The Supremacy of the Constructivist Approach in the Field of Physics Education: Myths and Real Challenges

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Abstract
We intend, first of all, to show that the supposed "supremacy of the constructivist epistemology" in the field of physics teaching is just a myth that hides the actual supremacy of the ineffective transmission/reception model. We then centre our analyses and proposals on the real challenges to improve students' learning and attitudes.

Résumé
Nous essayons de montrer que la prétendue « suprématie de l'épistémologie constructiviste » dans le domaine de la didactique de la physique n'est qu'un mythe, qui cache la suprématie effective du modèle inefficace de la transmission/réception. Nous centrons ensuite nos analyses et propositions sur les défis réels pour améliorer l'apprentissage et les attitudes des étudiants.

Keywords: physics education, constructivist teaching-learning strategies, inquiry-based teaching-learning strategies.

Mots-clés: didactique de la physique, stratégies constructivistes pour l'enseignement/ apprentissage, stratégies d'enseignement/apprentissage basées sur l'investigation.

I. Introduction

This issue of *Tréma* has been conceived to aim “at questioning the supremacy of the constructivist approach in the field of physics teaching” and at opening the discussion to questions such as the following:

- How has the choice of the constructivist epistemology in this field been justified?
- In particular, does the teaching strategy based on the idea of the reconstruction of knowledge by the pupil necessarily imply endorsing a constructivist epistemology?
- What are the limitations of the constructivist epistemology in the field of physics teaching?

In this paper we shall discuss these and other interesting questions, but, first of all, we intend to show that the supposed “supremacy of the constructivist approach” (conceived as the philosophical constructivist epistemology) in the field of physics education is just a myth that hides the real challenges to improve students’ learning and attitudes.

II. The myth of the supremacy of the constructivist epistemology in physics education

In the most recent Handbook of Research in Science Education (Abell & Lederman, 2007) we learn that according to the huge bibliography on constructivist-oriented research on teaching and learning science by Duit (2009), that covers more than 500 single-spaced pages (!), about 64% of the studies documented are carried out in the domain of physics (Duit, Niedderer & Schecker, 2007, p. 599). In fact many of the 39 chapters of the Handbook make reference to constructivist perspectives of science learning and teaching and specifically to the conceptual change tradition, designed as “the one with the longest history and the most influence within the science education community” (Anderson, C., 2007, p. 7).

Why then do we affirm that the supremacy of the constructivist epistemology in the field of physics education is just a myth? Ronald Anderson in his chapter “Inquiry as an Organizing Theme for Science Curricula” is very clear in this sense: “as used here to discuss learning, *constructivism* is not the same *constructivism* used in discussions of the nature of science” (Anderson, R., 2007, p. 808). We had already pointed out this difference (Gil-Pérez *et al.*, 2002) in order to answer the voices that had begun to question constructivist strategies in science education, speaking, for example, of “Constructivism *Deconstructed*” (Suchting, 1992) or of “ise *and Fall* of Constructivism” (Solomon, 1994).

Why did Suchting, Solomon and others criticize the constructivist strategies for science learning And what was our defence of these strategies? Let us consider, for example, Suchting’s criticism. In his article “Constructivism deconstructed”, Suchting (1992) starts by saying that constructivism is “a doctrine which has for some time been very influential in thinking about education (…) associated especially with the name of its originator and principal exponent, Ernst von Glasersfeld”.

Without questioning the interest of such criticisms as Suchting’s of von Glasersfeld’s philosophical theses, we pointed out that this debate had little to do with constructivist proposals *in the field of science education*. In fact, Suchting’s article contains no references to research in this field, which he appears to be ignorant of, to the extent of considering von Glasersfeld, whose name only began to be mentioned at the end of the 80’s, as the “originator”.

