The History and Philosophy of Science in Physics Teaching: A Research Synthesis of Didactic Interventions#

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Abstract. This work is a systematic review of studies that investigate teaching experiences applying History and Philosophy of Science (HPS) in physics classrooms, with the aim of obtaining critical and reliable information on this subject. After a careful process of selection and exclusion of studies compiled from a variety of databases, an in-depth review (general description, analysis of quality and summary of the results) of those considered to be of high quality was undertaken. The results indicate positive effects in the didactic use of HPS in relation to the learning of physics concepts, although there was no consensus regarding this. A stronger divergence was found regarding the occurrence of change in students' attitudes towards science. However, HPS may in fact foster a more mature vision in students in respect of their understanding of the Nature of Science (NOS). Moreover, potentially favourable results were found regarding the effects of the didactic use of HPS on the quality of argumentation and metacognition, although further research in this area would appear necessary.

1. Introduction

The incorporation of History and Philosophy of Science (HPS) in physics teaching has a long tradition. It may be traced as far back as Ernst Mach's addresses in the late 19th century. In the second half of the 20th century, with the support of James Conant and his Harvard Case Studies in Experimental Science, a lasting scholarly tradition of proposals and a production (and assessment of) of instructional materials were undertaken. The most influential of these were the Harvard Project Physics Course, which has recently been updated (Cassidy, Holton, and James Rutherford 2002). Furthermore, this contextual approach has gained an increasing number of advocates and adherents since the end of the 1980s (Matthews 1994), although this does not mean that it has major support amongst physicists and physics teachers. In addition to notable criticisms by the science historians Thomas Kuhn and Martin Klein (Matthews 1994, 71-77), most physicists and physics teachers seem to be indifferent to a contextual approach.

In this conflicting arena there is an urgent need to assess the efficiency of HPS in science teaching in the classroom, especially in relation to conceptual learning, opinions on and attitudes toward the nature of science, argumentation and meta-cognition This kind of assessment is also needed because in several countries HPS-inspired science teaching has become public policy and there is a need to establish an efficacy for this approach. Several reviews have recently appeared although they have not actually focused on physics teaching. Aikenhead's comprehensive review (Aikenhead 2003) dealt with humanistic perspectives within the science curricula, encompassing both an HPS and Science-Technology-Society (STS) approach. In fact, the studies analyzed regarding student learning mostly utilized an STS approach. Bennett et al. (2007) provides a systematic review to the STS approach, including an in-depth review of experimental designs. Abd-El-Khalick and Lederman (2000a) provide a critical review of attempts to improve science teachers' conceptions of the nature of science. In this way our study aims to enhance this area of research by focusing on the use of HPS in physics teaching.

The aim of the study is to undertake a systematic and critical review of the research published in internationally renowned journals which investigate the experiences of teaching HPS in physics classes, with the aim of systematically gathering critical and reliable information from literature on the didactic use of HPS in this research area. Therefore the question which informed the whole process of selection, exclusion and systematic analysis of the papers in this review was as follows: what reliable information can be obtained from research studies that describe the results of a didactic application of HPS in physics classes?

This particular review is in the tradition of systematic literature reviews, in that, in contrast to traditional forms of narrative review, it enables the gathering of relevant information from the mass of specialised literature in a specific area of research and in a systematic and critical form with regard to the main

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results of the area in focus, all of which may be extremely beneficial for researchers (Bennett et al. 2005; Dios et al. 2007).

A good example of the use of this technique in science education is found in Bennett et al. (2007) who undertook a systematic review of research about context-based and STS approaches in the teaching of science, evidencing its effects on students' attitudes towards science and their understanding of scientific ideas, amongst other things. The selection criteria for the studies used by the authors were: a broad sweep of databases to identify studies, generic criteria for the judgement of quality and the involvement of more than one researcher in the selection process, judgement etc. The authors arrived at 2500 studies; after applying predetermined exclusion criteria – established according to the research question – 17 studies remained, which were then analyzed in depth. The results of the review indicated, amongst other things, that the approaches investigated resulted in improvements in students' attitudes towards science, without, however, any significant difference in comparison to conventional approaches in terms of the understanding of scientific ideas. The use of the technique of systematic review in this case thus enabled the outlining of a reliable overview of the area mentioned. Similarly, it is the intention of the present study to achieve an overview of those studies which investigate didactic interventions based on the HPS in physics classrooms.

