Where are we? A contribution to a better understanding of the state of the art in science education research

¿Dónde estamos situados? Contribuciones para una mejor comprensión del estado del arte en la investigación sobre didáctica de las ciencias

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Abstract
The purpose of this study is to add our efforts to those of researchers who have been concerned with a better understanding of the state of the art in Science Education Research (SER). The study focuses on the nature and evolution of the main SER lines, e.g., what researchers actually do when they enter the research community in order to develop Science Education. We believe that the exercise may help to reinforce the identity of SER, to gain a better knowledge of the field, and to make some educational proposals for mid-term priorities, in short, to foster the advance of Science Education knowledge. The corpus of the study was formed by the 152 most influential SER papers published from 1993 to 2002. Two criteria were used to select the papers: they had to be published in three of the most important international research journals, plus a criterion based on the citation index. Content analysis of the corpus indicates that Concept-Learning-oriented studies tend to make way for studies emphasising the role of the Philosophy of Science and also for multidisciplinary approaches such as STS. Thoughts for the development of the research field are put forward.

Key words: *science education, research, content analysis.*

Resumen
El propósito de este estudio es el de unir esfuerzos con aquellos que se muestran preocupados por una mejor comprensión del estado del arte de la investigación en didáctica de las ciencias (IDC). El estudio se enfoca en la naturaleza y evolución de las principales líneas de la IDC, i.e., lo que hacen actualmente los investigadores con la intención de desarrollar la educación científica cuando se insertan en esta comunidad investigativa. Creemos que este ejercicio podrá ayudar a reforzar la identidad de la IDC, a ganar un mejor conocimiento del campo de estudio y, a hacer algunas propuestas educativas relativas a prioridades a mediano plazo, contribuyendo al avance del conocimiento en educación en ciencias. El corpus de análisis del estudio está formado por los 152 artículos más influyentes publicados entre 1993 y 2002. Dos criterios fueron utilizados para seleccionar los artículos, a saber: su publicación en tres de las más importantes revistas internacionales de investigación y, un criterio basado en las citaciones en el citation index. El análisis de contenido sobre el corpus nos ha indicado que los estudios en el ámbito del aprendizaje de conceptos están cediendo lugar a estudios que enfatizan el papel de la filosofía de la ciencia y a abordajes multidisciplinarios tales como CTS. Avanzamos algunas reflexiones respecto al probable desarrollo de este campo de investigación.

Palabras clave: *educación, didáctica, ciencias, investigación, análisis de contenido.*

INTRODUCTION

Analysing the state of the art in Science Education Research (SER) today is an exercise that the corresponding community feels has to be approached systematically. The interest in doing it is to gain a better comprehension of the nature of knowledge that has been constructed to help define or (re)direct the priorities of SER, and to think about the best ways of improving it. In all cases, the underlying assumption is that sound attention to research carried out would be a good starting point for portraying the present and prospecting the future of the field. Literature shows the different ways researchers have approached an analysis of this nature. For example, TSAI and WEN (2005) present a bibliometric study emphasising the main trends of SER between 1998 and 2002; BENNETT *et al*. (2005) explore the role of systematic reviews and present an overview of systematic review methods; FENSHAM (2004) looks at the emergence of science education as an international field of research from three dimensions: its identity as a research field, the researcher as a person, and trends in research. He interviewed several prominent researchers asking them two questions: "Tell me about two of your publications in the field that you regard as significant"; "Tell me about up to three publications by others that have had a major influence on your research work in the field". HOLLIDAY (2003) presents a selection of a representative sampling of the best articles published since 1963 in the *Journal of Research in Science Teaching*; Lopes et al. (submitted) point to some relevant aspects of SER in terms of their main orientations; JENKINS (2000) presents a critical analysis of key aspects of SER such as its diversity, the nature of the research domain and purposes, considering that "its future would seem to depend upon a better-grounded and thus defensible sense of identity and purpose" (p. 22). Some researchers have published critical reviews of various research themes, for example: "Primary science: past, present and future" (OSBORNE & SIMON, 1996); "Laboratory in science education" (HOFSTEIN & LUNETTA, 2004); "Attitudes towards science" (OSBORNE, SIMON & COLLINS, 2003); "conceptual change" (DUIT & TREAGUST, 2003). This type of study is the most common. Other researchers focus their attention on the actual profession of the educational researcher (MCINTYRE, 1997).