We insisted (and keep on insisting) on the negligible influence of von Glaserfled and his philosophical “radical constructivism” in the development of the “constructivist consensus” in science education. Effectively, the first references to von Glasersfeld in journals such as *Science Education, Journal of Research in Science Teaching, Studies in Science Education or International Journal of Science Education* appear in 1988 (Tobin *et al.*, 1988). They were very infrequent during the entire decade (three references in the *Journal of Research in Science*

Teaching, two in *Science Education*, two in the *International Journal of Science Education* and zero in *Studies in Science Education*). Besides, five of these seven references came from the same author, namely Kenneth Tobin. The same appraisal of the scarce influence of von Glasersfeld could be obtained considering the references included in the handbooks of research on science education published: In the one edited by Gabel (1994) we found only 8 references, 4 of them coming from the same author (Kenneth Tobin) and the other 4 corresponding to particular details. In a second handbook (Fraser & Tobin, 1998) we again found just 8 references.

And what has happened since then? In the most recent handbook (Abell & Lederman 2007) there is *only one reference* to von Glasersfeld. We can thus conclude that the debate put forward by Suchting and other authors (Nola, 1997, Hardy & Taylor, 1997…) *is not our debate*. We cannot accept, as Suchting seemed to, that because we use the word constructivism we are talking about philosophical constructivism and that we are 'applying' von Glasersfeld's theses: it is not the same constructivism (Anderson, R., 2007, p. 808). For this reason, Matthews (1997) wrote: "It is clear that the best of constructivist pedagogy can be had without constructivist epistemology". In fact constructivism in science education has a very different origin. We shall now try to summarise the origin and nature of what we call constructivism in science education.

III. Constructivism Consensus in Science Education Research

What is known as the constructivist consensus in science education has its origin in many specific researches about the different aspects of science education and more specifically of physics education: from concept learning, problem-solving or practical works to evaluation or attitudes towards science… Such research had been undertaken to improve the poor results of the reception learning paradigm seriously questioned by research on, for instance, "misconceptions", "alternative frameworks" and, more generally, students' conceptions (Viennot, 1976, Driver & Easley, 1978, Duit, 2009, Scott, Asoko & Leach, 2007). They had contributed, and continue to contribute, to a coherent body of knowledge which supports the need to implicate pupils in the (re)construction of scientific knowledge in order to make possible a meaningful and lasting learning, overcoming the well known limitations of the mere reception of knowledge already elaborated (National Academy of Science, 1995).

Constructivism in science education *research* stands against the transmission/reception model of science teaching/learning: a model that, in spite of its proven inefficiency, is still predominant in current physics *teaching*. We have to distinguish between trends in science education research and what is done in science teaching: it is true that In fact the dominating perspectives of research on teaching and learning science have been constructivist views (Duit, Niedderer & Schecker, 2007, p. 606), or the very similar proposals of the "generative learning model" (Osborne & Wittrok, 1985) and "inquiry learning" (Anderson, R., 2007, p. 809), which, although they use different terminology, constitute proposals coherent with what we understand to be the construction of knowledge in science education: students' participation in the (re)construction of knowledge, acting as *novice researchers*, with the teachers' assistance (Gil-Pérez, 1993, Gil-Pérez & Carrascosa, 1994, Gil-Pérez *et al.*, 2002). This assistance begins with the transformation of the curriculum into *programs of activities* to orientate pupils' research to (re)construct the knowledge and acquire the necessary competencies in the use of this knowledge (not only conceptual, but procedural and axiological as well). As Driver and Oldham (1986) have pointed out, from a constructivist point of view the curriculum is seen not as a body of knowledge or skills but as the programme of activities from which such knowledge or skills can possibly be acquired or constructed.

Notice that we do not speak of pupils as practising scientists working in frontier domains: this metaphor, used by several authors has, of course, many limitations and cannot give a useful view of how to organise pupils' learning: actually, it is obvious that pupils *by themselves* cannot construct *all* scientific knowledge. The metaphor that contemplates pupils as *novice researchers* gives a better appraisal of the learning situation. Effectively, every researcher knows that when someone joins a research team, he or she can catch up quite easily with the standard level of the team. And that does not happen by verbal transmission, but through the treatment of problems in fields where his or her more experienced colleagues are experts.

Summing up: The proposal to organise pupils' learning as a collective knowledge (re)construction corresponds to an *oriented research* carried on, at the classroom, by pupils structured in small groups, in fields well known by the 'research directors' (the teachers), and where the partial and embryonic results obtained by pupils' teams can be reinforced, completed or even questioned and reoriented by those obtained by the scientific community. This is the constructivism we practice in science education and strongly recommend to make possible a meaningful learning.

