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Utilising the '3P-model' to Characterise the Discipline of Didactics of Science

AGUSTÍN ADÚRIZ-BRAVO and MERCÈ IZQUIERDO-AYMERICH
Departament de Didàctica de les Matemàtiques i de les Ciències Experimentals, Universitat Autònoma de Barcelona, Facultat de Ciències de l'Educació, Edifici G5, Campus UAB, E-08193, Bellaterra, España/Spain (E-mail (first author): agustin.aduriz@campus.uab.es)

Abstract. In our research within didactics of science, we have been exploring contributions of the so-called *cognitive models* from contemporary philosophy of science. We have used these philosophical frameworks on different levels. As an outcome, we have formulated a model of didactics of science according to which this discipline adapts and transforms theoretical contributions from different scholarly fields. In this paper, we concentrate on this description of didactics of science, which we have called the *3P-model* (i.e., philosophy + psychology + pedagogy). This model of the internal functioning of the discipline may be useful to make innovations in science curriculum design and re-conceptualise the role of science teachers as professionals. We see didactics of science as a set of interrelated activities, performed by different individuals, and ranging from theoretical production to practice of science education at school. We find the concept of *technoscience* suitable to account for this diversity of goals. According to this concept, scientific disciplines are identified both with generation of knowledge and with active intervention on the world. Within current didactics of science, we recognise several kinds of research, having goals more or less directed to practical intervention in science education.

1. Introduction

In this paper, we present a concrete instance of contributions from the philosophy of science to science educational research. We are focussing on the so-called *cognitive models of science* from contemporary philosophy of science, especially on the one that has been developed by Ronald Giere at the University of Minnesota (1988, 1992, 1999a, b, 2001). We also take into account other cognitive and non-cognitive contributions pertaining to a broad *semantic* view on the nature of science (Suppe 2000). Such view, steadily growing in importance from the 1960s, challenges the syntactic approach of logical positivism and concentrates on how scientific theories give meaning to the world and make sense to scientists. In the context of semantic approaches to the study of science, a *model-based* view has been put forward. This view considers that *theoretical models*, rather than complete theories, are the structural and functional units of science.

During the last decade, we have explored several possible contributions of these recent philosophical models to help us in our activity of research and development within didactics of science (i.e., science education understood as an academic discipline). We have used cognitive models of science on the following levels:

1. In the first place, we have used Giere's description of science, along with other contributions, to provide an epistemological insight into the natural sciences that we find helpful during the process of *didactical transposition* (Chevallard 1990). That is to say, we have assumed a cognitive reconstruction of these sciences when performing a theoretical reflection on them aimed at improving science teaching (Adúriz-Bravo 1999; Izquierdo 2000; Izquierdo & Adúriz-Bravo 2003).
2. Related to this first strictly meta-theoretical use, the philosophy of science in its cognitive version has provided us with an adequate *nature of science* component for the science curriculum and science teacher education (Adúriz-Bravo et al. 2001, 2002). Among the numerous competing views that nowadays exist in the philosophy of science, we find Giere's ideas particularly suitable for science education, since they are consistent with what is known about students' cognition and about the historical development of science (see the papers collected in Giere 1992). The cognitive emphasis of this school of thought is complemented in our proposals with axiological considerations (Echeverría 1995) to account for the relations between science and society.
3. We have also adopted a model-based view of science, on a second level of discourse, in order to organise, classify and characterise the different scientific disciplines and locate didactics of science and the philosophy of science within this general picture (Adúriz-Bravo 1999, 2000; Izquierdo 1999; Adúriz-Bravo & Izquierdo 2001a).
4. Derived from the latter study, we have presented a model of didactics of science as an *activity* (as opposed to a 'product view'). According to this model, the discipline adapts, combines, transforms and deepens theoretical contributions from different scholarly fields with the ultimate aim of improving science education (Adúriz-Bravo 2000; Adúriz-Bravo & Izquierdo 2001a). Our model corresponds in many aspects to recent contributions from British scholars such as Driver (1997), Fensham (1999) and Millar (2001).
5. By analogy, we have also explored a model-based view of the philosophy of science; this permitted to construct a *pragmatic* approach to the selection of contents from this discipline for general science education and science teacher education (Adúriz-Bravo 2001; Adúriz-Bravo et al. 2001, 2002). This use of the cognitive models of science has allowed our proposal of a tentative answer to the on-going debate on what philosophy of science should be favoured in science education (McComas 1998).
6. In addition, we have characterised the emerging theoretical entity of *school science* (Astolfi et al. 1997; Porlán et al. 1998; Behrendt et al. 2001) by analogy with scientists' science, from a strong cognitive perspective (Izquierdo 1995a, b; Adúriz-Bravo 2001; Izquierdo and Adúriz-Bravo 2003).

