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Science curriculum development as a *technology* based on didactical knowledge

El desarrollo curricular en ciencias como una *tecnología* basada en el conocimiento didáctico

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Abstract

In this paper, we advance a model of didactics of science (science education as an academic discipline) that sees it as a set of interrelated professional activities. We sketch a multidimensional model of didactics in which different components may be identified. Among these, we explore the theoretical component, which is concerned with the development of original theoretical frameworks at a rather general level. Attention is paid to the nature of didactical models and how they may operate to inform science education. For us, curriculum development may be usefully seen as a technological practice that draws from scientific models within didactics, that is, as a practical activity informed by theoretical understandings of the different aspects of science education. We exemplify these ideas analysing some recent didactical innovations.

Keywords: didactics of science, meta-analysis, technoscience, curriculum development, cognitive model of science.

Resumen

En este trabajo se propone un modelo que considera la didáctica de las ciencias como un conjunto de actividades profesionales interrelacionadas; se trata de un modelo multidimensional que identifica diferentes componentes en ests disciplina. Entre ellas, exploramos la componente teórica, que se ocupa del desarrollo de marcos conceptuales originales en un nivel más bien general. Prestamos atención a la naturaleza de los modelos didácticos y cómo ellos pueden operar para fundamentar la enseñanza de las ciencias. Para nosotros, el desarrollo curricular puede ser visto como una práctica tecnológica que se nutre de los modelos de la didáctica de las ciencias, esto es, una actividad práctica sustentada en el estudio teórico de los diferentes aspectos de la educación científica. Ejemplificamos estas ideas por medio del análisis de algunas innovaciones didácticas recientes.

Palabras clave: didáctica de las ciencias, meta-análisis, tecnociencia, desarrollo curricular, modelo cognitivo de ciencia.

Introduction

Traditionally, curriculum design in the natural sciences (physics, chemistry, biology, geology) was undertaken by interdisciplinary groups of scientists. The core idea of this model of curriculum development was that selecting the *contents* to be taught came first. These contents subsequently determined the goals to be achieved and the activities to be conducted in the classroom. Curriculum design was then almost entirely informed by the *structure* of scientists' science.

Over the last 50 years, there has been a steady revolution in science curriculum design, one that parallels and is influenced by the revolutions in educational psychology (moving from classical Piagetian and Ausubelian approaches to cognitive and social perspectives), and in science studies (where the inclusion of historical and cognitive elements has brought a major transformation). One of the main objectives of the new curriculum models, as exemplified by the 1960s NSF and Nuffield projects, was to move science teaching away from the textbook and into the laboratory, favouring the process of *discovery* and the role of enquiry in science learning.

Other shifts followed this initial change of priorities. The epistemological focus, for instance, was moved from the justification to the *understanding* of science. Such change was accompanied by an increasing emphasis on theory *restructuring* against theory testing (Duschl, 1990), and by a discursive, conversational approach to classroom dynamics, more aligned with current cognitive and social views of science at school (Kelly, 1997).

The question that guides curriculum design may now be stated as: what do we want students to do and what do they need to know in order to do it? (Duschl, 1998, 2000). That is, we select an approach to science curriculum development focusing on school science as an *activity*, as an integration of cognitive, epistemic and social processes, rather than as an attainment of selected science contents and process skills. From our point of view, scientific contents should be integrated with more general goals different from the mere coverage of these contents. Such goals would include, among many others, the ability to critically evaluate scientific claims, and to understand the relationship between these claims and the existing evidence.

There are different specific bodies of theoretical knowledge to draw upon for the task of answering the curricular question: mainly the philosophical, psychological, and pedagogical; but the relative importance accorded to each of these has been varied through the twentieth century. In the early 1900s, pedagogy would be the central theoretical framework informing science education; afterwards, philosophy of science and instructional psychology alternatively disputed such a place until the 80s, in which more balanced views were achieved under the broad denomination of *constructivism* (Cleminson, 1990).

With the consolidation of didactics of science in continental Europe as an emergent academic discipline at the beginning of the 80s (Astolfi, 1993; Gil-Pérez, 1996; Porlán, 1998), an increasing amount of empirical research and various theoretical frameworks began to be available. This body of knowledge had the potential to inform the process of development of national curricula in several countries, as was the case of Spain (Jiménez-Aleixandre and Sanmartí, 1995). A new community of specialists, the *didactitians* of science, was slowly incorporated to the groups for curriculum design; they contributed providing some unifying criteria to make compatible the different theoretical views on this task coming from the disciplines mentioned above, and from others such as sociology, anthropology and linguistics.