But there is little evidence that these views and practices are spreading to large numbers of teachers (Anderson, C., 2007, p. 13). On the contrary, as the report of the European Commission "*Science Education Now: A Renewed Pedagogy for the Future of Europe*" has established, whereas the science education community mostly agrees that pedagogical practices based on inquiry-based methods are more effective, the reality of classroom practice is that in the majority of European countries these methods are simply not being implemented (Rocard *et al.*, 2007, executive summary). For this reason, our paper aims at questioning the supremacy, not of the constructivist approach (inexistent in usual science teaching), but of the transmission/reception approach which is common practice in the field of physics teaching.

III.1 The supremacy of the transmission/reception model in the field of physics teaching

Researchers in science education generally agree on the central finding about current school practice: *Our institutions of formal education do not help most students to learn science with understanding* (Anderson, C., 2007, p. 5). Nor do they help to get them interested in science, particularly in the field of physics: "physics clearly is the domain that is greeted with the lowest interest by students among the sciences" (Duit, Niedderer & Schecker, 2007, p. 599). As Aikenhead (2007, pp. 885-886)) summarizes:

> Most research into the science curriculum concluded that school science transmits content that is socially sterile, impersonal, frustrating, intellectually boring and/or dismissive of students' life worlds.

Rocard's Report states the seriousness of the situation: In recent years, many studies have highlighted an alarming decline in young people's interest for key science studies and mathematics. Despite the numerous projects and actions that are being implemented to reverse this trend, the signs of improvement are still modest (...) the origins of the declining interest among young people for science studies are found largely in the way science is taught in schools (Rocard *et al.*, 2007, executive summary).

This teaching, based on the mere transmission of knowledge, affects all levels of science education, including university teaching, as the Bologna Process has shown (http://www.ond.vlaanderen.be/hogeronderwijs/bologna/), and is characterized by an ensemble of distortions and reductionisms of the nature of science that need to be overcome (Gil-Pérez *et al.*, 2002, Gil-Pérez *et al.*, 2005, Gil-Pérez, Vilches & Ferreira-Gauchia, 2008):

- *A socially neutral view of science* which ignores (or treats very superficially) the complex relationship between Science, Technology and Society, STS or, better still, STSE, adding the E for Environment to direct attention towards the serious problems of environmental degradation which affect the whole planet. The social context is ignored (Stinner, 1995), as if science were an activity carried out in ivory towers, aside from life's contingencies by solitary geniuses who manage an abstract language of difficult access. This constitutes a second distortion of scientific activity that we must contemplate.