7. We have also used recent developments of the philosophy of science as an epistemological justification for science curriculum construction (Izquierdo & Adúriz-Bravo 2001).

8. And in the last place, we have infused a model-based approach into the design of instructional units for different scientific topics and educational levels (Adúriz-Bravo & Izquierdo 2001b; Adúriz-Bravo et al. 2001).

In this paper, we will concentrate on the fourth of these uses of the cognitive models of science, which has led us to produce a description of didactics of science as a discipline that we have called the *3P-model* (the Ps standing for philosophy, psychology and pedagogy). Such a meta-model[1] may be of use in order to perform innovative science curriculum design and re-conceptualise the role of science teachers. These two aims are given high priority in current science education reforms all over the world (AAAS 1989; Millar & Osborne 1998).

We start from our previous use of the cognitive model of science as an *epistemology* that justifies the natural sciences,[2] which are the object to be taught in science education. This particular use of the model generates the notion of *school science* and provides its epistemological foundations (Izquierdo 2000; Izquierdo & Adúriz-Bravo 2003). We now move on to a *second order* of discourse (Estany 1993), and we use the same philosophical frameworks in order to justify didactics of science, modelling it as a discipline that combines scientific research and technological practice. Our discussion of the legitimacy of this procedure of theoretical transference leads us to recognising the flexibility of Giere's account of science and other semantic and post-positivistic approaches to the nature of science.

The first section is devoted to stating what we understand by 'didactics of science'. We subscribe to the 'continental' tradition (Fensham 1999; Estany & Izquierdo 2001; Lijnse 2001), and we pinpoint possible differences with the Anglo-Saxon approach to the study of science education (as portrayed, for instance, by Gunstone & White 2000; Millar 2001). *En passant*, we also remark that didactics is slightly different from *curriculum studies*, very much established in English-speaking universities. In the second section, we provide a description of didactics of science that draws from current models in the philosophy of science; we use for this the concept of *technoscience* (Echeverría 1995). The third section introduces the idea of *register* (Martinand 1987) in order to account for an important characteristic of our discipline: that it combines several theoretical contributions that are inspired by, or adapted from, other converging disciplines (pedagogy, psychology, philosophy of science, sociology, linguistics, anthropology). The fourth section refers to actual applications of these rather abstract ideas that may be of help in order to improve didactics of science and take it closer to the ambitious aim of high-quality scientific literacy for all. The paper ends with some short reflections about the future of our ideas.

2. Didactics of Science as a Theoretical Practice

In continental Europe, there is a strong academic tradition that acknowledges the legitimacy, originality and autonomy of a kind of educational research that is centred on the *teaching* of each of the curriculum areas. Such research has organised itself in a series of disciplines known as *specific didactics* (*Fachdidaktiken*, *didactiques*, *didácticas específicas*, ...). What we may call a 'didactical tradition' can be identified in the scholarly activity in Germanic, Scandinavian, Slavic, Latin and Greek countries. In all these countries, a didactics of science has grown within the environment of educational studies and, at the same time, strongly related to the natural sciences (Adúriz-Bravo 1999). Spain and Latin America also belong to this tradition since as early as the beginning of the 20th century.