With the main focus of curriculum development shifted from the contents of science to the activities and therefore to the aims of scientific education, it would be possible to develop models of classroom science that pay attention to philosophical, psychological and pedagogical aspects in a more balanced and integrated way. Such models, concerning the co-ordination and synthesis of curriculum, instruction and assessment frameworks (C-I-A), which we will collectively refer to as *curriculum development* from now on, may act as a means of achieving important goals for science education, such as: forging a change of instructional practices away from recitation and into discursive practices (Kelly, 1997; Brown and

Campione, 1994; Izquierdo et al., 1999a; Roth, in press); informing the facilitator role of science teachers (Lehrer and Schauble, 2002); and enhancing the importance of formative assessment in the classroom (Duschl, 1995, 1998; Black and William, 1998; Sanmartí, 2000).

We suggest that didactics of science is nowadays sufficiently developed as a discipline as to provide robust theoretical models that can generate new insights into curriculum development (that is, C-I-A as integrated processes) in many different ways. First, these didactical models (DMs) can integrate current philosophical, psychological and pedagogical perspectives in a tightly coherent way focusing on the *cognitive*, *epistemic* and *social* aspects of science classroom activity (Izquierdo et al., 1999a). Second, DMs make possible an epistemological basis for school science (Izquierdo and Adúriz-Bravo, in press) that can produce guidelines and criteria for making decisions about several major issues in science education (e.g., roles of evidence, method and explanation, discourse, laboratory practice, intertextual teaching). Third, DMs pay attention to the dynamic role of debate, communication and argumentation in the science classroom (Duschl and Gitomer, 1991, 1997; Jiménez, 1998). Fourth, DMs make possible the design of instructional sequences building epistemic communities of enquiry in the classroom (Grandy, 1997). And fifth, DMs can provide a more balanced view of the nature of science that incorporates certain features of a constructivist approach while remaining realist and rationalist (Adúriz-Bravo et al., 2001). The latter is an aim of the utmost importance in current science education, in view of the strongly antiscientific movements that are widely spread within society and at school.

But although much progress has been made along these paths, the contributions of didactitians in curriculum development are still secondary compared to those of other professionals. New models of curricula are increasingly incorporating into the design of learning environments some general ideas coming from didactics, such as the use of the philosophy and history of science (Duschl, 1990; Adúriz-Bravo, 1999), problem-based conceptions of learning (CTGV, 1994), and the analysis of classroom reasoning and rhetoric (Brown and Campione, 1994; Jiménez, 1998; Osborne, 1999; Adúriz-Bravo et al., 2001). However, we can argue that these general ideas are still not sufficiently specific and theoretically articulate.

Our position is to argue that the shift of the main focus of curriculum development from first deciding the contents of individual disciplines to first deciding the general goals of scientific education makes possible the incorporation of models of classroom science that integrate the aforementioned philosophical, psychological and pedagogical aspects. What has yet to be developed is a clear and extensive articulation of the criteria from these three disciplines; this will require the input from in-service science teachers and classroom based research. It seems to us that these co-ordinating criteria may partly arise from a cognitive approach to the three disciplines of philosophy, psychology and pedagogy, strongly focused on the concept of *scientific modelling*.

To approach such broad concept, we turn in this paper to the semantic view within the contemporary philosophy of science (Suppe, 2000), in order to epistemologically define our idea of model and to show that this definition is compatible with some others currently held in psychology and pedagogy.

The goal of this paper is to advance the discussion of the issue of integrating theoretical criteria from philosophy of science, psychology, and pedagogy to construct effective DMs. We hope to make the case that didacticians of science, and not scientists or other specialists, should be the principal voice in making decisions about the design of science learning environments through using these DMs. We will try and show that various recent successful instructional proposals issued from didactics of science support such a statement.

Thus, one aim of this paper is to provide an argument for treating didactics of science as an academic discipline with several professional fields of action (Adúriz-Bravo, 1999/2000, 2000). We will pay particular attention to theoretical models within didactics that are coherent with successful transformations of classroom practices. For us, curriculum development may be usefully seen as a complex technological, or *design*, practice that draws from scientific models within didactics, that is, as a practical everyday classroom activity informed by theoretical understandings of the different aspects of science education.