- Scientific knowledge appears as the work of isolated "great scientists", ignoring the role of co-operative work and of exchanges between different research teams. In the same sense, science is quite frequently presented as *a domain only accessible to especially gifted minorities,* therefore conveying negative expectations to the majority of students, resulting in ethnic, social and sexual discrimination. No special effort is made to make science meaningful and accessible; on the contrary, the meaning of scientific knowledge is hidden behind mathematical expressions, without previous qualitative approaches. Nor is the human nature of scientific activity shown: an activity where errors and confusion are inevitably part of the process… as happens with pupils' learning. The individualistic and elitist image of scientific activity is made evident in iconographies which usually depict a man in white in an isolated laboratory, completely surrounded by strange instruments. Thus, we come to a third distortion: the one which associates scientific work almost exclusively to work done in a laboratory, where the scientist observes and experiments in search of a happy "discovery". Thereby, *an empirical-inductive view of scientific activity* is conveyed.
- The idea of experimentation as "the principal route to scientific knowledge" is, probably, the distortion which has been most studied and which most frequently appears in the literature (McComas, 1998). It is a conception which enhances 'neutral' observation and experimentation, forgetting the important role played by theoretically founded hypotheses as a guide to research. Although this distorted view of scientific activity is the most studied and criticised in the literature, many science teachers continue to adhere to this conception. To understand why, we have to take into account that, in spite of the importance verbally given to observation and experimentation, science teaching, in general, is mainly a simple transmission of knowledge, without real experimental work (beyond some 'kitchen recipes'). For this reason, experimentation is still seen, both by teachers and students, as an "awaited revolution", as we have observed in interviews with teachers. Unfortunately, the laboratory practices in school science prevent students, even in higher education from getting acquainted with the design and implementation of adequate experiments to test hypotheses, because they typically use designs already elaborated following *kitchen recipes*. Thus, science teaching focused on simple knowledge transmission favours the permanence of empirical-inductive conceptions which emphasize inaccessible experimental work as a key element of the so-called "Scientific Method".
- *The "Scientific Method" is presented as a sequence of steps to be mechanically followed*, enhancing quantitative treatments, rigorous control, etc, and forgetting – or even rejecting – anything related to invention, creativity, or doubt. In interviews held with teachers, a majority refers to the "Scientific Method" as a sequence of well defined steps in which *observations* and *rigorous experiments* play a central role and which contributes to the *exactness* and *objectivity* of the results obtained. Such a view is particularly evident in the evaluation of science education: as Hodson (1992a) points out, the obsessive preoccupation with avoiding ambiguity and assuring the reliability of the evaluation process distorts the nature of the scientific approach itself, initially vague, uncertain, and intuitive. Some teachers, in rejecting this rigid and dogmatic view of science, may accept an extreme relativism, both methodological – "anything goes", there are no specific strategies in scientific work (Feyerabend, 1975) – and conceptual: there is no objective reality which allows us to test the validity of scientific construction. "The *only* basis for scientific knowledge is the consensus of the research community". This is a relativism close to the theses of radical constructivism (von Glasersfeld, 1989), which has received serious criticism (Suchting, 1992, Matthews, 2000). Nevertheless, the dominant conception is the simplistic algorithmic one, which, like the related empirical-inductive conception, is easily accepted in as much as scientific knowledge is presented in a finished form just to be accepted and learnt: effectively, in this way, neither students nor teachers have the possibility of putting into practice and realising

the limitations of the so-called Scientific Method. For the same reason one falls easily into *an aproblematic and ahistorical view of scientific activity*.

- A teaching orientation based on the simple transmission of knowledge often results in ignoring the initial problems scientists intended to solve, neglecting the evolution of such knowledge, the difficulties encountered, the limitations of current scientific theories or new perspectives. In doing so, one forgets that, as Bachelard (1938) stated, all knowledge is the answer to a question. The omission of the problem studied and of the process to construct an answer makes it difficult to perceive the rationality, relevance and interest of the knowledge constructed and its tentative character.
- The distorted, impoverished view of science we are discussing here includes two other misconceptions which both fail to consider that one of the aims of science is the construction of coherent bodies of knowledge. We are referring to *an "exclusively analytical" view* and to *a "linear, cumulative" view of scientific processes*. Why do we speak of an exclusively analytical view as a distortion? It is obvious that analyses and simplifications are initially necessary, but we should not forget the subsequent efforts to synthesise and increasingly construct larger bodies of scientific knowledge, or the treatment of problems which overlap different disciplines and can be integrated. It is the omission of these syntheses and integration processes which constitutes a distortion. This is the reason we speak of an *exclusively* analytical view. The last relevant misconception we have detected consists of the consideration of the evolution of scientific knowledge as the result of a linear, cumulative progression (McComas, 1998). This ignores periods of crisis and profound change (Kuhn, 1970) and the fact that the development of scientific knowledge does not fit into any well-defined predictable pattern of evolution (Giere, 1988). This misconception complements, in a certain sense, the rigid and algorithmic view we have already discussed, although they must be differentiated: while the latter refers to how a particular piece of research is organised and carried out, the cumulative view is a simplistic interpretation of the evolution of scientific bodies of knowledge, which is seen as a linear process. Science teaching reinforces this distortion by presenting theories in their current state, omitting the process of their construction, which includes occasional periods of confrontation between contrary theories or outbreaks of authentic "scientific revolutions" (Kuhn, 1970).

