalism is isomorphic to the input-output scheme used in system theory;

d) the duration of the presentation is an important factor.

Appendix 1 - The linear response (memory) function approach: some salient features

The scheme (PIPPARD, 1985; MARCH and TOSI, 1976) may be synthesized in a general relation between an *Effect E* and a *Cause C* which is called the *Response R*. The scheme is of large use in everyday life in various context: when we do something (Cause) on an external object (also a person, the system) the object reacts (the Effect) in relation to its characteristics. Therefore, the relation Cause/Effect defines the Response of the system to the Cause.

In the approach we are using the scheme:

a) in a qualitative way to describe the work of an experimental scientists. The object of study is a material system which may change (effect) in consequence of the actions (cause) of the experimentalist who is interest in correlating the changes in the system (effects) to the independent variables of his action (cause). Simple examples:

Cause: establishing the contact between two objects at different temperatures (cause ΔT) and measuring the changes in volume of one object (effect) ΔV. If $\Delta V = A\Delta T$, A will be the response of the system to a change in temperature.

Cause: establishing a potential difference ΔV on a resistor and measuring the current I: $\Delta V = Ri$, R will be the response of an electrical conductor to a potential difference.

b) It follows that all equations of state of any system may be quantitatively framed in the scheme: the isothermal compressibility of a gas is the response of the fluid system to a change in pressure at constant temperature:

• the specific heat is the response to a flow of energy due to a temperature difference;

• the magnetic susceptibility is the response of a system to the application of a magnetic field;

• the elastic constant of a resort is the response of the solid system to a particular stress (Hooke's law).

c) Besides a static response one may consider a dynamic response function by correlating the actual effect to any previous cause with the integral relation

$$E = \int_{-\infty}^{t} R(t-t')C(t')dt'$$

The response (or memory) function must be such as to decrease in the past while being absent in the future. The effect may be always defined as the first order change in the leading variables of the phenomena that is velocity for movement, current in electricity, etc., in general, a "generalized velocity = dx/dt", x being the leading variable of the phenomenon.

Let us see some applications:

• movement: *Effect* = $E = v$, *velocity;* $C = F$ active conservative force

$$v = \int_{-\infty}^{t} R(t-t')F(t')dt'$$

which, if $R = constant = R_0$ gives,

$$v = R_0 \int_{-\infty}^{t} F(t')dt'$$

or $dv/dt = a = R_0 F(t)$ equivalent to $F = ma$, while if $R = R_0 \delta(t-t')$, corresponding to an instantaneous reaction, $v = R_0 F(t)$ corresponding to Stokes law.

A more general R of the form $R = R_0 e^{-t/\tau}$ will give the relation

$$a \equiv R_0 F(t) - (v/t) \longrightarrow F = (a/R_0) + [v/(R_0 t)]$$

the equation of motion in presence of a friction proportional to the velocity.

• *Electric flow* $E = i$, current intensity; $C = \Delta V$, potential difference; the case with $R = R_0 e^{-t/\tau}$ will lead to

$$\Delta V = A(di/dt) + Ri$$

the general equation of an RLC circuit.

• *Thermal flow* $E = q$, heat flux; $C = \Delta T$, temperature difference,

$$\Delta T = A(dq/dt) + Kq$$

the heat conduction equation with a transitorial term. Therefore, at the descriptive level, the response algorithm, permits the unification of different phenomena of change in a "generalized kinematics".

d) From the time to the frequency domain. The use of Fourier transforms leads from the convolution product in the time domain to a proportionality relation in the frequency domain,

$$E(\omega) = R(\omega)C(\omega)$$

Examples of everyday use of the formalism may be found in audiocassettes (that report on the cover sheet the frequency response as a function of frequency), microphones, etc. Also the discussion of the functioning of the vocal cords of a human being is generally using the scheme (MATHELITSCH and FRIEDRICH, 1995). In general the fields of electricity, optics and acoustic are particularly apt to discuss the approach in the frequency domain.

• Optics. In any optical system one can identify the cause or input C in the electromagnetic field that sheds light on an object. An intervening filter, a material characterized by a response function determines on the image plane an effect-output-E which is visible as a modification of the appearance of the object.

• Acoustic. The input is provided by a sound generator. The ear, musical instruments, ... change (with their response function) some of the characteristics of the sound.

• Electricity. Historically this is the field where the formalism has been developed. *RC, RL* filters are good examples of its use.

e) One may then introduce the energy concept with a generalized potential energy *U(q)* and a generalized kinetic energy *k(q)*, (q are the leading variables of the phenomena). Now one may define

$$C = -dU/dq \quad E = dK/dq = q$$

and prove that

$$d(K+U)/dt =$$
$$-[q/R(0)] \int_{-\infty}^{t} (dR/dt)|_{t-t'} \, (dU/dq)|_{t'} \, dt'$$

The sum of potential and kinetic energy is constant only with a constant memory function. Otherwise the conservation of energy requires the existence of an internal energy U_i

$$Ui = +[q/R(0)] \int_{-\infty}^{t} (dR/dt)|_{t-t'} \, (dU/dq)|_{t'} \, dt'$$

One may then extend the discussion on conservation/dissipation, causality and show the extension to the case of stochastic causes (the fluctuation dissipation theorem) and a general treatment of process thermodynamics.

Appendix 2

A - Second presentation. Some examples of non acceptance of the utility of the scheme. Only the group on Optics analyses an experiment in the Cause-Response-Effect scheme, but they show problems in general in defining the three elements. The other groups, while considering cases that could have been good examples of the formalism (heat conduction and the green house effect, the risk of the effect by electromagnetic fields, musical instruments and sound recording apparata) do not even try to use it.

B - Third presentation

a) The group on mechanics: "The new formalism is undoubtedly more adequate than the traditional one to the intuitive ideas of students as it permits the identification of the effect in the velocity. Moreover, it does not need to introduce friction forces to justify the reaching of equilibrium ... The response function formalism enables to reorganize theoretically all physics as phenomena (described by conceptually equivalent laws) are unified in the same scheme. Therefore it may be utilized in school at the beginning as an introduction to physics or later for the possibility of looking at the phenomena from a different point of view" ... "However, we think that we would have needed more time to think".

b) The group on optics: ... a simple way of reasoning in many dialogues plays around three basic elements: the effect, the cause and the response. Then it seems reasonable to use them in the study of physical phenomena. The formalism furnishes a logical scheme near to our way of reasoning and may be effective in teaching. Resistance, mass ... are all "responses" that relate causes and effects ... In optics, when light goes through an optical system we may identify the incoming light as the cause, as the effect, the image formed by the optical system which gives the "response".

Appendix 3 Organization of the proposals developed by the groups

1) Mechanics
   - Didactical and epistemological aspects
   - Linear Response theory
   - An experimental set-up
   - A new look on response theory

   The experiment consists of the study of the oscillatory motion of an object suspended to a vertical resort which may be immersed in various fluids. Data are taken with a computer on-line and analyzed in time and frequency. The fluids used are: water and shampoo at various concentrations, water, air.

2) Heat conduction
   - Fourier analysis in general
   - Heat conduction and Fourier
   - Response function
3) Optics
   - Introduction on learning and response formalism
   - Optical filters in general
   - The interaction of light and objects in the response function formalism
   - Examples of digital elaboration of images (with a computer on-line)
4) Acoustics
   - Fourier transform applied to sound phenomena
   - Linear Response theory and acoustics
   - Applications to musical instruments and the human voice
5) Electricity
   - A proposal for introducing the Cause-Response-Effect scheme starting from experiments
   - Analysis of oscillating circuits
   - Practical applications
   - Other electrical circuits

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