In the first section of the paper we sketch a multidimensional model of didactics in which different components may be identified. The second section is dedicated to explore, among these, the theoretical component, which is concerned with the development of original theoretical frameworks at a rather general level, valid for the different science subjects. Some attention is paid to the nature of these DMs and how they may operate to inform science education.

Among the DMs now available, we consider the *cognitive model of school science* (Izquierdo et al., 1999b; Izquierdo and Adúriz-Bravo, in press) as an interesting one. The cognitive model of school science focuses on science in the classroom as a cognitive, epistemic and social activity, matching and supporting the shift in curriculum models that we outlined above, and being able to connect with ideas from other disciplines concerned with science education. This model is initially taken from the philosophy of science and may provide strong epistemological foundations for school science due to its *representational* conception of scientific theories, that is, one focusing more on how theories are understood by and make sense to students than on how they are internally built.

The third section aims at conceptualising curriculum development as a technological activity based on DMs, that is, as a process of co-ordinately changing C-I-A practices with the input and participation of science teachers. This will generate as a consequence regarding science classrooms as a laboratory for applied research. We will use an analogy with other well-known technological fields, such as medicine and engineering. As a result of this approach to didactical research, we recognise the strategic importance of classroom based research programmes in collaboration with teachers in the near future.

In the fourth section we present some examples that deal with these rather abstract theoretical ideas. Such examples may be considered interesting contributions to science education. Lastly, we review some implications of our suggestions for the development of didactics of science in the near future; these implications concern the role of the didactician as a professional in the field of curriculum development in its different levels of concretion.

A dynamic model of didactics of science as a discipline

The epistem logical status of didactics of science as an academic discipline has been an issue of debate among didacticians (Jiménez-Aleixandre, 1988; Porlán, 1998; Adúriz-Bravo, 1999, 1999/2000, 2000). Some researchers consider didactics to be a social science, along with disciplines such as the sociology of education. Others regard didactics more as a technology, aimed at intervening extensively in science education. In this sense, a whole *didactical engineering* has been developed in France (Joshua and Dupin, 1993). Finally, some authors locate didactics among human studies, focusing on its philosophical aspects and its connections with broader educational issues (Bliss, 1995).

Such different considerations may be due, among other things, to the implicit conceptions of science that these different authors maintain, which can correspond more or less to a limited epistemological model of science that has been mainly inspired by physics. But these different views on didactics of science can be mainly attributed to the fact that these authors are examining different aspects of didactics as a professional practice. We are going to elaborate this idea of multiplicity for didactics through an epistemological model of how it works.

Didactics of science as a set of interrelated professions and activities

We will present here a model of didactics of science as a set of different activities ranging from scientific research to the practice of science education (figure 1). These activities are performed by a range of people and in a variety of places, but it may be argued that these different actors and scenes are getting more strongly related nowadays, and are slowly beginning to share a common theoretical corpus.