2. Methodology

The studies included in this systematic review were selected by a consultation of the following databases: *Education Resources Information Center* (ERIC), *SpringerLink* and *Wiley InterScience*, as well as a direct search of the following journals' websites: *Science and Education*, *Science Education*, *International Journal of Science Education*, *International Journal of Science and Mathematical Education*, *Research in Science Education*, and *American Journal of Physics*. The consultation of databases was initially undertaken on a broad basis to increase the validity of the review (Bennett et al. 2007), by the alternately combined use of the following key-words: *science teaching*, *history of science*, *philosophy of science*, *nature of science*, *physics teaching, physics education*, which generated a total of 1183 articles from 31 English-language journal[1].

It is important to stress two things about our choice of studies for analysis. Firstly, the studies selected are: articles published in English; studies in the form of dissertations; book chapters; papers presented in conferences. Evaluation reports or articles published in other languages are therefore not included. This criterion, although restricting the number of research studies concerning this subject – since, for example, Linjse (2004) suggests that most research about the didactic sequences of different approaches is published in local languages – allows for work on those research studies to be made accessible to the international community and to meet the selection criteria of internationally renowned journals[2]. In fact, this is a quality criterion, since the selected studies had already passed by the criteria of peer-review in acknowledged journals.

After reading the titles, keywords and abstracts, 152 articles directly related to the didactic use of HPS in the teaching of science were selected. Great care was taken with this process; where there was a lack of clarity in the reading of the abstracts, the entire paper was read. Articles were found that had been published from the 1940s to 2008 (when the present review was undertaken) which enabled the outlining of a general overview of publications about the use of HPS in science teaching throughout this period. Following this, the articles were submitted to the following exclusion criteria which were applied once the full paper was read and repeated twice over a three month period, obtaining the same results:

(i) articles which fail to discuss the teaching of physics but discuss the teaching of science in general or of another specific scientific subject such as biology, chemistry etc. (81 articles were excluded using this criterion);

(ii) articles of a theoretical nature without a didactic application (24 articles were excluded using this criterion);

[1] Articles such as Cooley and Klopfer (1963), Welch and Walberg (1968) or Aikenhead (1974), although approaching the evaluation of specific teaching strategies using history of science (History of Science Cases in the first study and Harvard Project Physics in the others), did not appear in this research database as their main focus was to analyze the evaluation methodology used.

[2] The same type of systematic review (using the same criteria) is being undertaken by the authors in the five main Brazilian journals in the area of science teaching (and of physics teaching), as well as an important Spanish-language journal. Of the 117 works selected, 11 meet the exclusion criteria for in-depth analysis, which is quantitatively similar to the number found in the present study. This, allied to the fact that many studies presented at local and international congresses are not converted into published articles, suggests that a greater number of studies on this subject are being undertaken than the international community is aware of.

(iii) articles which dealt with general applications of HPS such as the production, use and analysis of didactic materials but without reporting the results of a didactic application in the classroom (35 articles were excluded using this criterion).

Thus, once the exclusion criteria had been applied, 11 studies, with a profile appropriate to the in-depth review remained, that is those research studies which investigated the didactic application of HPS in physics classrooms; these were then analyzed in depth. It should be stressed that we did not use any exclusion criterion relating to experimental and non-experimental research designs, being of the opinion that both designs, when well conducted, offer valuables insights into the process and outcomes of intervention.

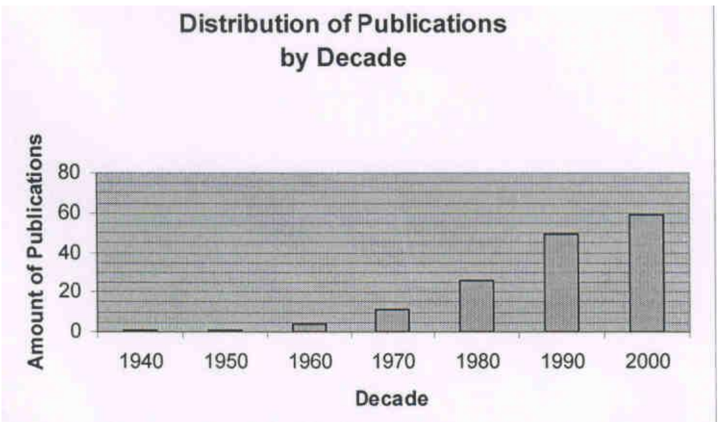
The limited number of articles, as a consequence of the exclusion criteria, offers a preliminary view of the current condition of the research area. Approximately 53% of the studies submitted to the exclusion criteria were not related to physics teaching and approximately 39% were not concerned with research investigating effective intervention in classroom. This demonstrates the relative scarcity of published research of an empirical nature regarding the use of HPS in physics classroom interventions. However, the scope of the survey undertaken, together with the criteria utilized throughout the process of this review, enables the necessary confidence consider it for a good indicator of the state of the art of this area of research.