These interrelated misconceptions we have summarized transmit a socially accepted naïve image of science and technology which the transmission/reception model (that remains prevalent in science teaching) reinforces, sometimes explicitly, but most of the time implicitly, by omitting the discussion of such erroneous views and, above all, by not giving pupils the opportunity of getting acquainted with scientific strategies, that is to say, of engaging in and developing expertise in scientific inquiry and problem solving (Hodson, 1992b, Gil-Pérez & Carrascosa, 1994, Gil-Pérez *et al.*, 2002, Anderson, R., 2007, pp. 807-830).

What is being done to change this situation? The answer is not much, according to the last Handbook of Research on Science Education: "One of the most striking observations we can offer concerns the extent to which science education research appears not to be extended and extrapolated to programs of science teacher education" (Russell & Martin, 2007, p. 1151). In other words: "there continues to be a gap between research knowledge and science teaching practice" (Roth, 2007, p. 1206). In the same vein, Rocard's Report recognizes:

> The current initiatives in Europe actively pursuing the renewal of science education through 'inquiry based' methods show great promise but are not of the scale to bring about substantial impact, and are not able to exploit fully the potential European level support for dissemination and integration.

III.2 What can be done to improve physics teaching and learning?

The first thing to do should be to recognize what the problem is: we do not face the supposed supremacy of the constructivist approach in the field of physics education, but the supremacy of the transmission/reception model that conveys a distorted and impoverished image of science and technology (National Academy of Sciences, 1995, McComas, 1998; Aikenhead, 2007; Rocard *et al.*, 2007; Gil-Pérez, Vilches and Ferreira-Gauchia, 2008).

The second difficulty we have already mentioned is that although abundant research has shown the potential of an inquiry-learning approach (Anderson, R., 2007, pp. 807-830), there continues to be a gap between research knowledge and science teaching practice (Roth, 2007, p. 1206) and even teacher education (Russell & Martin, 2007, pp. 1151-1178). This gap is reinforced by structural constrictions (such as the high number of classes to teach or the lack of resources available to undertake experimental work) that have to be eliminated if really we want to improve teaching and learning. But these constrictions aren't the only difficulty: it is quite striking to see that even when the number of pupils is small many teachers continue to lecture as they usually do, without trying to incorporate more active strategies.

One way to close this gap is for teachers to participate in research tasks (Roth, 2007). This research is necessary, specifically regarding science teacher attitudes and beliefs. Recent research on this domain has revealed how individuals' epistemological systems are constructed through their formal and informal experiences as students. These systems of conceptions of science nature and science teaching are extremely stable because they have been modelled for a number of years and the new information is filtered through them (Jones & Carter, 2007, pp. 1067-1104). For this reason science teacher education must pay special attention to elicit these conceptions and to analyse them in the light of what the history and philosophy of science show about how scientific knowledge is built (Bell & Pearson, 1992, Désauteles *et al.*, 1993, Guilbert & Meloche, 1993). In fact, teachers understanding and taking into consideration_how scientific knowledge is constructed appears to be a conditio sine qua non –albeit insufficient (Hodson, 1993) – for really effective science teaching, overcoming the "spontaneous" distorted and impoverished image of science.

For this reason we have conceived a workshop which gives teachers the role of researchers who have to critically analyse the image of science and technology usually transmitted by science teaching. Participation in this oriented research makes it possible for teachers to begin to overcome their distorted views of the nature of science and technology and approach current epistemological views (Fernández *et al.*, 2002, Gil-Pérez *et al.*, 2005). We complete the workshop by synthesizing these epistemological views as a way of reinforcing teachers' questioning of the distortions of the nature of science and technology. Because, in spite of some discrepancies in specific aspects and many nuances, the views of most contemporary philosophers of science show a basic consensus which presents an image of science that is radically opposed to the naïve view reflected by the seven distortions we have discussed in the previous section (Toulmin, 1961, Popper, 1968, Kuhn, 1970, Bunge, 1976, Lakatos, 1970, Feyerabend, 1975, Laudan, 1984...). These are some points of consensus that we believe must be enhanced (Gil-Pérez, Vilches & Ferreira-Gauchia, 2008):

1. First of all, we must refer to the general rejection of the idea of the "Scientific Method" as a sequence of perfectly defined rules to be applied mechanically and independently of the research domain. The expression (Scientific Method) is misleading because it may cause us to believe that there is a set of exhaustive and infallible recipes (Bunge, 1976, McComas, 1998).