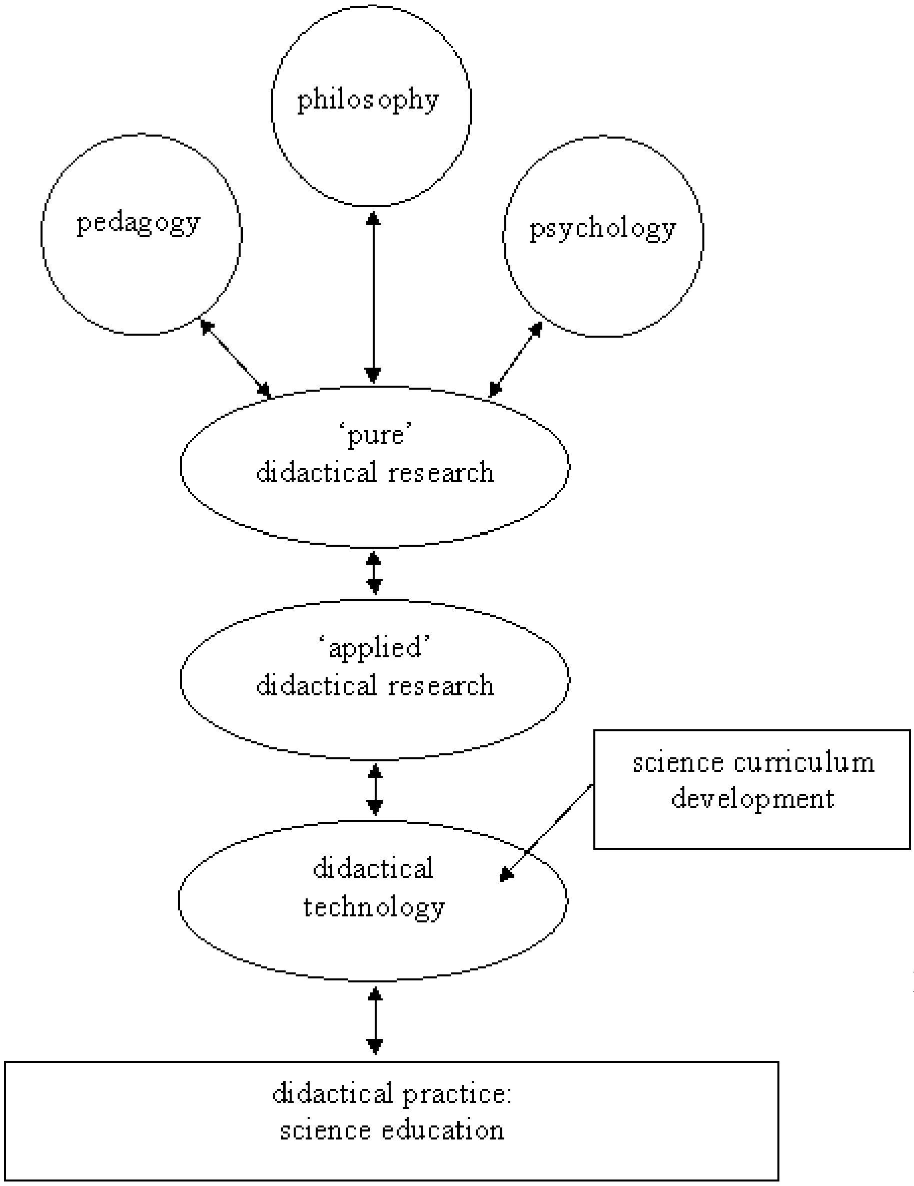

Figure 1. Didactics of science as a set of interrelated professional activities. Curriculum development plays the role of a technology.

According to this model, the aims and goals of didactics as an activity are directed to the ultimate improvement of science education in all its aspects. To achieve such improvement, an increasing division and specialisation of tasks has evolved; nowadays, this *didactical activity* is developed in very different contexts.

On the one hand, we find 'pure' didactical research, that is, the development of original theoretical models on science teaching and learning at different levels. These models focus on one or several components of the *didactical system* (teacher, students, content, context), and the relationships between them. Examples of such kind of research would be, for instance, the development of general teaching models, sequences or patterns that are to some extent content-independent, such as the *allosteric* model

(Giordan, 1982) and the *generative* model (Osborne and Wittrock, 1985).

Within this scientific dimension of didactics, we claim that we can find theoretical models integrating at least three converging perspectives, or *registers* (Martinand, 1987): the philosophical, psychological and pedagogical. The discipline that studies science education then goes beyond classical educational perspectives.

Along with this pure research, there are other kinds of research that are more classroom-based and more specific. These would correspond to what has been classically known in the philosophy of science as 'applied' research. The study of misconceptions in a domain, and the development of survey and interview protocols, would be examples of such a category.

At an even more applied level, we find technological research and development within didactics of science. These are aimed at producing a direct intervention in actual science educational situations, such as classrooms and curricula. Curriculum design at a national level, the writing of textbooks, and the development of instructional materials within the science education department at a school are three very different examples of this kind of technological practice. It is to be noted that, according to the model of didactics that we support here, science teachers may be regarded as *technologists* involved in the production of new didactical knowledge in concrete settings. This would need a change in the traditional role of 'deliverers' attributed to classroom teachers in didactical research.

Didactics of science and curriculum development

Within the model of didactics that we are advancing, the process of curriculum development at all levels can be seen both as applied and technological research and as a technological application of the DMs into curriculum materials, classroom- and laboratory-based instruction, student assessment, and teacher training.

In this setting, didactics of science may be considered as a technology, or *design science* (Estany and Izquierdo, 2001), that has its own body of scientific knowledge (all the DMs), and seeks to adapt this knowledge, modified with strong contextual considerations, to specific educational situations. Didactics would function as other technological fields such as medicine or engineering, ranging from a corpus of scientific knowledge (that can be either imported from other disciplines or specifically designed) to an informed professional practice.