In order to undertake an in-depth review a detailed description of the studies was initially carried out, followed by a quality analysis and finally a summary of the results reported in those studies considered to be of high quality, with the aim of extracting reliable information about the didactic application of HPS in physics classrooms. This final process was carried out independently by two of the authors of this paper and disagreements (in 2 out of the 11 studies) were subject to discussion until consensus was reached.

3. Results

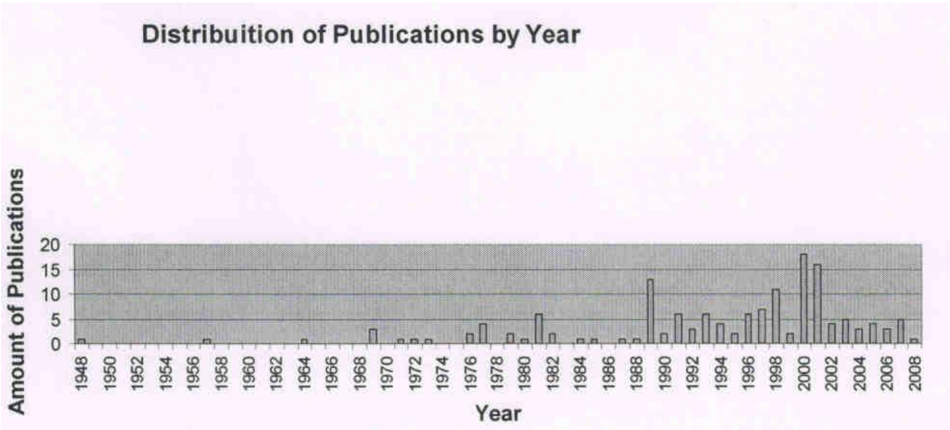
3.1 General Overview of Publications which Incorporate HPS in Science Teaching

After the selection of 152 articles it was possible to outline a general overview of the evolution of production in the area of research that investigates the use of HPS in Science Teaching. Table 1 presents a summary of quantitative results from the selected articles and presents the number of articles by decade, the number of articles by year and the number of articles by journal per year. The graphs below were constructed from this table’s data. A feature which can be immediately observed in Graph 1, which shows the distribution of publication by decade, is the substantial increase in the number of research studies published that refer to the incorporation of HPS in science teaching over the last seven decades. This increase, which has been widely documented (Justi and Gilbert 2000; Matthews 1994; Abd-El-Khalick and Lederman, 2000b; James Rutherford 2001; Robinson 1969), may be explained by the growing preoccupation of researchers regarding the subject in question. Taking this into consideration, Graph 1 can be seen to represent a growth trend for future decades.



Graph 1 – Distribution of the number of publications selected for the research by decade (total = 152 articles).

In observing Graph 2, distribution of publication by year, we note the presence of a peak in the number of publications between the end of the 1990s and the 2000s. The arguments presented by Matthews (1992) regarding the tendency for the reestablishment of a connection between HPS and science teaching in the middle of the 1980s provide a straightforward explanation for this occurrence. The perception of a general crisis in science teaching at the end of the 1980s led the community of educators and researchers to undertake a series of conferences in the United States and Europe regarding the teaching of HPS in the science curriculum, and also led to the curriculum reform which occurred during the same period, with the inclusion of HPS and the emergence of appropriate teacher training programmes (Matthews 1992). All of this resulted, in the 1990s, in the formation of a community focused on investigating and considering this subject, as well as in the creation of the *International History, Philosophy and Science Teaching Group* (IHPST), and in the creation of the specialist periodical *Science and Education*. It is worth noting that 33% of the selected papers and 45% of the studies included in the in-depth review came from this journal (see Table 1). As a consequence, there was a substantial increase during this period in the production of studies focused on this subject. In Graph 2 another, more localised peak may also be observed (in 1989) which in this case was due to a special edition dedicated to this subject and published in the periodical *Interchange – A Quarterly Review of Education*.