The titles of papers published with this orientation are indicative. For example, "Research in Science Education: Time for a Health Check" by JENKINS (2000), or "Defining an identity: The Evolution of Science Education as a Field of Research" by FENSHAM (2004) clearly state the relevant concerns that deserve careful attention from researchers. These aspects improve the burden of systematising the research done and of characterising the particular research community.

This paper is in line with these concerns. Despite being a preliminary study with temporal limitations, it aims to add our reflection to the pool through a meta-interpretative exercise focusing on the content analysis of three foundational research journals (*Science Education*, *Journal of Research in Science Teaching* and *International Journal of Science Education*), in order to contribute to a better comprehension of the state of the art in SER. Both epistemological and pragmatic reasons led us to focus our inquiry on the nature of the research lines, a particular meta-dimension of SER that needs careful attention. This is what researchers effectively do as part of a well-defined community, i.e., their specific focus of interest with the aim of developing science education. The increasingly international nature of SER has motivated our interest to identify the nationalities represented in the analysed papers, i.e., who the researchers are.

In epistemological terms, a better knowledge of SER lines may help to: pinpoint the dominant characteristics of SER and their evolution over time; understand why it is difficult to construct a specific and coherent corpus of knowledge; bring together the too many fragmented results that still exist; and gain a better understanding of the nature of the knowledge that has been constructed. In pragmatic terms, it is important to study the research in the main research lines, as this may help to understand why SER has little influence on science teaching, on science teacher education and on policy. Despite its epistemological and pragmatic relevance, however, there is a clear gap in the research literature on systematic studies into SER lines. The main research question is, therefore: in the 1993-2002 ten-year period, what were the main SER lines as revealed by the most influential research papers and how did they evolve?

SER ANALYSED FROM THE ANGLE OF THE MAIN RESEARCH LINES

Science education today is established as an interdisciplinary area with a solid epistemological structure, embedded with contributions from the paradigms of Science, the History and Philosophy of Science, Educational Psychology, the Sociology of Science, as well as from areas such as Ethics or Linguistics (CACHAPUZ, PRAIA, JORGE, 2002).

Also, the map of research in each field must permit the extraction of relevant data in order to establish the value of the findings, and the synthesis and reporting of the outcomes (BENNETT *et al.*, 2005, p. 387). This research is part of a more general study by the same team that also involves an earlier two-day international brainstorming seminar on the state of the art in SER. Sixteen invited senior science education researchers from Australia, Brazil, Spain, United Kingdom, United States of America and Portugal attended this seminar (hereafter simply called the Seminar) (CACHAPUZ *et al.*, 2005).

Eleven different research lines which may help to map the field were identified (table 1). Their scope and illustrative examples are presented. They emerged from a cross analysis of a wide range of SER journals, from the outcomes of the Seminar and from our own research experience. We do not pretend they account *for all* the possible research lines, but they are representative of the most cited. Overall, Table 1 is the key instrument used for the content analysis of the research papers. Some of the decisions taken may be somewhat debatable, e.g., to include assessment and evaluation in the same research line.

METHODOLOGY

The corpus of the selected papers was formed by the most influential SER papers in the period 1993-2002). Two main criteria were used to select the papers:

i) Papers published in three of the most important international SER journals.

ii) Papers from a restricted group of “most often cited”.

The first criterion was satisfied using the impact factor of each SER journal indexed in the most important database: Institute for Scientific Information (ISI). With this criterion, the most important journals were *Science Education* (SE), *Journal of Research in Science Teaching* (JRST) and the *International Journal of Science Education* (IJSE). This yielded a universe of 1898 papers published (459 in SE, 724 in JRST and 715 in IJSE).

The second criterion was more difficult to satisfy. If the criterion “number of citations” per paper was applied blindly, the great majority of the most recent papers might be rejected. Furthermore, the three journals do not have the same impact factor. In other words, if the criterion “number of citations” was used indiscriminately, the oldest papers in the period considered and the papers in a certain journal could be favoured. So, we introduced two additional sub-criteria: “temporary partition of the considered decade” and the “impact factor” of each journal. Thus, based on the ISI database, the papers were listed in each journal and in each year by decreasing order of times cited. The papers were selected until the order number was reached. The value of such number is given by the following formula:

