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Technology as 'Applied Science': A Serious Misconception that Reinforces Distorted and Impoverished Views of Science

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Abstract. The current consideration of technology as 'applied science', this is to say, as something that comes 'after' science, justifies the lack of attention paid to technology in science education. In our paper we question this simplistic view of the science-technology relationship, historically rooted in the unequal appreciation of intellectual and manual work, and we try to show how the absence of the technological dimension in science education contributes to a naïve and distorted view of science which deeply affects the necessary scientific and technological literacy of all citizens.

1. Introduction

When we ask science teachers 'what technology is', almost one hundred per cent of the answers make reference to 'applied science'. This common view justifies the lack of attention to technology in science education. In fact, the most frequent references to technology included in science textbooks are simple enumerations of applications of scientific knowledge (Solbes and Vilches 1997). On the other hand, most studies about the nature of science do not pay any attention to the science-technology relationship (Fernández et al. 2002). An analysis of the proceedings of the six precedent History, Philosophy and Science Teaching International Conferences shows very clearly this lack of attention, which is coherent with the view of technology as something which comes after science.

In this paper we intend to show that this simplistic conception of the science-technology relationship reinforces distorted views of science, considered by many authors as one of the main obstacles to renovation in science education (Bell and Pearson 1992; Gil 1993; Guilbert and Meloche 1993; Hodson 1993; Meichtry 1993; Désautels and Larochelle 1998a, b; McComas 1998). We shall begin by questioning the idea of technology as applied science.

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2. Technology as 'Applied Science'?

It is very easy to question this simplistic view of the science-technology relationship: we just have to briefly reflect on its historical development to understand that technical activity has preceded the mere existence of science by thousands of years (Gardner 1994). This obliges us to disregard the notion of technology as a by-product of science (Maiztegui et al. 2002).

But the most important thing to clarify is what citizens' scientific education may lose because of this under-valuation of technology. This leads us to ask, as Cajas (1999) does, if there is something in technology useful for citizens' scientific literacy that we science teachers are not taking into consideration. Several authors have pointed out, in connection with this, some characteristics of technology which, if ignored, impoverish science education (Gardner 1994; Cajas 1999; Maiztegui et al. 2002). We shall study here a particularly important consequence of the oblivion of the role of technology in the construction of scientific knowledge: the reinforcement of serious distortions of the nature of science.

3. A Decontextualised, Socially Neutral View of Science

We shall start with a misconception criticised by abundant literature (Fernández et al. 2002): the transmission of a socially neutral view of science which ignores, or treats very superficially, the complex relationship between Science, Technology and Society, STS or, better yet, STSE, adding the E for Environment to direct attention towards the serious problems of environmental degradation which affect the whole planet.

This superficial analysis implies, as we have already seen, the consideration of technology as a mere application of scientific knowledge, so *exalting science, more or less explicitly, as an absolute factor of progress*.

In contrast to this naïve view of science, there is *a growing tendency to blame science and technology for the environmental degradation in process on our planet*, with the destruction of the ozone layer, acid rain, etc. In our opinion this is also a serious misconception: it is true that scientists and technologists have a clear responsibility for, for instance, the production of substances which are destroying the ozone layer … but along with businessmen, economists, workers or politicians. Criticism and calls to responsibility should be extended to all of us, including the 'simple consumers' of dangerous products. Besides, we cannot ignore that many scientists study the problems humanity has to face nowadays, draw attention to the risks and look for solutions (Giddens 1999).

These simplistic attitudes of absolute exaltation or rejection of science are not founded at all and must be criticised. Nevertheless, *the most serious problem in science education comes from purely operative approaches* which

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completely ignore the social context (Stinner 1995), as if science were an activity carried out in ivory towers, at the margin of 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.

4. Science as an Individualistic and Elitist Activity

This individualistic and elitist conception is one of the distortions most frequently signalled in literature (Fernández et al. 2002), together with the closely related socially neutral view we have just studied. Scientific knowledge appears as the work of isolated 'great scientists', ignoring the role of co-operative work and of exchanges between different research teams. Particularly, it is implicitly suggested that results obtained by only one scientist or team may be enough to verify or falsify a hypothesis or even a theory.

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: science is presented as an eminently 'masculine' activity.

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.

We sometimes find a contrary distortion which presents scientific activity as something pertaining to common sense, thereby forgetting that science begins by questioning the obvious (Bachelard 1938). Still, the dominant view is the one which regards science as an activity of isolated geniuses.