The following epistemological features may be chosen in order to rapidly characterise the didactical tradition for the purposes of this paper (Adúriz-Bravo 1999, 2001):

1. This scholarly tradition has generated an autonomous discipline – didactics of science – in order to study the problems specifically concerning science education. By 'autonomous' we mean that professionals in this field have a particular background (usually a first degree in science and then very focussed educational studies); mainstream educational researchers do not usually consider themselves qualified for this kind of research.
2. Didactics of science is neither an interdisciplinary area nor an application of psychology, pedagogy, philosophy, or curriculum studies to science education. It is a discipline of its own, producing its original theoretical models. A strong argument in favour of this rather polemical statement is provided by scientists from other disciplines (mainly psychology and pedagogy), who consider didactics as a separate speciality (Pozo 1993).
3. Didactics of science only in part belongs to the domain of educational studies. In addition to its educational background, didactics of science has a *meta-theoretical* character regarding the natural sciences. (This character can be appreciated, for instance, in the contributions of many scientists and science educators to the American journal *Science Education* for almost a century.)
4. Didactics of science is not completely identifiable with 'curriculum studies' (Hopman & Riquarts 1995), since the former is a discipline especially centred on teachers and teaching. *School contents* – which are the object of both kinds of studies – are seen from a strict disciplinary perspective in curriculum studies, whereas didactics is more interested in the processes through which science teachers *transpose* these contents during their professional activity.

Fensham (1999), a representative of the English-speaking community, acknowledged this difference in the 1999 ESERA conference:

> In the Didaktik [i.e., didactical] tradition, much more than in the Curriculum tradition, there is recognition of a process that turns primary sources of knowledge, like the science disciplines, into knowledge that is worthy of being taught in school science, in other words the knowledge of biology

or chemistry or physics, as it exists in these sciences, is not automatically in a form that makes it worthy of a place in schooling.

5. Academic activity in the university is only one of the aspects of didactics of science. This discipline also has a traditional, and powerful, line of intervention in science education, and a corpus of methodological knowledge regarding the teaching of science, which is transmitted within the community of teachers.

These features mark some differences in the status that is accorded to didactics of science in Europe, as opposed to the discipline of 'science education' in the English-speaking countries. In fact, Hamilton (1999) highlights the existence of this same divergence at a more general level, opposing the Anglo-Saxon generic 'curriculum studies' and the continental 'pedagogy' (i.e., educational science) and 'general didactics'. But our acknowledgement of the existence of two diverging meta-models on science education does not ignore the fact that this is now a professional field theoretically and methodologically standardised all over the world. This fact permits dialogue between professionals of the two communities (we may respectively call them 'didacticians of science'[3] and 'science educators'), who recognise themselves as part of the same academic community and share their forums and literature.

We find it useful to talk about a 'theoretical practice', meaning that science education as an activity, with its several interrelated aspects, can be professionalised through basing it on theoretical models generated from research. This view of didactics of science (adequate to both scholarly traditions) permits a comparison, in many respects, with medicine or engineering as *technologies*. Such activities are also professional practices that resort to a corpus of basic and applied knowledge that is expanded both through specific research and through the input of the practice that is illuminated by it. In the case of technologies, it is usual that research and practice are performed by two sections of the community; this seems to be the case in didactics too.

Another fruitful way to look at theoretical practice is with the use of the concept of *design science* (Niiniluoto 1993). According to Niiniluoto, a design science (among them: computer science, veterinary medicine, pharmacy, logopedics) changes the world, and can be characterised by its practical aims. Research in this kind of science aims at

> knowledge that is useful for the activity of design (...), instrumental knowledge for the production and manipulation of natural and artificial systems. (Niiniluoto 1993, pp. 8–9)

Estany and Izquierdo (2001) have used these ideas to characterise didactics of science as a scientific discipline aimed at designing transformations on reality in the field of science education broadly understood. Recently, several influential authors (Driver 1997; Gunstone & White 2000; Millar 2001; Viennot 2001) have advanced similar ideas inspired in very diverse epistemological resources.

3. Didactics of Science as a Technoscientific Activity

Didactics of science, as a professional field, can be seen as a set of diverse interrelated activities, performed by different individuals, and ranging from the production of original theoretical knowledge to the practice of science education in schools. We have found that the concept of *technoscience* from contemporary philosophy of science (Hacking 1983; Estany 1993; Echeverría 1995) is particularly suitable to account for the diversity of goals and values in our discipline. This concept portrays the intimate combination of theoretical and practical aims that every science has (including traditional 'hard' sciences). Scientific disciplines are now identified with the generation of knowledge, as it was usually done, but also with an active *intervention* on the material and cultural world (Hacking 1983).