Graph 2 – Distribution of the number of publications selected by year (total = 152 articles)

	Number of articles per decade	Number of articles per year	Science Education	Science and Education	Journal of Research in Sc. Teaching	International Journ. of Sc. Education	Interchange-A Quarterly Review of Educ.	Electronic Journal of Sci. Education	School Science and Mathematics	American Biology Teacher	Science Teacher	Teacher Magazine	Physics Education	Teaching Education	Scandinavian Journal of Educ. Research	American Journal of Physics	Journal of Science Teacher Education	Social Education	Journal of College Science Teaching	College Teaching	Review Educational Research	Journal of Chemical Education	Australian Science Teachers Journal	Education	Teachers College Record	European Journal of Science Education	The Physics Teacher	Educational Theory	School Science Review	Indiana Social Studies Quarterly	European Journal of Physics	Research in Science education	International Journ. of Sc. and Math. Educ.
1948	1	1														1																	
1957	1	1	1																														
1963	5	1			1																												
1964		1														1																	
1969		3			2																1												
1971	11	1														1																	
1972		1																	1														
1973		1														1																	
1976		2														2																	
1977		4																					4										
1979		2				1																1											
1980	26	1																							1								
1981		6																						1		1		1	2	1			
1982		2			1																						1						
1984		1																	1														
1985		1																	1														
1987		1			1																												
1988		1				1																											
1989		13	1				11			1																							

Table 1 – Summary of studies obtained by selection (decade, year and journal)

	Number of articles per decade	Number of articles per year	Science Education	Science and Education	Journal of Research in Sc. Teaching	International Journ. of Sc. Education	Interchange-A Quarterly Review of Educ.	Electronic Journal of Sci. Education	School Science and Mathematics	American Biology Teacher	Science Teacher	Teacher Magazine	Physics Education	Teaching Education	Scandinavian Journal of Educ. Research	American Journal of Physics	Journal of Science Teacher Education	Social Education	Journal of College Science Teaching	College Teaching	Review Educational Research	Journal of Chemical Education	Australian Science Teachers Journal	Education	Teachers College Record	European Journal of Science Education	The Physics Teacher	Educational Theory	School Science Review	Indiana Social Studies Quarterly	European Journal of Physics	Research in Science education	International Journ. of Sc. and Math. Educ.
1990	49	2																	1												1		
1991		6	3		1									1			1																
1992		3		2	1																												
1993		6		4			1				1																						
1994		4		1	1								2																				
1995		2	1																	1													
1996		6		5	1																												
1997		7	2	1			2											1														1	
1998		11	1	4	3				1						1																	1	
1999		2		1		1																											
2000	59	18	1	10	2	2		1								1															1		
2001		16	1	14						1																							
2002		4		2	1			1																									
2003		5	2	3																													
2004		3	1				1				1																						
2005		4		1	1																												2
2006		3		1			1					1																					
2007		5		1	1	1	1																									1	
2008		1	1																														
Totals	152	152	15	50	17	6	17	2	1	2	2	1	2	1	1	7	1	1	4	1	1	1	4	1	1	1	1	1	2	1	2	3	2

Continuation of Table 1 – Summary of studies obtained by selection (decade, year and journal)

3.2 General description of studies

Having employed the selection criteria, a description of the 11 works selected for analysis was carried out according to the following aspects: country in which the study was undertaken; the involvement of physics as a subject in the study; whether the study considered only the use of the History of Science (HS) in the didactic intervention, only the Philosophy of Science (PS) or both together; the general objectives of the study; how HPS was used in Physics Teaching (PT); teaching level; number of students; length of didactic intervention; teaching strategy employed in the didactic intervention; research design for the teaching strategy; and whether the students' prior knowledge was taken into consideration, either in relation to the subject of physics within the intervention or in relation to HPS. This detailed description is summarised in tables 2 and 3; the studies are denominated in the following tables by the letters **A, B, C**[3]**, D, E, F, G, H, I**, **J** and **K** (referenced at the end of the article).

