GENERAL ARTICLES

New trends in science education

Daniel Gil-Pérez, Department de Didàctica de les Ciències
Universitat de València, Spain

I intend to review the main contributions from the impressive developments made in science education research during the last decade. These developments have made the construction of a coherent body of knowledge possible allowing us to expect a significant improvement in the science teaching/learning process. I shall refer, in particular, to the new trends in science education research, both in the domain of science learning and science teacher-training.

A new scientific domain

At the beginning of the 1980s, science education was still considered a preparadigmatic domain (Berger 1979, Klopfer 1983). Moreover, in many countries (France, Italy, Spain), science education practically did not exist: there were no specific journals, the number of PhD theses was small and the syllabus for science teacher-training did not include any reference to science education research.

Since then, science education has experienced, in my opinion, an impressive development, becoming a specific domain of research. An indication of that development is, for instance, the evolution of the number of papers published. Duit (1993) has shown that the number of studies on preconceptions follows an exponential pattern and I have found the same evolution for studies on science education in general (Carrascosa et al. 1993).

In the same way, if we analyse the evolution of research journals in science education, we can see that almost 50 years pass from the appearance of Science Education (USA, 1916) to that of Journal of Research in Science Teaching (USA, 1963), and another nine years until the publication of Studies in Science Education (UK, 1972). From the beginning of the 1980s numerous journals have appeared and continue to appear. Some titles are: European Journal of Science Education (UK, 1979), Enseñanza de las Ciencias (Spain, 1983), Australian Journal of Science Education (1985), ASTER (France, 1985), Science and Technological Education (UK, 1985), Revista de Enseñanza de la Física (Argentina, 1985), Revista de Ensino de Física (Brazil, 1988), Didaskalia (France, 1993), Alambique: Didactica de las Ciencias Experimentales (Spain, 1994).

We even begin to find journals focusing on specific aspects, for example, Science and Education (1992), which studies the role of the history and philosophy of science education. Additionally, journals focusing on scientific content (such as American Journal of Physics, Journal of Chemical Education, Bulletin de l'Union des Physiciens, La Fisica nella Scuola) are publishing, with increasing frequency,
research papers in science education. A similar trend is evident in journals of general education.

We can obtain the same dynamic view of the development in science education when we analyse those authors who are most often quoted: today's references correspond, in general, to science education researchers who are our contemporaries, while 15 years ago the most often quoted writers were educational psychologists (Carrascosa et al. 1993).

Researchers themselves are aware of this development: if at the beginning of the 1980s they qualified science education as a preparadigmatic domain (Klopfer 1983), today they conceive the possibility of constructing a coherent body of knowledge on science education (Furio and Gil-Pérez 1989, Hodson 1992, Gil-Pérez 1994).

We can conclude that science education has effectively become a new field of science, with a specific research community and a specific corpus of knowledge. I do not intend to ignore, of course, the contributions of other scientific fields such as educational psychology or the history of science. On the contrary, the very existence of a specific corpus of knowledge makes the integration of those contributions possible (Linn 1987).

A review of the impressive developments of the last few years is essential in order to get a complete picture of the whole field and profit from the advances made during this period.

The origins

Emphasizing the qualitative leap experienced by science education during the 1980s, as I have done, I do not intend to minimize the work carried out during the preceding period of much slower development. On the contrary, if we really intend to show the emergence of a coherent body of knowledge, we need to show the thread of its evolution. There is a real danger in viewing science education as a simple question of finding ‘the correct recipe’. As Linn (1987) has pointed out, ‘To develop and sustain the new thrust in science education research, we must avoid the chronic amnesia that often characterizes research in education’.

We have to recognize the contribution of first attempts. We cannot completely reject, for example, the learning by discovery movement as we have frequently done (Gil 1983, Hodson 1985, Millar and Driver 1987) with an exclusive reference to its failure, both in the field of conceptual learning and in the understanding of the nature of science. The fact that a systematic process of research and curricular reform has been initiated bears much more significance than any of the errors made.