The Spanish philosopher of science Javier Echeverría favours the use of the composite term 'technoscience' as a reminder that even basic disciplines such as physics and biology, usually regarded as mere pursuit of new knowledge *per se*, are also directed to changing the natural and cultural world.

Within current didactics of science, we can also recognise several kinds of research and development, having different goals more or less directed to active intervention on science education. For instance, generation of innovative instructional models (such as those proposed by Giordan 1982; Osborne & Wittrock 1985) would be 'pure research'; elaboration of a protocol or an interview to elicit alternative conceptions could be seen as 'applied research'; design of actual instructional materials for secondary science would be 'technological research'; and assessment in the classroom would be an example of 'technological practice'.[4]

Seeing didactics of science as a technoscience implies taking into account both the academic activity of research conducted from within the universities, and the practical activity of science education in the different educational settings. Both activities respond to the same professional community, even if they may be separately performed by two different sections of that community (more or less identified with science education experts and science teachers).

The next two subsections are devoted to refining this 'technoscientific' view of didactics by means of some constructs provided by the cognitive models of science. We want to remark that our '3P-model' draws from several philosophical contributions that only have as a common element their rejection of the *received view* (Suppe 2000). Nevertheless, we will only develop in detail Giere's position; other philosophical tools are briefly presented when they are needed in the text.

3.1. A RAPID ACCOUNT OF GIERE'S IDEAS

The American philosopher of science Ronald Giere adheres to a *semantic view* in his analysis of the nature of science. The use of the term 'semantic' suggests that many recent accounts of science pay little attention to its internal logical structure (a practice very much favoured by previous philosophical schools) and are more focussed in how science makes sense to people and gives meaning to the world (Suppe 2000).

The cognitive view postulates scientific *models* as the most adequate structural and functional units for the analysis of science (whereas *theories* had traditionally occupied this place). Giere gives the name of 'theoretical model' to a highly abstract representation of reality that is *paradigmatic*, in the sense that it gives meaning to a broad range of phenomena and works as an analogue for the construction of new applications. 'Correspondence' between models and reality is done through their similarity; this generates a refined *perspectival* realism (Giere 1999a). Models are non-linguistic entities but they need linguistic characterisation to be transmitted. This 'definition', as Giere calls it, is composed of propositions (such as principles, laws, theorems).

In this framework, theories are *families* of models that are linked by their similarity and their use, and also because they share a formal apparatus. Disciplines can be seen as families of theories, loosely connected by their object and perspective. In this sense, current scientific disciplines have diffuse limits.

3.2. THEORETICAL MODELS IN DIDACTICS OF SCIENCE

We suggest that the first of the four kinds of didactical activity that we have defined above, *pure research*, can be usefully described in terms of Giere's (1988) cognitive model of science. We can see didactics of science as the production of *theoretical models* that explain and modify different aspects of science education (Adúriz-Bravo 1999; Espinet 1999; Izquierdo 1999). The theoretical models of *didactics of science*, which in short can be called *didactical models*, are usually inspired, through an analogical mechanism, in theoretical models coming from other disciplines that study science and its 'management' in society. This strategy of analogical *transference* is usual in new fields that are being structured.

A well examined instance of this strategy in didactics of science is the resorting to the new philosophy of science of the 1960s that inspired the widely used model of *conceptual change*, proposed and refined by Posner and colleagues since the 1980s (Posner et al. 1982). This model tries to account for how students' knowledge develops through, or as a consequence of, science education, and how more effective pedagogical interventions can be designed for the science classroom. Both these aspects are founded on a strong analogy with how knowledge grows and changes in the history of science; this is called the parallel between ontogenesis and phylogenesis. (We are aware, of course, that such parallel has been established on different levels and with several restrictions; some authors discard it as fundamentally erroneous.)