It is worth noting that the 11 works selected for the in-depth review come from a variety of countries across almost all continents: 5 works are from Europe; 2 from South America; 2 from North America; 1 from Africa and 1 from the Middle East. There is also variety in terms of the subjects covered in the classroom applications of HPS with Optics prevailing with 5 works, followed by Electricity and Mechanics with 2 works each, and Modern Physics with 1 work. One of the studies does not specify the subject, suggesting that HPS was used as an approach to a variety of topics. PS appears in conjunction with HS in only 5 out of the 11 studies; the other 6 only make reference to the didactic use of HS without PS, which may represent a difficulty in didactically presenting HS in an epistemologically contextualised way (Matthews 1994).

Overall, the objectives of the works are concerned with the investigation of the effects of the use of didactic materials and/or strategies in teaching based on HPS in terms of a better understanding of concepts, ideas about the Nature of Science (NOS) and the subjects' attitudes toward science. In a majority of the studies, these objectives are associated with the idea of conceptual change concerned with similarities between the students' alternative ideas and the historical development of scientific concepts. Although the idea of parallelism between these two processes – ontogenetic and phylogenetic – has already been considerably criticised in the literature (Matthews 1994; Driver and Easley, 1978; Rowlands et al. 1999; Moreira and Greca, 2003), it remains present in the arguments of researchers who explore the didactic use of HPS.

[3] This study has been published in two articles: (a) Galili and Hazan (2000); (b) Galili and Hazan (2001).

Study	Study Country	Subject	Use of		Objectives	How HPS is used in PT	Teaching level	Length of classroom application	Teaching strategy	Previous knowledge	
			HS	PS						In the subject	In HPS
A	Germany	Electrostatics	X		To describe a course in electrostatics focusing on the reproduction of 18th century historical experiments	Through the replication of historical experiments and discussion of original texts related to the experiments	Secondary	One unit	Experimental classes through discovery, coupled with discussions about the development of concepts and their specific experiments	Yes	No
B	Brazil	Optics (Galileo's use of telescope)	X	X	To present evidence about how HPS may contribute to science teaching (ST) and the implications that stem from the way HPS was implemented in ST	Through reading and discussion of historical texts	Secondary	Not specified	Group reading activities followed by discussion of the text, guided by questions proposed and mediated by the teacher	No	No
C	Israel	Optics (light and vision)	X	X	To evaluate the effectiveness of a course based on HS concerned with the students' views of NOS and technology and content knowledge	Through the use of historical materials which allows the students to identify their own alternative learning plans regarding the subjects covered	Secondary	One year	Not specified	No	No
D	Spain	Various	X		To ascertain the perception of science and students' attitudes towards science after using HS in physics and chemistry classes	Through the use of historical materials (including originals) in considering parallels between scientific ideas prevalent during different historical periods and the students' first ideas (psychogenesis) - envisaging a possible conceptual change; problem solving and laboratory work	Secondary	Three years	Not specified	No	No
E	USA	Movement and strength	X		To investigate the effectiveness of historical curricular materials on science learning, NOS and the students' interest in science	Through the use of materials incorporating HS, concerning: similarities between the students' alternative ideas and the historical development of scientific concepts; class discussions about how scientists produce knowledge; short accounts of scientists' personal lives. All with the aim of investigating the learning of concepts, NOS and the students' interest in science	Secondary (equivalent to 8th grade in Brazil)	Four months	Four different teaching strategies using material based on HS, involving discussion sessions and undertaking of experiments	Yes	Yes
F	USA	Optics (Fraunhofer lines, speed of light); Hydrostatics (air pressure)	X	X	To evaluate the effectiveness of the HOSC instruction method in changing student understanding of science and scientists, and achievement in the regular content of the physics course	Through presentation of historical science cases using texts containing historical narratives, citations from original articles, as well as experiments and exercises correlating with historic cases.	Secondary	Four weeks	Reading of historic cases as part of students' homework and subsequent classroom discussion following instructional material.	No	Yes
G	Argentina	Electric field lines	X		To analyse the effects of historical materials on the students' conceptual change in relation to the ontology of the concept of field lines	Through the presentation of historical episodes in Faraday's research on electromagnetism and discussions regarding the ontological status which Faraday attributed to field lines and the differences between the concepts of that period and current ones; contextualizing and undertaking experiments similar to Faraday's. All this with the aim of conceptual change	Physics graduate	Not specified	Theoretical, experimental and problem-solving classes; material of a historical nature was used in the theoretical classes of the experimental group	Yes	No