Scientific models in didactics of science

Many DMs are highly specific, that is, they cannot be reduced to a mere adaptation of external theoretical models to the field of science education. Even if they use and transform theoretical ideas coming from other disciplines, DMs are constructed to fit specific science teaching situations with a definite perspective that differs from that of the other disciplines. There are many examples of DMs that are considered by didacticians as their established theoretical knowledge; they have been loosely grouped under the broad label of *constructivism* (Adúriz-Bravo, 1999, 1999/2000). Other academic communities regard this knowledge base as an original and specific creation of didactics that cannot be reduced to external disciplinary frameworks (Pozo, 1993).

We have suggested that many successful DMs that have been advanced within didactics of science strongly co-ordinate philosophical, psychological and pedagogical components. The unifying thread that permits this integration has different dimensions: social, epistemic and cognitive. These elements can be found within instructional psychology in many of its current streams (Donovan et al., 1999). In the philosophy of science, they constitute the basis of the so-called *cognitive turn* (Duschl, 1994). In pedagogy, they have led to the production of strong models of assessment hinging on the idea of self-regulation (Duschl and Gitomer, 1997; Sanmartí, 2000).

The cognitive model of science in didactics of science

Among the new DMs now available, we consider that the *cognitive model of school science* (Izquierdo et al., 1999a; Izquierdo and Adúriz-Bravo, in press) is one of the most promising. This is because such model focuses on science in the classroom as a cognitive and discursive activity within an epistemic community. This model is adapted from a cognitive philosophy of science strongly influenced by psychology, and compatible with current models from pedagogy (Izquierdo, 2000). It provides a unifying bridge between scientists' science and school science due to a strong representational conception of scientific theories, which shifts the attention from strict logical aspects to developmental and pragmatic ones.

We will now contextualise this model describing its philosophical sources, namely the *model based view* as proposed by Ronald Giere (1988, 1992, 1999) and other philosophers of science, and then sketch some of its core ideas along with their implications.

The model based view of science

Some of the new orientations in the philosophy of science have taken theoretical reflection upon science closer to other empirical disciplines, including it in the interdisciplinary arena of *cognitive science*. New models of scientific knowledge are elaborated that can be related to models of other kinds of knowledge. This major change in the philosophy of science has been motivated as a *third way* in the intense debate between the strongly relativistic views of the sociology of science and the rigid and normative rationality of analytical philosophy.

The model based view of science is related to a broader *semantic* conception of theories (Giere, 1988, 1992; Suppe, 2000). The semantic conception concentrates on the representational aspects of theories, that is, it considers that theories are sets of non-linguistic entities that represent some aspects of the world by means of *analogical* mechanisms; these entities and their relationships to the real world can then be explained using several linguistic strategies. Theories are explicative as long as they are *similar* to the aspects of the world that need to be explained, and this similarity is expressed by means of a linguistic apparatus. This cognitive approach to the study of science provides a basis for fruitful relationships between the history and philosophy of science and cognitive psychology, among other disciplines (Giere, 1992; Nersessian, 1992).

The model based view portrays science as a very complex activity aimed at making sense of the world; both *cognitive* and *social* factors play a key role in shaping the *epistemic* features of this scientific activity. Theories are regarded as the most important entities in science; they are constructed, selected and modified in order to interpret the world (Duschl, 1990). But theories do not need to be axiomatic, that is, they do not have as a necessary condition their linguistic presentation as a set of deductively-connected basic laws. On the contrary, theories can be to some extent identifiable with analogically connected sets of models (Giere, 1988). Theories and experimentation may be mutually justifiable according to a refined realist view, in which the pragmatic consideration of such connection plays a key role.

A model is then to be understood as an abstract, non-linguistic entity that fits some aspects of reality and can be characterised and represented by means of several languages (natural, symbolic, mathematical, graphic, etc). This broad conception of a model is sufficiently flexible and allows for an integration of different disciplinary perspectives on the process of *modelling*. For instance, this conception of model fits several of the categories in the taxonomies proposed by Greca and Moreira (2000), Harrison and Treagust (2000) and Galagovsky and Adúriz-Bravo (2001), namely: theoretical, pedagogical (didactical), analogical and mental models.