4. Didactics of Science as the Convergence of Three Registers

The more 'pure' scientific dimension of didactics of science generates *original* knowledge, centred on the specific scientific contents to be taught (and hence the difference with pedagogy and curriculum studies as more general disciplines). This didactical knowledge is structured in theoretical models, which, according to Giere's description, are abstract representations of the educational reality defined by symbolic means (e.g., specialised terminology). Model-based knowledge in didactics of science cannot be seen as a mere *adaptation* of external theoretical frameworks, even if it is influenced by, and takes ideas and tools from, disciplines such as the history and philosophy of science, cognitive science, linguistics and sociology.

Knowledge from didactics of science specifically concentrates on the four elements of the *didactical system* (contents, teacher, student and context: Shulman 1986; Chevallard 1990), and on their relations. Those elements define three broad theoretical perspectives. Following a suggestion by Martinand (1987), we call them *registers* (Adúriz-Bravo & Izquierdo 2001a). So far, scholars have reached some consensus on three main tendencies within didactics of science, to a certain extent independent of one another: the *philosophical* register (focussing on contents, its structure and history), the *pedagogical* register (focussing on teacher, teaching, discourse and context), and the *psychological* register (focussing on students, learning and cognition). These registers generate three very active research lines in our discipline.

Current developments from the philosophy of science, cognitive psychology and pedagogy (the 'three Ps') provide an enormous range of theoretical and methodological tools, which to a certain extent inspire models of didactics of science along the three registers. For instance, philosophy contributes with a consideration of school science as a process of theoretical *explanation* of the world (Duschl 1990; Leach 2001). Psychology provides an account of how students' mental models are generated, used and modified (Giere 1992; Gardner 2000). Pedagogy points to the importance of self-regulation, discourse and peer collaboration in the science classroom (Sanmartí 2000). The thread that connects the contributions of these three disciplines is the *cognitive* view that they currently favour (Izquierdo 1999; Izquierdo & Adúriz-Bravo 2003).

But, as we have already said, didactical models cannot be reduced *solely* to an application or adaptation of these contributions to the field science education. Didactical models combine the three registers with each other and with scientific contents, and deeply transform this knowledge base in order to make it adequate for each particular situation encountered in science education. In this sense, we find it useful to introduce the term 'register' instead of the more conventional concepts of 'perspective' or 'view', since the former can enforce our claim that didactical knowledge is not an application of the three Ps to the teaching of science.

The idea of the existence of original knowledge that would establish didactics of science as an autonomous discipline is controversial and needs to be accounted for.[5] A sign that hints at the existence of specific didactical activity is the construction of theoretical ideas that were not previously postulated in other disciplines. A good representative of this knowledge-generation process would be the construct of 'misconception', which was rapidly adopted by other disciplines.

The authors of this paper and a host of other European and Latin American didacticians (Porlán 1998; Gil Pérez et al. 2000) have been producing literature devoted to the disciplinary status of didactics of science. This literature, almost unknown in the English-speaking academic circles, suggests that – at least in some countries – didactics of science is now a separate discipline. Empirical support to this conclusion includes bibliometric analysis, interviews to experts of different fields, and examination of university curricula.

5. The '3P-Model' to Generate Didactical Innovations

At what we have called the *technological* level within didactics of science,[6] we can argue a similar convergence of contributions from the philosophy of science, psychology of learning and pedagogy. Our hypothesis is that these three Ps may contribute to the development of new science curricula, textbooks, instructional materials, and teacher training courses that are adjusted to the current general guidelines that have been agreed on for science education all over the world (Adúriz-Bravo et al. 2001; Adúriz-Bravo, Duschl and Izquierdo in press).

This way of interpreting the discipline of didactics of science can have major implications in the way in which we think about science curricula and science teachers. The *development* – rather than just 'design' – of the science curriculum may now be seen as a *technological practice* of intervention in science education that is based on the theoretical models coming from research in didactics of science (Adúriz-Bravo & Izquierdo 2001a; Izquierdo & Adúriz-Bravo 2001; Viennot 2001).

Results that are now part of the established knowledge base of didactics of science can be used in order to intervene in actual science classrooms. A theoretically informed science curriculum can then be seen as a set of *hypotheses* guiding the practice of science teaching. These hypotheses need to be developed, modified and adapted according to contextual reasons that appear during real practice. It is customary that such hypotheses are initially generated by science curriculum designers and then, at a more concrete stage, by science teachers. But the image of teachers as *experts* resorting to a technoscience blurs the limits between those two communities and changes their professional status in science education.