2. In the second place, we must point out again a general rejection of what Piaget (1970) denominates "the myth of the sensorial origin of scientific knowledge", that is, the rejection of an empiricism that conceives knowledge as the result of inductive inference from "pure data". These data do not make sense on their own. They have to be interpreted according to a theoretical system. Thus, for example, when using an ammeter, one does not observe the intensity of the current, but the movement of a needle. We have to insist upon the importance of conceptual paradigms, of theories, in the carrying out of scientific work (Bunge, 1976), which is a complex process, not reducible to a defined model of scientific development. This may include breaks and revolutionary changes in the prevailing paradigms and the emergence of new ones (Kuhn, 1970). We also have to stress that scientific problems are initially "problematic situations": the problem is not given, it must be stated in a precise way, taking decisions to simplify the situation, clarify the aim, etc. And all of this is done starting from the available body of knowledge (Lakatos, 1970).

3. Thirdly, we have to point out the role played by divergent thought and creative thinking, such as the *invention* of hypotheses and models or the design of experiments, neglected in the empiricist-inductivist approach. One does not reason in terms of certainties based on "facts", but in terms of hypotheses, i.e., "tentative answers" based on available knowledge, which must be tested as thoroughly as possible. This results in a complex process in which there are no universal normative principles for accepting or rejecting a hypothesis and the subsequent changes in the theoretical corpus (Giere, 1988). Although experimental evidence obtained in defined and controlled conditions undoubtedly plays an important role in scientific research, we have to recognise that hypotheses play the central role: we do not arrive at scientific knowledge by applying an inductive procedure of inference to previously gathered data, but through the construction of hypotheses as tentative answers to be tested (Hempel, 1966).

4. Another fundamental aspect is the search for coherence (Chalmers, 1990). Thinking tentatively and working with hypotheses introduces supplementary demands: we need to systematically doubt the results obtained and the processes followed to obtain them. This leads to continuous revisions and regulations, trying to obtain these results using different strategies and, more specifically, testing their coherence with the whole body of knowledge.

It is necessary to warn against a possible experimentalist reductionism: experimental testing is not sufficient basis to accept or reject a hypothesis; we need to verify the existence, or not, of the global coherence of these results with the available body of knowledge.

In fact, one of the most important outcomes of science consists in linking apparently unconnected domains. In a world characterised by diversity and change, science looks to establish general laws and theories, applicable to the widest number and variety of phenomena. The atomic-molecular theory, the conservation and transformation laws (of mass, energy…), the electromagnetic synthesis… are good examples of this search for coherence and global validity which begins with addressing initially specific and narrow problems and situations. Scientific development entails this search for generalisations applicable to real situations. And it is this coherence and applicability to the description of phenomena, in prediction-making, in the treatment of new situations, etc., which gives a growing validity – never certainty – to the concepts, laws and theories constructed.

We must also be aware that an essential characteristic of the experimental approach is an explicit will to simplify and rigorously control the studied situation. This introduces artificiality, which must not be ignored or hidden: scientists *decide* to treat solvable problems and this causes them to consciously put aside many of the characteristics of the studied situation, therefore moving away from reality. They also move away from reality by *imagining* models and *inventing* hypotheses. A scientific approach demands, as we see, artificial, partial and simplified treatments. But this approach should not be seen as a reductionist and simplistic one: as analyses and simplifications are conscious, scientists are aware of the need for further syntheses and more profound treatments.

We must recognise that this strategy has made the unification of apparently unconnected fields possible, sometimes with strong ideological resistance, provoking persecution and damnation as in the well known examples of Heliocentrism and Evolutionism.

The history of scientific thought is a permanent confirmation of the validity of these initially partial and limited treatments which lead to the growing construction of coherent bodies of knowledge and to the establishment of links between separate domains.

5. Finally, it is necessary to take into account the social nature of scientific work: current theories – which constitute the point of departure for the treatment of new problems –, are due to the contributions of many researchers. Besides, research is increasingly promoted and controlled by institutions where the work of individuals is oriented by established lines of research, by teamwork, by sponsors' interests… (McComas, 1998).