The model based view is particularly useful to study the new context of theory development, that drives the attention of the philosophy of science, psychology and didactics of science. Its results seem to be the most adequate for didactics, especially because of the new conception of scientific theories that this view puts forward, looking for the *meaning* of theories and for the relationships between models and the world, which are important features of school science as it is seen today in didactical research (Duschl, 2000).

A contribution that we consider extremely suitable is that of Ronald Giere (1988, 1992), specifically centred on the complex relationships between theories and the facts they refer to. In his work, he gives paramount importance to *theoretical models* in the construction of science. Theoretical models are considered a kind of mental representations similar to internal maps of the outside world. Due to the lack of strict logical connections, the relationship between theoretical models and reality is that of similarity, not of correspondence or of convention, as was characterised before within the philosophy of science.

Relationships between models and facts are developed through *theoretical hypotheses*, which can be more or less true or false, because they have empirical content. A scientific theory is then a family of models, together with a set of theoretical hypotheses that establish the degree of similarity between these models and the real world; thus, the theory necessarily contains its applications and it is partly the interpreted world (Giere, 1988, 1999). This idea of families of models provides a very *flexible* picture of scientific domains that is especially suitable to the recent history of didactics of science. This conceptual flexibility also provides a setting in which the role of teachers as technologists can be understood.

A cognitive model for school science

The teaching and learning of science may be usefully regarded as another aspect or *context* of the use and development of scientific knowledge (Echeverría, 1995). If the aim of teaching science is to teach how to think theoretically and understand the world, the first question to be answered is what school science should be like within this semantic conception. The model based view of science provides an answer to this question at a general level. This model denies that axiomatic presentations of a theory are its most important aspect; therefore, to learn such heavily formalised representations should not be the central objective of school science. On the other hand, it maintains that a theory has as main function allowing people to understand the world. If a theory fails to reach this goal, it is of little value in science education. This model also shows that facts of the world need to be *reconstructed* in the framework of theoretical models in order to be meaningfully understood by students (Izquierdo, 1995, 2000; Duschl, 1990, 2000).

The core idea of this model for school science is that scientific activity in the classroom is a process of attributing sense to the world by means of some non-linguistic entities, the theoretical models. These models and the phenomena interpreted by them constitute school science, which is similar in many aspects to academic science. But school science is characterised by its own aims and goals related to the democratic values of scientific literacy for all. In this sense, school science is rather independent from scientists' science; and this leaves a wide field of action to teachers as professionals. The process of transforming scientific models into school science models is generally known as *didactical transposition* (Chevallard, 1990).

In the last few years, we have been developing this cognitive model of school science (Izquierdo, 1995, 2000; Izquierdo et al., 1999b; Izquierdo and Adúriz-Bravo, in press), and we are now applying it to several research fields within didactics of science. One field of particular interest where the model can be used is that of non-scientific conceptions in students and teachers, which has evolved from the classical *misconceptions* in the early 80s to new approaches such as mental models (Chi, 1992) and theory theory in the late 90s (Gopnik, 1996; di Sessa, 2000).

Curriculum development as a technology

The point of this very short section is to argue that didactics of science has reached a stage of development that allows it to theoretically inform science education in many different issues so as to achieve actual improvements in classroom practices. Technology, in this sense, wants to refer to an active intervention on the world aimed at transforming it with the aid of a set of scientific models that are adapted to particular contexts.

Our conception of technology comes from contemporary philosophical models portraying science as an *activity* involving the representational, discursive, and material transformation of the world (Hacking, 1983). In this sense, technology is richly related to science but not linearly derived from it. Both components of this so-called *technoscientific* enterprise contribute to their mutual development.

We talk about the process of science curriculum development as actually belonging to the realm of technological research and development within didactics of science (figure 1). This idea is to be understood in the sense that the construction of a science curriculum implies a *transformation* of a specific aspect of reality –science education. But this is no longer done exclusively relying on experience and practice; it is now done resorting to a theoretical corpus.

This view has an important consequence in the way didactics considers the role of science teachers, which would approach to that of other technologists, such as medical doctors and engineers. Medicine and engineering as technosciences find their communities usually divided between those practising their profession and those doing scientific research to enlarge the body of knowledge that can be used in this practice; but this specialisation does not mean that both sections of the community are isolated. The same can be the case with didactics of science, if we consider classrooms as the source for research questions and for experimental settings. Within this framework of ideas, science teachers would be the technologists practising their profession using the body of established didactical knowledge that may have been developed by didacticians within the same community.