Table 2 – General Description of Studies

Study	Study Country	Subject	Use of HS	Use of PS	Objectives	How HPS is used in PT	Teaching level	Length of classroom application	Teaching strategy	Previous knowledge: In the subject	Previous knowledge: In HPS
H	Nigeria	Cosmo-logical Concepts	X	X	To determine: the nature of traditional cosmological views in the literate and non-literate; whether demographic characteristics affect these views; the impact of a university HPS course on these views	Through reading and discussion of historical material to stimulate rational thought	University students	Not specified	Not specified	Yes	No
I	France	Optics (visual mechanism)	X		To analyse the cognitive impact of a teaching sequence based on an historical text (drama)	Not specified	Secondary (12 to13 years of age)	Not specified	Drama was used (as a means of depicting a part of HS) as a potentially useful teaching strategy in advancing significant learning and the students' better understanding of NOS. The students were encouraged to identify themselves with old views and overcome these by the strength of the arguments contained within the drama which correspond to the pathway, present in the drama, inspired by HS	Yes	No
J	England	Brownian motion	X	X	To evaluate the impact of a course based on HPS concerned with the teaching of Brownian motion and NOS	By introducing one of the teacher-researcher's historical texts and requesting students to write a 'letter to Brown' persuading him to submit his theory to current interpretations. Use of Perrin's (1916) book together with a current didactic book for the re-analysis of data concerning Brownian motion with the aim of recalculating the Avogadro number	BA in Education	1 unit (of a 2-year course)	Reading an historic text about the subject, the production of a text by the students and undertaking an exercise in analysis of Perrin's original data	Yes	No
K	Greece	Optics (the formation of images)	X		To investigate the effects of a teaching intervention based on HS aimed at transforming students' representations of the formation of images	After the students had had their perceptions disoriented by taking part in an experiment, Kepler's experiment was reproduced in an interactive environment with the objective of training the students to reorganise their ideas (conceptual change)	Primary and secondary (12 to 16 years of age)	Not specified	Students' experimental tasks to create cognitive disequilibrium and then reorganise their representations through an historic experiment. For each part of the work the students were asked to predict, experiment and confront the results of their predictions and then to rectify or ratify their ideas	Yes	No