It is true that, when science teachers try to renew their teaching, they usually fall into the same trap of the learning by the discovery paradigm: extreme inductivism, lack of attention to content, insistence on a completely autonomous activity of pupils. The scientific treatment of problems is reduced to a linear sequence of fixed stages, disregarding the most creative aspects. It is necessary, therefore, to show clearly—as science education research has done—the limitations of this orientation. It is, however, also necessary to recognize the significance of that innovative intent, because, in spite of its flaws, it stimulates a process of questioning which will be the source of subsequent restructuring.
The limitations of the learning by discovery model brought about a reappraisal of learning by reception. Nevertheless, the reception learning paradigm (Ausubel 1968, Ausubel et al. 1978, Novak 1979) cannot be interpreted as just a return to a valueless ‘traditional teaching’. We must recognize some essential contributions as, for instance, the idea of meaningful learning, instruments such as conceptual maps and Gowin's epistemological Ve (Novak and Gowin 1989) and, particularly, the attention given to pupils' previous knowledge. This attention is associated with the importance acquired by the research on preconceptions, which rapidly became the most widespread line of research during the 1980s.

**Alternative conceptions**

Research in science education during the 1980s has prioritised the study of what is known by the terms such as preconceptions, alternative frameworks and pupils' representations (Abimbola 1988). I have already mentioned the analysis by Duit (1993) of the increasing importance of this research. Viennot (1989) has tried to explain the reasons for this prioritisation. She refers to the importance given to pupils' 'initial state' and to another and more pragmatic reason: research on misconceptions and preconceptions produces clearer and more convincing results than other studies. So, given the need to show, in a reasonable period of time, the relevance and interest of science education research, many researchers have devoted themselves to this field.

Nevertheless, the most important questions are: What has brought about this research on alternative conceptions? Which perspective has been opened? I shall briefly summarize what I believe to be the main contributions that this research has given.

In the first place, research on alternative conceptions has seriously questioned the effectiveness of teaching by transmission of knowledge. In fact, this research has contributed more to questioning the spontaneous teachers' conception of teaching as 'something easy which demands only a certain knowledge of the subject and some experience' than any other study (Gil 1991).

This research has shown a high capacity for integrating studies on different subjects, such as language (Ross and Sutton 1982, Solomon 1987), genetic epistemology (Driver 1981, Linn 1987) and, particularly, the history and philosophy of science (Posner et al. 1982, Gilbert and Swift 1985, Matthews 1990).

It has facilitated the emergence of the constructivist approach, which is considered today as the most outstanding contribution to science education over the last few decades (Gruender and Tobin 1991). Resnick (1993) has summarized the characteristics of this new approach in three statements:

- Learners construct understanding. They do not simply mirror what they are told or what they read. To understand something is to know relationships.
- Bits of isolated information are forgotten or become inaccessible to memory.
- All learning depends on prior knowledge.

This summary is, as Resnick recognizes, a simplification but it allows us to notice the importance given to preconceptions and, what is more important, the undeniable similarity with the contemporary view of the construction of scientific knowledge. This resemblance has been pointed out by many science education researchers (Posner et al. 1982, Gil 1983, Gil and Carrascosa 1985, 1990,

This converging of research on alternative conceptions with the constructivist approach has led to a growing consensus about how to orientate the teaching/learning process. We can recognize a basic coincidence — in spite, of course, of some nuances — in many teaching proposals presented as different models (Nussbaum and Novick 1982, Posner et al. 1982, Osborne and Wittrock 1983, 1985, Driver and Oldham 1986, Hodson 1988, Giordan 1989, Pozo 1989). In all of them we can find the view of science learning as a conceptual change in three basic steps:

- An elicitation phase of pupils' ideas, making them conscious of the plausibility and productivity of those ideas.
- A restructuring phase, creating cognitive conflict, generating pupils' dissatisfaction with their current ideas and preparing them for the introduction of scientific conceptions.
- An application phase which gives opportunities for using the new conceptions in different contexts and consolidating them.