In fact, the stereotype of completely autonomous research is invalid. The work of scientists, as in any other human activity, cannot take place outside society and is affected, logically, by problems, interests and the circumstances of the historical moment. And at the same time, the work of scientists influences their physical and social environments.

To remember all this may seem superfluous; but the idea of science as an activity only for solitary geniuses, working apart from the world, is a stereotype which teaching, unfortunately, does not help to dispel, because it is almost exclusively centred on the transmission of conceptual knowledge.

These characteristics of science we have summarised may seem to draw a vague, nebulous image of scientific activity, far removed from the idea of a precise and infallible algorithm, but reveal science in a more authentic and complete light. We could say that the essence of scientific strategies –putting aside any idea of "method"- lies in overcoming a thought process based on dogmatic securities and common-sense evidence, in order to adopt tentative, hypothetical reasoning. Reasoning which is both more creative (it is necessary to go beyond what seems obvious and imagine new possibilities) and more rigorous: it is necessary to construct well founded hypotheses, to test them carefully, to systematically doubt the results obtained and to look for global coherence. These are current points of consensus about the nature of science which draw an image contrary to the distorted views we referred to in section III.1.

When we present such a summary to the teachers' teams involved in research about distorted views of science, they easily point out how this summary overcomes each of the studied distortions. This reinforces, of course, the clarification efforts made to approach current epistemological views and achieve a better appreciation of the nature of science and technology. But, what *practical* interest could this have? Guilbert and Meloche (1993) stated, "A better understanding by science teachers in training of how science knowledge is constructed is not just a theoretical debate but a highly practical one". In fact, the clarification of the possible distortions of the nature of science and technology makes it possible to move away from the typical reductionism of the activities included in science teaching and the incorporation of aspects which give a more adequate view of science as an open and creative activity, relevant to the construction of knowledge and/or the attainment of technological innovations, capable of satisfying human needs.

This strategy aims basically to involve pupils, with the aid and orientation of the teacher, in an open and creative work, inspired by that of scientists and technicians, thus including essential aspects currently ignored in science education, such as the following (Gil-Pérez *et al.*, 2002 and 2005, Gil-Pérez, Vilches & Ferreira-Gauchia, 2008):

- *The discussion of the possible interest and worthiness of studying the situations proposed*, taking into account the STSE implications, in order to make this study meaningful and prevent students from becoming immersed in the treatment of a situation without having had the opportunity to form a first motivating idea about it. In this way pupils, as members of the scientific community, will have the opportunity to practice decision making about undertaking (or not) a certain research project or innovation (Aikenhead, 1985).

- *The qualitative study of situations*, taking decisions -with the help of the necessary bibliographic research- to define and delimit specific problems. If we want pupils to really understand what they are doing, it is essential to begin with qualitative and meaningful approaches… as scientists themselves do.
- *The invention of concepts and forming of hypotheses* as tentative answers, based on pupils' previous knowledge and personal conceptions, which will help to focus the problems to be studied and orientate their treatment.
- *The elaboration and implementation of possible strategies for solving the problems*, including, where appropriate, experimental designs to check hypotheses. It is necessary to highlight the interest of these designs and the implementation of experiments which demand (*and aid to develop*) a multiplicity of knowledge and skills, including technological work to solve the practical difficulties usually posed by designs.
- *The analysis and communication of the results*, comparing them with those obtained by other pupils' teams and the scientific community (represented by the teacher and the textbooks). This can produce cognitive conflicts between different conceptions and demand auto and inter regulation, that is to say, the formation of new hypotheses and the reorientation of the research. At the same time this could be the opportunity to approach the evolution, sometimes dramatic, experimented by the knowledge accepted by the scientific community. It is particularly important to enhance communication as an essential aspect of the collective dimension of scientific and technological work. This means that students must get acquainted with reading and writing scientific reports as well as with oral discussions.
- *The recapitulation of the work done,* connecting new constructions with the body of knowledge already possessed and paying attention to building bridges between different scientific domains, which occasionally may generate authentic scientific revolutions.
- *The contemplation of possible perspectives*, such as the conception of new problems, or the realisation and improvement of technological products, which can contribute to the reinforcement of pupils' interest.