As a result of this meta-conception, science teachers can now be seen as one of the collectives actively participating in didactical activity. They generate, apply and assess didactical technology in their own classrooms. We advance a model of science teachers as *technologists*, comparing them to other professionals, such as medical doctors and engineers. The comparison wants to emphasise the autonomy of teachers, who must develop their own criteria to select, combine and adjust the knowledge of reference to use it in their daily work in front of the class.

The analogy can be supported by data of empirical nature that comes from examining the conditions of production in current didactics of science. Didactical problems are faced by resorting to the reference knowledge, suiting it to contextual constraints. In this process, new concepts and models appear.

Developing a meta-model for didactics of science may appear as a rather abstract effort that is strictly reserved to the philosophy of science. Nevertheless, we think that this effort can lead to an actual improvement of didactics of science. If we start by considering that our discipline can be developed as a technoscience, new kinds of research and innovation appear, especially classroom-based and teacher-conducted investigations (Adúriz-Bravo et al. in press). This meta-model also permits to recover traditional knowledge that has belonged to the community of teachers for many years and is now disregarded from the university. The same meta-model permits an open and dynamic approach to the science curriculum design, in which the different communities (didacticians of science, scientists, policy makers, science teachers, parents, students) are represented and have their own specific contribution to make.

We are now constructing some actual instances of research based on this model of didactics of science. The most important application that is being conducted is a design of instructional materials on ‘waves and fields’ for secondary physics education (Adúriz-Bravo and Izquierdo 2001b; Adúriz-Bravo et al. 2001). Such design is organised according to a view of the science curriculum that fits the 3P-model.[7]

6. Conclusion

In this paper, we sketched rather rapidly a specific application of the cognitive models and other tools from the philosophy of science that we have devised in our work within didactics of science. We have been inspired by our previous use of this eclectic ‘epistemology’ in justifying the natural sciences to be taught. The promising results (Izquierdo and Adúriz-Bravo 2001, 2003) led us to an attempt of using the same model to account for didactics of science as a discipline.

Our transference of Giere’s ideas to the modelling of didactics of science and, in another research project (Adúriz-Bravo 2001), to the modelling of the philosophy of science as disciplines, has led to positive outcomes. By this we mean that we have produced coherent, plausible views of the internal functioning of these disciplines to which their own researchers relate without major problems. This supports our claim that a cognitive model of science may prove extremely powerful due to its versatility. Such model provides a complex and operative description of scientific disciplines (not excluding *a priori* young disciplines from the area of social sciences) and, at the same time, permits an adequate *demarcation* of the different intellectual activities.

We are aware that this paper is only a very preliminary presentation of a conglomerate of ideas that need to be further developed, discussed and confronted. But it is also an attempt to diffuse, among English-speaking researchers, some general lines of thinking that convoke much interest in Europe.

Notes

[1] By 'meta-model' we mean a second-order model, i.e., a theoretical view from the philosophy of science on how scientific models are constructed and used.
[2] Through this paper, in the expressions 'didactics of science', 'science education', and others, the term 'science' is a compact reference to the *natural sciences* (physics, chemistry, biology, ...). Mathematics and the social sciences have their own didactics.
[3] We are aware that the word 'didactician' is not in use in English, but we have proposed it in some academic forums as an acceptable translation of an expression that exists in most European languages.
[4] Our use of these four labels stems from a need of economy and clarity, but we are aware that several alternative terms have been proposed in the literature concerning the philosophy of technology (Niiniluoto 1993).
[5] We are grateful to an anonymous reviewer of the paper that pointed to the centrality of this idea and committed us to explaining it in more length.
[6] Use of terms related to 'technology' in connection with didactics of science should be understood as a reference to a *disciplinary model*; we do not refer to 'educational technology' in its usual sense.
[7] The Catalan curriculum project *Ciències 12–16*, directed by the second author of this paper, is a seminal effort containing early applications of the different ideas developed in here.

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