Towards the end of the 1980s, research on preconceptions has begun to pay attention to teachers own conceptions about the nature of science and about science teaching and learning, and their influences on the teaching/learning process (Gene and Gil-Pérez 1987, Hewson and Hewson 1987).

We can conclude that research on preconceptions has been very fruitful. But we should also consider the possible disadvantages of this almost exclusive attention to alternative conceptions.

**Against conceptual reductionism**

Although some isolated ideas had previously been voiced (Gil-Pérez and Carrascosa 1985, Hashweh 1986), in the 1980s researchers on science education began to reject the serious reductionism of the conceptual change proposals (Duschl and Gitomer 1991) which could explain the limitations of the conceptual change strategies (Shuell 1987, White and Gunstone 1989). Duschl and Gitomer criticize the hierarchical view of conceptual change that 'assumes that changes in central commitments to a theory of science bring simultaneous changes to other ontological, methodological and axiological commitments within the conceptual framework'. This flawed version of how conceptual changes take place is given as the cause for the insufficient study of the nature of procedural knowledge (Duschl et al. 1990) and the partial inefficiency of conceptual change teaching strategies; 'if we are to produce radical restructuring of concepts, the personal correlate of Kuhn's revolutionary science, then it seems that we must also teach the procedural knowledge involved'.
This has given a new sense and purpose to research on practical work (Gil-Pérez et al. 1991, Hodson 1993b) and pencil and paper problem-solving (Gil-Pérez et al. 1990). These activities are now seen as instruments of the methodological and epistemological change which has to accompany the conceptual change. This requires a profound change in those activities, from simple recipe and application exercises into open problematic situations, capable of favouring pupils' research (Gil-Pérez et al. 1991, Wheatley 1991) and a similar transformation of evaluation (Gil-Pérez et al. 1991, Hodson 1992b): 'Innovations in the curriculum fail to persist unless they are reflected in similar innovations in testing' (Linn 1987).

We have also begun to understand that the construction of knowledge has axiological commitments: we cannot expect, for instance, that pupils will become involved in a research activity in an atmosphere of 'police control' (Briscoe 1991). This has stimulated research on classroom and school atmosphere (Welch 1985), pupils' (and teachers') attitudes towards science (Schibeci 1984, Yager and Penick 1986) and STS relationships (Solomon 1990). The construction of knowledge has to be associated with the treatment of problematic situations which are relevant and interesting to pupils (Gil-Pérez et al. 1991), enabling them 'to assume the social responsibilities of attentive citizens or key decision makers' (Aikenhead 1985).

These different contributions are beginning to appear to be related components of an integrated body of knowledge (Linn 1987, Gil-Pérez 1991, 1994, Hodson 1992). I shall refer to this integration in the next paragraph.

**Three propositions to summarize recent advances in science education**

If each one of us asks what the main contributions of science education research to the science teaching/learning process have been, the answers will probably vary in many ways, but they will also have certain points in common. In any case, a discussion is provoked that can surely help us to get a more integrated vision of recent advances in science education. To contribute to this debate, I shall state three propositions which, in my opinion, are generating a growing consensus. The first proposition affirms that:

It is not possible to separate these three elements: learning science (acquiring conceptual and theoretical knowledge), learning about science (developing an understanding of the nature and methods of science and awareness of the complex interactions between science and society) and doing science (engaging in and developing expertise in scientific inquiry and problem solving (Hodson 1992).

It is, in fact, possible to make this separation. Science teaching usually does so, practising what we can call a conceptual reductionism (Duschl and Gitomer 1991) which limits science education to learning science. The trouble is that this reductionism doesn't work and pupils don't experience the expected conceptual change. They acquire deformed views of science and, particularly, of the interactions between science and society. On the contrary, recent research in science education shows that 'Students develop their conceptual understanding and learn more about scientific inquiry by engaging in scientific inquiry, provided that there is sufficient opportunity for and support of reflection' (Hodson 1992). In the same sense, Driver (1993) writes: 'Learning science involves young people entering into a different way of thinking about and explaining the natural word; becoming socialized to a greater or lesser extent into the practices of the scientific community'.
It is true that this is an old intuition, as old as the learning by discovery movement which, as has been repeatedly shown, did not work too well (Ausubel 1968, Gil 1983, Hodson 1985, Millar and Driver 1987).