Some examples of these ideas

Recent research in didactics of science has advocated for a multidimensional perspective, integrating frameworks from various disciplines such as cognitive psychology, sociology, anthropology, ethnography and linguistics (Estany and Izquierdo, 2001; Viennot, 2001). Such an integration may be accounted in our model of didactics by means of the three converging general registers that we have mentioned: philosophical, psychological, and pedagogical (that is, mainly centring on content, student and teacher respectively). As we have stated before, the conducting thread that unifies these registers is their combined attention to social, epistemic and cognitive aspects of the nature, teaching and learning of science.

Kelly and Chen's (1999) and Kelly and others' (2000) studies on oral and written discourse processes in physics and oceanography classes may act as an initial example of what we see as *converging* registers. Different frameworks from science studies are used to illuminate discursive activities in the classroom. These frameworks can be broadly classified in our three categories. A socially focused pedagogical perspective is explicitly provided by educational ethnography, "studying how what counts as science is interactionally established by members within given communities". The epistemological register is supplied by social studies focusing on "the discursive shaping of disciplinary knowledge"; these involve three specific models of power negotiation, scientific writing, and the process of fact production. Finally, a weaker psychological perspective is provided by the attention to the relationship between discursive practices in the classroom and actual science learning by individual students. Similar frameworks are integrated in the paper by Kelly et al. (2000).

Richard Duschl's work in the context of project SEPIA (Duschl, 1995, 1998; Smith, 1995; Erduran, 1999) may be presented as another comprehensive example supporting our point. A strong conception of *assessment as self-regulation* can be identified as the core of the pedagogical component, and this is developed in the so-called assessment conversations. Along with this, a careful epistemological basis is provided, relating the process of curriculum development in different subjects to a specific model of theory restructuring within epistemic communities (Duschl, 1990; Longino, 1990; Kitcher, 1993). To complete the three registers, the model of learner that this project explicitly adheres to is shaped by recent findings in cognitive psychology (Bransford et al., 1999; Donovan et al., 1999).

Moving on from this curricular project, the same author has turned to examining the importance of *explanation* in the science classroom (Duschl, 1998, 2000). Again his perspective on this task can be analysed from the point of view of the three converging registers. Philosophy of science provides a general framework, also integrating findings from rhetorics, in which the process of argumentation and its role in science can be accounted for. Specific tools, such as Stephen Toulmin's *argumentation pattern*, are also provided by this register. Cognitive psychology relates this epistemological conception to mental processes in teachers and students, illuminating the opposition between common-sense and scientific explanation. A third step is the actual design of instructional tools in order to scaffold the argumentation process in students. This can be related to a pedagogical conception drawing from neo-vygotskian ideas and sequential teaching models (Sanmartí, 2000).

A recent paper by Lehrer and others (2001) advocates for the need of reconsidering the role of experiment in science education. This role is analysed from three integrated perspectives: the psychological aspect is students' understanding of experimentation; an epistemological foundation is taken from recent studies in the sociology of science; finally, the pedagogical register is represented by an analysis of "rhetoric, representation, and modelling in instruction".

Concluding remarks

In this paper, we have used the model based view at two different and very distinct levels. On the one hand, it is the general epistemological conception that underlies our model for didactics of science as an academic discipline. At a second level, we use the model based view, integrated with pedagogical and psychological contributions, in order to construct a specific didactical model, the cognitive model of school science. With this model, we hope to be able to develop innovative science curriculum units.

Several authors (Munby et al., 1984; Espinet, 1999; Adúriz-Bravo, 1999/2000; Viennot, 2001; Lehrer and Schauble, 2002) have pointed out to the role of research in didactical innovation, stating ideas similar to those developed in this paper, though acknowledging that this research-design integration is not yet common practice in many areas of science education.

A problem that needs to be considered is how the different dimensions within didactics of science can interact. In the early 80s, Roberts (1984) advanced the concept of *interface* to "incorporate the logical, epistemological and ethical considerations involved in moving back and forth between theory and practice" (p. 69). Recently, the prestigious French didactician of science Laurence Viennot (2001) put this issue in the centre of didactical development for the years to come. In this paper, we have sketched our particular perspective on such an important issue, which we hope can be examined and discussed in further debates.

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