$$N_{year\,i.journal\ A} \leq 0{,}1{*}f_A{*}n_{Ai},$$

Table 1
Research lines

Research line	Rationale/Range/Focus	Examples of papers
Philosophy of science	Students and science teachers’ conceptions of science and scientific knowledge, attitudes related to science and technology…	Pomeroy, 1993; Lakin and Wellington, 1994; Smith and Scharmann, 1999…
Concept learning	identification of students’ conceptions and teaching and learning scientific concepts, conceptual change…	Linder and Hewson, 1993; Raghavan and Glaser, 1995; Duit and Treagust, 2003…
Problem solving	problem-solving strategies, meta-cognitive strategies…	Richmond and Striley, 1996; Voska and Heikkinen, 2000…
Science, technology and society (STS)	social and cultural dimension of science, how it relates to scientific literacy and the public comprehension of science	Hurd, 1998; Hand, Prain, Lawrence and Yore, 1999; DeBoer, 2000…
Practical work	experimental work, field work including its foundations, modalities and role in the teaching and learning processes	Rollnick, Zwane, Staskun, Lotz and Green, 2001; Chinn and Malhotra, 2002…
Language	communication processes, argumentation, use of scientific terminology, the role of metaphors and analogies in teaching and learning	Harrison and Treagust, 1993; vanZee and Minstrell, 1997…
Information and communication technologies (ICT)	use of the educational software in learning, teaching and teacher education…	Roth, 1995; Songer, Lee and Kam, 2002…
Assessment and evaluation	the appraisal of learning and teaching, as well as curriculum and innovations	Ruiz Primo and Shavelson, 1996; Stren and Ahlgren, 2002…
Learning in informal contexts	relations between school and family, museums, media… and their role in the promotion of science learning…	Dierking and Falk, 1994; Stocklmayer and Gilbert, 2002…
Multicultural and gender studies	socio-cultural, ethnic studies, gender studies (implications in science learning, scientific interests…)	Baker and Leary, 1995; Aikenhead and Jegede, 1999; Rodriguez, 1997
Pedagogical studies	teaching strategies, motivation strategies, group environment, classroom organisation…	Tobin and McRobbie, 1996; van Driel, Verloop and de Vos, 1998

where, $N_{year\,i.journal\,A}$ - number of papers of the journal *A* in the year *i* that is in the percentage $0{,}1{*}f_A$ of the most cited papers; n_{Ai} - total number of papers of journal A in the year i; f_A - mean impact factor of journal A. So, the number of selected papers for journal A is given by:

$$N_{journal\ A} = \sum_{i=1993}^{2002} N_{year.journal\ A}$$

The 152 most influential papers were thus identified: 43 from SE; 73 from JRST; and 36 from IJSE.

It should be noted that our study involves the most influential SER papers in the decade referred to above. By no means it is assumed that they represent the universe of SER papers. It is simply assumed that they represent a significant corpus which we believe may have an important influence on science education research.

Each article was analyzed until saturation of the data, identifying the main research lines and the nationality of the authors. Consistency of the dimensions of analysis with the research question and research aims was ensured.

Following a pilot study (three papers randomly selected and independently analysed by all the members of the research team in order to test the consistency of the analysis), papers were randomly assigned to individual researchers; each paper was independently analysed by two researchers. The results obtained were cross-analysed and discussed to reach a consensus decision. After this first step, the concordance was 95%. The remaining cases were reanalysed by a third researcher in order to reach a decision and to be included in the final corpus. No consensus was possible for six papers (3,6%) and these were placed in a single category (*Other*). Because of the low numbers obtained for some research lines and in order to better clarify the evolution of the research lines over time, data are presented in two quinquennia. The trend obtained is nonetheless analogous to the one obtained for the per year analysis.

RESULTS AND DISCUSSION

A picture of the science education research community

Table 2 shows the involvement of the most influential communities publishing in the three referred to journals.

Of 170 participant authors (there is some author overlap), the United States of America (USA) is by far the biggest community, and Canada and the United Kingdom (UK) are second with almost the same amount of authors. Together with Australian and South African authors, English speakers account for 87% of all the authors identified. French speakers are poorly represented in these most influential papers. The same is true of Iberoamerican authors, corresponding to more than 500 million speakers. Authors from the European Union amount to 48% of the total.

It seems as if authors from different countries have different cultures of research publication. It is impossible to disagree with TSAI and WEN (2005), whose study falls in our second quinquennium 1998-2002, when they attribute the supremacy of papers from English speakers to the language used in these three Journals. As highlighted in the Seminar, "there was a substantial growth of the SER community and of its international dimension in the last fifty years". Nevertheless, as explicitly acknowledged, "we still lack an appropriate knowledge of much research which is not published in English" and "this does not facilitate the effective communication of SER outcomes among the research community" (CACHAPUZ *et al*., 2005).