However, today's proposals are different in two fundamental respects. In the first place, and this constitutes my second proposition:

It is necessary to stress that I am not thinking of pupils as practising scientists, working in frontier domains. This metaphor, used by several authors against the treatment of pupils as simple receivers, has many limitations and cannot give a useful view of how to organize pupils' work (Pope and Gilbert 1993, Burbules and Linn 1987). A metaphor that presents pupils as novice researchers (Gil-Perez 1993, Gil-Pérez and Carrascosa 1994) gives, in my opinion, a better appraisal of the learning situation.

In effect, any researcher knows that when someone joins a research team, she or he can catch up quite easily with the standard level of the team. That does not happen by verbal transmission, but through the treatment of problems in domains where more experienced colleagues are experts. The situation changes, of course, when problems which are new for every member of the team are taken into account. In this case, the progress (if any) becomes slow and sinuous.

This is, of course, just a metaphor and I do not forget the grave differences between a pupil and a real novice researcher; but it is a better metaphor, I think, than those which present pupils as simple receivers or as practising scientists.

This metaphor is associated with three basic elements of what we can call a 'radical social-constructivist orientation' for science learning: open problematic situations, scientific work in cooperative groups and interactions between the groups and the 'scientific community', represented by other pupils, the teacher and the text books (Gil-Pérez and Mtnez-Torregrosa 1987, Wheatley 1991). This social constructivist perspective is coherent with the work of Vygotsky on the role of experts to support less experienced members (Driver 1993) and with the nature of the scientists' training (Gil 1993).

In synthesis, the teaching strategy that appears to be the most consistent with the constructivist cognitive approach and with the characteristics of scientific reasoning, is the organization of learning as a treatment of problematic situations that pupils can identify as worth thinking about. This strategy basically aims to involve pupils in the construction of knowledge, giving to the pupils' activity the characteristics of a well orientated investigation (Gil-Pérez 1993, Gil-Pérez and Carrascosa 1994). It can be summarized as follows:

1. Conceive problematic situations that generate interest and provide a preliminary conception of the task, taking into account the ideas, world view, skills and attitudes of pupils.
2. Propose the qualitative study of the problematic situations, taking decisions (with the help of the necessary bibliographic researches) to define and delimit concrete problems, an activity during which pupils begin to make their ideas explicit in a functional way.
3. Guide the scientific treatment of the problems, which implies, among other things:
   Invention of concepts and forming of hypotheses (opportunity for use of alternative conceptions to make predictions).
Elaboration of possible strategies for solving the problems, including, where appropriate, experimental designs to check hypotheses in the light of the body of knowledge.

Realization of the elaborated strategies and analysis of the results (checking them with those obtained by other pupils and by the scientific community) which can produce cognitive conflicts between different conceptions (taking all of them as hypotheses) and can require the formation of new hypotheses.

4. Propose the application of the new knowledge in a variety of situations to deepen and consolidate them, putting special emphasis on the STS relationships which frame the scientific development, and leading all this treatment to show the construction of a coherent body of knowledge.

5. Favour particularly synthesis activities (schemes, reports), the elaboration of products which help to give a purpose to the task and increase the interest in it and the conception of new problems.

This leads to my third proposition:

The effectiveness of this orientation demands breaking many reductionisms and distortions of the nature of science transmitted by science teaching as a consequence of teachers’ spontaneous epistemology.

Here we are touching upon the second big difference between today’s proposals and the preceding essays of organizing science learning as scientific research: the attention given to those reductionisms and distortions of the nature of science transmitted by science teaching.