Lack of attention to technology contributes to this individualistic and elitist view. On the one hand, the complexity of scientific-technological work which demands the integration of several kinds of knowledge, impossibly mastered by a single person, is ignored; on the other hand, importance is not given to the contribution of technicians who play a vital role in scientific-technological development. The starting point of the Industrial Revolution, for example, was the steam engine invented by Newcomen, a blacksmith and smelter. As Bybee (2000) has pointed out: 'In reviewing contemporary scientific research, one cannot escape the reality that most advances in science are based on technology'. This questions the elitist vision of scientific-intellectual work being ranked above technical work.

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

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distortion: the one which associates scientific work almost exclusively with 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, which the oblivion of technology contributes to.

5. An Empiricist-Inductivist, Non-theoretical View of Science

The idea of experimentation as ‘the principal route to scientific knowledge’ (McComas 1998) is, probably, the distortion which has been most studied and which most frequently appears in literature (Fernández et al. 2002). It is a conception which enhances ‘neutral’ observation and experimentation, forgetting the important role played by theoretically founded hypothesis as a guide to research.

Several studies have shown the discrepancy between the view of science given by contemporary epistemology and certain teachers’ conceptions, which lean heavily towards empiricism (Giordan 1978; Hodson 1985; Nussbaum 1989; Cleminson 1990; King 1991; Stinner 1992; Désautels et al. 1993; Lakin and Wellington 1994; Hewson, Kerby and Cook 1995; Thomaz et al. 1996; McComas 1998). These erroneous empiricist-inductivist views of science are frequently voiced by even scientists themselves, because they are not always explicitly conscious of their research strategies (Mosterín 1990).

We should point out that the view of scientific knowledge as a result of experimentation, overlaps with the notion of scientific ‘discovery’ presented by mass-media and other forms of popular culture (Lakin and Wellington 1994).

Although this distorted view of scientific activity is the most studied and criticised in literature, most 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 (Fernández 2000).

This absence of experimental work in science classes is in part caused by teachers’ lack of acquaintance with technology. Effectively, experimental work always requires the support of technology: for instance, to test the hypotheses which guide a research, we are obliged to conceive and construct experimental designs; and to speak of *designs* is to speak of technological work. It is true that, as Bunge (1976) points out, experimental designs are based on theoretical knowledge: the conception and construction, for instance, of an ammeter demands a sound knowledge of electrical current. But this con-

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struction also requires the solution of many practical problems in a complex process which has all the characteristics of technological work. It is not just a question of saying that *some* technological developments have been crucial to make possible *certain* scientific advancement (like, for example, the role played by lenses in astronomical research): *technology is always at the centre of scientific activity*; the expression experimental *design*, we insist, is perfectly illustrative of this.

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 impedes the understanding of the role played by technology in scientific development and favours the permanence of empirical-inductive conceptions which emphasise inaccessible experimental work as a key element of the so-called 'Scientific Method'. This conveys two other serious distortions which we shall discuss next.

6. Science as a Rigid, Algorithmic and Infallible Process

This is a very well known distortion which presents the 'Scientific Method' 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.

This is a wide-spread view among science teachers, as we have confirmed using different designs (Fernández 2000). For example, in interviews held with teachers, a majority have referred to the 'Scientific Method' as a sequence of well defined steps in which *observations* and *rigorous experiments* play a central role 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 (1992) points out, the obsessive preoccupation with avoiding ambiguity and assuring the reliability of the evaluation process distorts the nature of the scientific approach itself, essentially vague, uncertain, intuitive. This is particularly true when we refer to experimental work, where technology plays an essential role and, as we have already remembered, many unexpected problems appear which must be solved in order to obtain the correct functioning of the experimental designs. Evaluation should take into account this ambiguity instead of trying to eradicate it.

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

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consensus of the research community'. This is a relativism close to the theses of radical constructivism (Glasersfeld 1989) which has received serious criticism (Suchting 1992; Matthews 2000; Gil-Perez et al. 2002).

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 which we shall comment on in the next section.

7. An Ahistorical and, therefore, Closed and Dogmatic View of Science

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 this, one forgets that, as Bachelard (1938) stated '*all knowledge is the answer to a question*'. The omission of the problem 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.

Let us emphasise the close relationship between the distortions we have considered thus far. For example, this dogmatic and ahistorical view reinforces simplistic ideas regarding science-technology relationships which present technology as a by-product of science. We should bear in mind that research is an answer to problems that are often linked to human needs and so to the search for adequate solutions to previous technological problems.