Finally, it is worth noting that seven of the countries represented in our sample only emerged in the second quinquennium (France, Germany, Mexico, Philippines, Singapore, Spain and Taiwan). The two quinquennia are surprisingly evenly balanced in terms of papers from USA authors (43/45), UK authors (10/10) and Australian authors (7/7).

Dominance and evolution of the research lines

Table 3 shows the number and percentages of the influential papers of each research line and their evolution from the first to the second quinquennium. Because there is some overlap of the research lines the total number of instances is slightly higher than 152. Taking the whole decade, *Concept Learning* (39 papers – 23,1%), *Philosophy of Science* (33 - 19,5%) and *Language* (21 - 12,4%) were the dominant lines. But there is a lessening of emphasis with time in the case of *Concept Learning*, probably reflecting the declining interest for studies focusing on the so-called alternative conceptions or, the more general rejection of conceptual reductionism. On the other hand, lines on *Philosophy of Science* and *Language* are both fairly stable. The results obtained for *Philosophy of Science* are congruent with one of the outcomes of the Seminar, viz., "There is now a considerable body of SER carried out in the area of the nature of science that is growingly influential in curriculum orientations. Clearly, more and more science education researchers are aware of the relevance of studies made by philosophers and historians of science from the last fifty years". The same researchers nevertheless also considered that "research on teachers' conceptions about the nature of science, as well as teaching practices, showed that positivism still held a heavy influence on teachers", and that part of this problem is related to a lack of adequate teacher training courses and curriculum materials.

Table 2
Nationality of the authors in the set of papers analysed/per quinquennium

Language/ Nationality	Country	Number of authors				Total
		1rst quinquennium		2nd quinquennium		
English speakers	United States of America	43		45		
	Canada	17		6		
	United Kingdom	10	(78)	10	(71)	
	Australia	7		7		149
	South Africa	1		3		
Iberoamerican (Portuguese and spanish speakers)	Spain	0		2		
	México	0		1		3
French speakers	France	0		1		1
Other	Israel	1		3		
	Netherlands	1		2		
	Germany	0		1		
	Japan	1		0		
	Norway	0	(4)	1	(13)	17
	Philippines	0		1		
	Taiwan	0		1		
	Singapore	0		3		
	Lebanon	1		1		
European Union		**11(a)**		**17 (a)**		**28 (a)**
Total authors (152 papers)		**82**		**88**		**170**

(a) Papers also considered in the earlier lines

The relative emphasis on *Language*, which involves the complex nature of classroom discourse and the value of discourse for effective learning, is a good example of the multidisciplinary nature of SER, as it can be looked into from pedagogical, psycholinguistic, sociolinguistic, etc., perspectives.

For some research lines there is considerable difference between papers focusing on teacher education (pre-service and in-service) and on teaching and learning, e.g. *Concept Learning* (5 *vs*. 29) or STS (2 *vs*. 16), respectively. Smaller differences were noted for Philosophy of Science (14 vs. 19). The relatively low incidence of studies in some landmark areas of SER, e.g., *Practical work*, is probably because these are now embedded in more inclusive research lines.

Table 3
Research lines by quinquennia (decade 1993-2002)

Main research lines	Total f %	1st quinquennium 1993-1997	2st quinquennium 1998-2002
Epistemology of Science	33 19,5%	16	17
Concept Learning	39 23,1%	26	13
Problem Solving	3 1,8%	2	1
Science, Technology and Society	9 5,3%	2	7
Practical Work	7 4,1%	4	3
Language	21 12,4%	10	11
Information and Communication Technologies	5 3,0%	2	3
Assessment and Evaluation	7 4,1%	2	5
Learning in informal contexts	5 3,0%	2	3
Multiculturalism and Gender	19 11,2%	11	8
Pedagogical studies	16 8,9%	5	10
Others (for example, communities of practice)	6 3,6%	2	4
Total occurrences	**169**	**84**	**85**

STS studies, undoubtedly a research line taking its cue from current trends, is gaining ground, and it may perhaps become a promising field of work in the coming decades, with particular reference to curriculum reform to promote more socially relevant science education. The modest result obtained for *ICT* may be simply due to the fact that researchers may feel they are better understood when publishing in more specific journals.