Transforming teachers’ views about the nature of science

As Bell and Pearson (1992) have pointed out, it is not possible to change what teachers and pupils do in the classroom without transforming their epistemology, their conceptions about how knowledge is constructed, their views about science. This is not just a question of the well known extreme inductivism denounced so many times previously: we have to pay attention to many other distortions (Gil 1993, Hodson 1993, Meichstray 1993, Guilbert and Meloche 1993), as, for instance:

- Extreme inductivism, enhancing ‘free’ observation and experimentation (‘not subject to aprioristic ideas’) and forgetting the essential role played by the making of hypotheses and by the construction of coherent bodies of knowledge (theories). On the other hand, in spite of the great importance assigned to experimentation, science teaching remains purely bookish, quite frequently with little practical work. For this reason, experimentation keeps the glamour of an ‘unaccomplished revolution’. This inductivist vision underlies the orientation of learning as discovery and the reduction of science learning to the process of science.

- A rigid view (algorithmic, exact, infallible, dogmatic). ‘Scientific Method’ is presented as a linear sequence of stages to be followed step by step. Quantitative treatment and control are enhanced, forgetting—or even rejecting—everything related to invention, creativity, tentative constructions. Scientific knowledge is presented in its ‘final’ state, without any reference either to the problematic situations which are at its origin, its historical
evolution or the limitations of this knowledge which appears as an absolute truth not subject to change.

- An exclusively analytical vision which enhances the necessary division and simplification of the study, but neglects the efforts of unification in order to construct wider bodies of knowledge, the treatment of 'border' problems between different domains. Going in the opposite direction, today there is a tendency to present the unity of nature, not as a result of scientific development but as a starting point.

- A merely accumulative vision. Scientific knowledge appears as the result of a linear development, ignoring crisis and deep restructurings.

- A 'commonsense' view which presents scientific knowledge as clear and 'obvious', forgetting the essential differences between the scientific strategies and the common-sense reasoning. This view is characterized by quick and very confident answers, based on 'evidence'; by the absence of doubt or consideration of possible alternative solutions; by the lack of consistency in the analysis of different situations; by reasoning which follows a linear causality sequence. The 'conceptual reductionism' of most science teaching contributes to this commonsense view forgetting that a conceptual change can not take place without a simultaneous and profound epistemological and attitudinal change.

- A 'veiled' and elitist view. No special effort is made to make science meaningful and accessible; on the contrary, the meaning of scientific knowledge is hidden behind the mathematical expressions. In this way, science is presented as a domain reserved for specially gifted minorities, transmitting poor expectations to most pupils and favouring ethnic, social and gender discriminations.

- An individualistic view. Science appears as the activity of isolated 'great scientists', ignoring the role of cooperative work and of interaction between different research teams.

- A socially 'neutral' view. Science is presented as something elaborated in 'ivory towers', forgetting the complex STS relationships and the importance of collective decision making on social issues related to science and technology.

In contrast to this vision of science out of context, today there is an opposing tendency, in secondary schools, towards a 'sociological reductionism', which limits the science curriculum to the treatment of STS problems and forgets the search for coherence and other essential aspects of science.

This teachers' spontaneous epistemology constitutes a serious obstacle to the renewal of science teaching in as much as it is accepted acritically as 'commonsense evidence'. However, it is not difficult at all, in my opinion, to generate a critical attitude towards these commonsense views. When teachers have the opportunity for a collective discussion about possible distortions of the nature of science transmitted by science teaching, they easily become aware of most of the dangers (Gil-Pérez et al. 1991). In other words, the real danger seems to be the lack of attention to what is given as common-sense evidence.

We can conclude, following this review, that research in science education has experienced a particularly profitable development during the last decade, initiating the construction of a specific body of knowledge on science teaching and learning.
NEW TRENDS IN SCIENCE EDUCATION

problems. We can hope that this body of knowledge will be developed and consolidated during the years to come, making an effective displacement of the transmission/reception model by the constructivist approach possible, both in classroom activity and in teacher training. That is, in my opinion, the general perspective. I shall discuss it in more detail in the last paragraph.

New trends in science education

Reviewing the evolution of a certain domain, as I have tried to do here with science education, has, as a fundamental aim, to favour the integration of the different contributions and to provide perspectives for further development. Those perspectives become working hypotheses which will allow us to test the validity of the analysis carried out and of the conclusions thereby obtained.