All this allows the application of the new knowledge to a variety of situations to deepen and consolidate it, putting special emphasis on the STSE relationships which frame scientific development and, even more, human development, without forgetting the serious situation of planetary emergency (Gil-Pérez *et al.*, 2003), as international institutions demand of educators in any area (United Nations, 1992).

We would like to highlight that *the orientations above do not constitute an algorithm* intended to guide pupils' activity step by step. Instead, they must be taken as general indications which draw attention to essential aspects concerning the construction of scientific knowledge that are not sufficiently taken into account in science education. We are referring both to procedural and to axiological aspects such as STSE relationships (Solbes & Vilches, 1997, Koballa*,* & Glynn, 2007), decision-making (Aikenhead, 1985, Hart, 2007, Roberts, 2007), communication (Sutton, 1998, Carlsen, 2007, Kelly, 2007), etc., in order to make possible a meaningful learning and a better appraisal of scientific activities. This has nothing to do, as we can see, with the philosophical theses of von Glasersfeld's radical constructivism.

IV. Conclusion and perspectives: Promoting future scientists' and citizens' preparation for decision-making about socio-techno-scientific issues. An Ethical Commitment

We have tried to show that the supposed "supremacy of the constructivist epistemology" in the field of physics teaching is just a myth. With this aim, we have distinguished between trends in science education *research* and what is done in science *teaching*. It is true that the dominating perspectives of research on teaching and learning science have been the constructivist views, also designed as inquiry-based proposals. But although pedagogical practices based on inquiry-based methods are more effective, the reality of classroom practice is that in the majority of classrooms these methods are simply not being implemented. Supremacy in physics teaching actually corresponds to the reception learning model, in spite of its proven inefficiency. Tradition and structural constrictions (as the number and size of the classes to teach or the scarce time and resources available for experimental work) contribute to this supremacy.

In addition, we have shown that what we understand by constructivism in science education has nothing to do with the epistemological theses of radical constructivism: it consists in creating a climate of collective research undertaken by students' teams, acting as *novice researchers*, with the teacher's assistance. In this way, pupils participate in the (re)construction of knowledge, learn more meaningfully and acquire a higher interest in science (Hodson, 1993, Gil-Pérez *et al.*, 2002, Anderson, R., 2007, Gil-Pérez, Vilches & Ferreira-Gauchia, 2008).

We would like to finish by giving another important reason for improving physics education, overcoming the distortions and reductionisms of the nature of science transmitted by the mere transmission of knowledge already elaborated: the United Nations General Assembly, given the serious and urgent problems humanity has to face nowadays, has adopted a resolution establishing a *Decade of Education for Sustainable Development* (2005-2014). This constitutes a new urgent call to educators *of all levels and areas* to contribute to citizens' awareness and understanding of the situation of planetary emergency (Bybee, 1991) in order to enable them to participate in well-founded decision-making and contribute to a sustainable future (Vilches & Gil, 2003).

In the opinion of many authors (Fourez, 1994, Bybee, 1997, DeBoer, 2000, Gil-Pérez & Vilches, 2005, Koballa & Glynn, 2007), the preparation of citizens to participate in decision-making justifies scientific and technological literacy as a basic component of citizens' education and especially of scientists' training, in order to revert a degradation process that is constantly sending us unequivocal signals in form of global heating, unnatural catastrophes, loss of biological and cultural diversity, millions of deaths by inanition and wars – consequence of suicidal short-sighted interests and fundamentalisms–, dramatic migrations… and a long etcetera. We have to be capable of generating a universal trend for a sustainable future that has to begin right now

This is the aim that we can and must incorporate into science education, teaching and research, conscious of the difficulties, but determined to contribute, as educators, scientists and citizens, to build up the conditions necessary for a sustainable future (Vilches & Gil, 2003, Hart, 2007). In fact there are many opportunities to incorporate the state of the world and education for sustainability in physics education. For instance, studying energy constitutes an excellent opportunity to deal with the world's situation and to contribute to a better understanding of the related problems and the possible action to be taken in light of the current situation of planetary emergency (Furió *et al.*, 2005). This is for us a very important ethical commitment that justifies in itself the efforts to improve physics education.

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