Pedagogy doubled its occurrences from the first to the second quinquennium, a result that is compatible with the increase of practically-oriented research in the same period (Lopes *et al.*, 2007, submitted). In this case, there were more studies on teacher education than on teaching and learning (9 *vs.* 6).

Learning in informal contexts is an emerging research line and the small number of papers identified was not surprising. Most of the papers analysed acknowledge the increasing importance of non-traditional frameworks to the learning of science, and admit that there is a long way to go before science education is properly coordinated in both formal and informal contexts. We only can forecast an increase in studies of this kind in the short term.

Multicultural studies, mainly involving socio-cultural and gender studies, is a relatively recent, yet important line. In our view, the increasing worldwide mobility of communities with different cultural backgrounds and its implications for science teacher education, the teaching and learning of science, and a democratic approach to the role of women in society will give more and more importance to solid work in this area.

As mentioned earlier, when there was no consensus among the researchers, papers were placed in the category *Other*. One important example is *Communities of Practice* (Barab and Hay, 2001), which highlights the importance of seeing learning as "a trajectory" (p. 72). Despite its centrality to the learning context, it is possible to extend it to a larger "notion of communities of practice" presented as fundamental by the authors, as "an activity that embodies and builds understandings, as well as one that has the potential to wed an individual to a community which uses and values the particular practices being carried out" (p. 73).

Although the nature of the specific subject areas of science involved in the papers was not a main concern of this study, it is worth noting that Physics, and to a lesser extent Biology, were the most salient ones (Lopes *et al.*, submitted).

Finally, some important research areas such as *Historical Cases* did not appear as such in our sample. The absence of papers from our selection of most often cited papers is probably because these studies appear in more specific journals and books (examples: Matthews, 1990; Cahan, 1993; Moreno, 2001; Freire, 2003).

CONCLUSIONS AND PROSPECTS FOR A NEW DECADE OF *SER*

Each research line represents the attempts of researchers, supported by a set of questions and guided by an accepted theoretical framework (sometimes 'crossed' frameworks), to search for evidence, following a methodology designed to give the likeliest answers to the guiding research questions.

Some of the outcomes of our study were expected; for example, that the English-speaking community was the best represented. The results obtained should nonetheless be useful to a consideration of the research already done and help us to plan future work.

(i) The results show that SER is a scattered field with some well established research lines. This general result should be understood as reflecting the maturity of the research area; this is quite a different situation compared to the 60's. We now have a coherent body of knowledge allowing us to say that there is research in Science Education and that some important results have been coming forth from that research. As pointed out in the Seminar, "this means that Science Education is now a real research area".

(ii) Despite the dispersion of research lines, trends can be observed over the decade. In particular, there is a clear change of direction in lines with a focus on Concept Learning in favour of more multidisciplinary frameworks and studies with an emphasis in the Philosophy of Science.

The prevailing climate of the time seems to encourage research about *STS*, *Multicultural Studies*, and *Learning in Informal Contexts*. These lines are not yet well established and do need further attention.

(iii) More often than not, research into teacher education was not conspicuous. This situation should be revised in order to find an appropriate balance between teacher education research and teacher and learning research. For example, a promising research line is the study of the communities of practice. Maybe teachers' communities of practice have been in existence for a long time, but they have never attracted the attention of science education researchers. Its relevance is not simply that more should be known about teachers' communities in order to understand the processes of teacher education (generating a group that creates a space for deliberation and cooperative work based on reflecting on practice, group organization and functioning…), but also that the communities may play a strategic role in bridging research with innovation in the schools.

(iv) The research community must formulate priorities and be aware of the relevance of potentially effective priorities. The point is that different stakeholders have different priorities and research must pay attention to all of them, but this does not mean a blind dependence on their immediate interests. Science education researchers should question what Science Education is for and be aware that while some of the most important convictions held are that Science Education should foster economic, cultural and disciplinary advancement, first of all it is for citizenship.

Our work is different from other works that have been published. It has certain limitations, yet it presents a portrait of relevant science education research lines and their evolution over a recent ten-year period and offers a prospective reflection on the evolution of that research. Studies like this should have a systematic character. We hope it may help to promote a critical debate on these important issues among the community of science education researchers, especially among the research communities poorly represented in our sample and influential in the world, like the Iberoamerican community, with more than 500 million Spanish and Portuguese speakers.

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