Nothing can guarantee, of course, that the results of those analyses will be correct, but the explicitation of the perspectives makes criticizing them and stating other predictions and recommendations possible.

We can remember, for example, the meta-analysis made by Welch, more than ten years ago (Welch 1985), of the research carried out in different fields of science education. Welch intended to answer the following questions, which show a clear prospective approach: What do we know at present and what should we know? Which are the most urgent investigations to be made? How can we improve science teaching?

In his conclusions, Welch predicted (and recommended) a growing research emphasis on some aspects scarcely studied at that point, like pupils' attitudes towards science, environmental influences (classroom atmosphere) and types of activities carried out by pupils. I agreed in a short note (Gil-Pérez 1986) with those predictions which, effectively, opened up new perspectives to our research. But I rejected other predictions and recommendations: I was particularly surprised by Welch's lack of attention to alternative conceptions and I completely disagreed with his insistent recommendation of disregarding teachers' behaviour as a line of research. In fact, research has given a clear priority to the study of preconceptions and the research focused on teachers' thinking has increased.

I insist, nevertheless, in the interest of Welch's recapitulation, which offered some interesting suggestions and stimulated alternative predictions. I would wish that the perspectives I am going to state now—based on the analyses undertaken in the preceding paragraphs—could, at least, stimulate alternative predictions and recommendations. Here are, then, my predictions for the development of the research in science education over the next few years:

In the first place, concerning today's most developed line of research, I believe that a displacement from the detection of preconceptions (using instruments which, in general, give information about pupils' immediate answers and reactions) to the study of the 'zone of potential development' (eliciting what pupils can think or do when we facilitate a reflexive and critical work) is necessary. In other words, the abundant results from alternative conceptions show, in my opinion, a student's superficial approach to the situations studied, facilitated by the instruments used. In my opinion equally, as important as these results, are those obtained when we put pupils in the situation of thinking in a more reflective way. So we can expect that this approach will displace the simple detection of alternative conceptions.
The evolution of the research in alternative conceptions involves another essential change: overtaking the conceptual reductionism which has characterized, in general, this research and the derived teaching proposals. Taking both the conceptual, procedural and attitudinal aspects into consideration will increase the efficiency of the constructivist approach and facilitate the consensus on science learning as an orientated research. We can expect, in the same sense, an increased emphasis on technology education (Gilbert 1992).

Associated with this consensus on the constructivist approach, we can foresee an important development in curricular innovation, orientated towards the production of programmes of activities, it is to say, programmes of research for the construction of knowledge.

We can expect, on the other hand, an extension of the constructivist approach to teacher training. This means, firstly, a growing critical awareness of the teacher's common-sense thinking about science and science teaching and learning and, secondly, to transform teacher training into a research activity which enables student teachers to (re)construct the science education corpus of knowledge.

We can expect at the same time the extension of science education to the university level, although this is more of a wish than a prediction. We know that, in general, the university has not taken part in the renewal of science education. Nevertheless, the rapid increase of the student population and some problems thereby created (rate of failure, student rejection of normal teaching methods, etc.) are generating an incipient concern among university teachers. We can hope that this concern will produce a growing awareness of the teaching and learning problems at university level. In this way, the renewal of science education and, particularly, the initial teacher training, would not continue to be hindered by a teaching style at odds with the recommendations derived from science education research.

All the aforementioned expectations and recommendations can be summarized in a heightened search for global coherence, leading to the development and the consolidation of a specific corpus of knowledge of science teaching and learning.

I do not intend to ignore the fact that these expectations can seem the expression of my wishes more than objective predictions. Nevertheless, what I have learned about the nature of science shows me that there are no 'neutral' approaches, that our hypotheses and even the selection of the problems we decide to study are determined, not only by our knowledge, but also by our interests and ideology. Without 'subjective' wishes and expectations, the advances I have predicted will not take place, but I believe that those expectations also have a solid foundation in recent science education research and are generating a growing consensus.

References