As a matter of fact, the absence of a technological dimension in science education impregnates the naïve and distorted views of science we are eliciting. This lack of attention to technology is historically rooted in the unequal appreciation of intellectual and manual work, and deeply affects the necessary scientific and technological literacy of all citizens.

But 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 analytic' view and to a 'linear, cumulative' view of scientific processes. Although they are not so directly related to the oblivion of technology, we shall briefly refer to them, because this ensemble of distortions form a relatively well integrated framework and they support each other. We need, for this reason, to analyse all of them, in order to question the ensemble and make possible a more adequate vision of scientific activity.

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8. An Exclusively Analytical Approach

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 construct increasingly 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.

Current science education is strongly affected by this omission of the integration process. We have verified (Fernández 2000) that most of the teachers and textbooks do not enhance, for example, the integration achieved by the Newtonian synthesis of heaven and earth mechanics; an integration which had been rejected for more than a century with the damnation of Copernicus' and Galileo's work and the inclusion of their books in the '*Index Librorum Prohibitorum*'. The same happens with the presentation of biological evolution (still ignored by many teachers and opposed by some social groups) or organic synthesis (considered *impossible*, for ideological reasons, until the end of the XIX century).

9. A Linear, Cumulative 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; Izquierdo et al. 1999). 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; Estany 1990).

This misconception complements, in a certain sense, the rigid and algorithmic view we have already discussed, although they must be differentiated: while the later refers to how a particular 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).

10. To Overcome a Distorted and Impoverished Image of Science: Some Implications for Science Teaching

These are the seven major distortions we have detected in current science teaching by means of, among other procedures, analysis of textbooks, laboratory guides and assessment exercises; direct observation of classroom activities; questionnaires; interviews … (Fernández 2000). This study has shown that the naïve image of science expressed by the seven distortions we have mentioned is deeply rooted in current science teaching, centred almost exclusively in the transmission of conceptual knowledge. This occurs even at the university level, the result being that future teachers implicitly embrace this naïve image of science and related ineffective teaching strategies based on the simple transmission of conceptual knowledge.

We have to emphasize that the seven major distortions we have elicited do not constitute seven autonomous 'deadly sins'. On the contrary, as we have already shown, they form a relatively well-integrated conceptual framework and they support each other, transmitting an impoverished view of science, *and technology*, which generates negative attitudes in many students and makes meaningful learning more difficult. This is the reason why Guilbert and Meloche (1993) have 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 possible the movement 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. An activity centred in a *contextualized approach* (Klassen 2003) of *problematic situations* (Gil-Pérez et al. 2002) – or, in other words, *Large context problems* (Stinner 1995) – 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 in that of scientists and technicians, thus including essential aspects currently ignored in science education, such as the following (Gil et al. 2002):

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 occasion to practice decision making about undertaking (or not) a certain research or innovation (Aikenhead 1985).

The qualitative study of the situations, taking decisions with the help of the necessary bibliographic researches to define and delimit concrete 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, founded in pupils' previous knowledge and personal conceptions, which will help to focus the problems to be studied and orientate their treatment.

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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. This can produce cognitive conflicts between different conceptions and demand auto and inter regulation, this is to say, the formation of new hypotheses and the reorientation of the research. At the same time this can be the occasion 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 the new constructions with the body of knowledge already possessed and paying attention to establishing bridges between different scientific domains, which occasionally may generate authentic scientific revolutions.

The contemplation of possible perspectives, such as the conception of new problems, 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 in a variety of situations to deepen and consolidate, 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 of any area (United Nations 1992).

We would like to highlight that *the orientations above do not constitute an algorithm* that tries to guide the pupils' activity step by step, but rather they must be taken as general indications which draw attention to essential aspects concerning the construction of scientific knowledge not sufficiently taken into account in science education. We are referring both to procedural and to axiological aspects such as STSE relationships (Solbes and Vilches 1997), decision-making (Aikenhead 1985), communication (Sutton 1998), etc., in order to create 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 and learn more meaningfully (Hodson 1993; Gil et al. 2002).

The including by science teachers of activities such as those mentioned above, is an example of the positive incidence that the clarification of the nature of science may have. We don't think, naturally, that this is enough to

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correctly guide the science teaching/learning process, but we do think that this is a valuable contribution, a sine qua non requisite.

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