Continuation of Table 2 – General Description of Studies

Study	Number of subjects	Teaching Strategy Research Design
A	15	Qualitative description of the activity carried out by the author in the classroom without the use of data collection instruments.
B	40	Qualitative research: observation and video recording of the classes for episode analysis. The researchers designed the activity, conducted the research (gathered and analyzed data), but did not carry out the intervention.
C	141 (exp.) + 93 (control) = 234	Quali-quantitative research: questionnaires on students' views about science (where open and multiple choice questions without a provided context were selected from previously performed studies of the subject) and a conceptually-oriented test for knowledge evaluation (test items were also taken from previous studies of students' knowledge of optics) about the subject were applied simultaneously to all groups in natural classroom settings after the intervention and evaluated independently in qualitative and quantitative analysis; open–ended questionnaires about the subject and interviews of some students and teachers from the experimental groups; analysis of frequencies of specific categories developed for each aspect of the research (opinion of science and content knowledge). The researchers prepared the textbook and conducted the research (gathered and analyzed data) while volunteer teachers without experience in HPS developed the experimental unit.
D	233 (exp.) + 694 (control) = 927	Quantitative research using three different post tests (on the development of science and the contribution of the scientist; social aspects of history; interest and attitudes towards science) with open questions in the absence of a provided context and qualitative observations. The researchers prepared a course and conducted the research (gathered and analyzed data); the researchers and others teachers developed the intervention.
E	91 randomly distributed in four groups (three groups with experimental intervention)	Quantitative research using instruments (pre- and post- test), such as demographic information (IQ level and pre-grades), questionnaires about nature of science previously used in others studies about the subject (POSE-Perspective on Scientific Epistemology), conceptual mapping for measure of meaningful learning, interest survey (items on a six points Lickert scale) and semi-structured interviews conducted with 6 students randomly chosen from each class. The data was analyzed using multivariate analysis of variance. The researchers elaborated the curricula for three different teaching strategies (with the "control group" using a traditional teaching strategy) and conducted the research (gathered and analyzed data) a volunteer teacher without experience in HPS developed the curricula.
F	15 experimental groups and 13 control groups (c.580 subjects in total)	Quantitative research using experimental design: pre- and post-test on understanding science for the students (TOUS test) and a related pre-test for teachers, pre-test to measure student scholastic aptitude (Otis Mental Ability Test) and post-test on the specific subject (Cooperative Physics Test), all tests published by national testing services. Groups were randomly selected and class means were used as the unit of analysis, (of variance with covariance adjustment). The researchers designed the activity and conducted the research (gathered and analyzed data).
G	33 (exp.) + 33 (control), randomly distributed = 66	Quantitative research using pre- and post-test (multiple choice questions to elicit students' ontological views about lines of forces, with the possibility of choosing more than one option), students' statements justifying their choices and interviews centred on two situations. Answers were analyzed using propositional analysis and analysis of variance. The researcher designed the activity and conducted the research (gathered and analyzed data).
H	105 (exp.) + 138 (control)	Quantitative research using a pre- and post-test questionnaire (TCT- Traditional Cosmological Test) to determine cosmological ideas, consisting of fictitious stories followed by statements on which subjects express their opinion on a three-point Lickert scale as well as a list of traditional cosmological ideas common in Southern Nigeria and rated from 0 to 10 according to the way such concepts influence their viewpoints about natural phenomena. The data was analyzed using multivariate analysis of variance and factor analysis.
I	12	Qualitative research in the form of a "teaching experiment", using interviews centred on the drama developed by the researchers about the way vision operates. The researchers designed the activity, carried out the intervention and conducted the research (gathered and analyzed data).
J	23	Qualitative research using a final questionnaire and certain students' written materials (the 'letters to Brown'). The researcher designed the activity, carried out the intervention and conducted the research (gathered and analyzed data).
K	48	Quali-quantitative research using audio-taped semi-structured interviews applied pre- and post-intervention, with open questions adjusted to the empirical content of specific experimental situations regarding the formation of images, designs on schematic reproductions of the experimental setting and special protocols to encode relevant non-verbal responses. The data was analyzed using frequency analysis, goodness-of-fit test and the Kruskal-Wallis non-parametric test. The researcher designed the activity, carried out the intervention and conducted the research (gathered and analyzed data).

Table 3 – Research design of the selected studies

The studies exhibit a variety of teaching levels, and examine research subjects at three educational stages (primary, secondary and higher). However, the majority of research is concentrated at the primary and secondary stages demonstrating a need for more studies exploring this subject at university level, especially studies involving mature students with the ability to understand historic-epistemological issues.

Study **A** describes a didactic unit of electrostatics with a class of secondary school students. This was achieved by replicating a classroom where various historical electrostatic experiments were carried out, enabling the students to have their experiences augmented by discussions supported by historic texts that explained the development of concepts as well as the experiments themselves and contained views that took into consideration the changes in experiment style that occurred towards the end of the 18th century. As electrostatics was a compulsory course subject, the teaching of the history of science can be seen, according to the author, from the perspective suggested by Matthews (1994) of a didactic approach integrated with HS.

Study **B** involves a qualititative research with a group of secondary school students on the historical development of Optics, especially events involving Galileo using a telescope. Group activities took place in a classroom with questions proposed and mediated by the teacher. After reading and analyzing historical texts there were activities in which students discussed the subject with a view to better understanding essential aspects of science, as well as learning how to develop arguments and appreciate attitudes as to the direction of science. The authors presuppose HPS to be an "*integral part of scientific knowledge, and therefore, they must be studied in science courses*" (Carvalho and Vannucchi 2000: 427). In this way, they incorporate the view of Matthews (1994) as an integrated way of including HPS in the science curriculum in terms of content: [HPS] "*as elements that are inherent in science itself, since a well-based understanding of science necessarily implies a knowledge of its history*" (Matthews 1994; Carvalho and Vannucchi 2000: 428).

Study **C** (published in two articles) investigated the effects of a one year Optics course that incorporated historical materials about light and vision models on students' perceptions about NOS and technology and the extent of subject knowledge. HPS was introduced through historical texts, in terms of drawing parallels between the students' conceptions and historical conceptions of the concepts of light and vision, although no specific teaching strategy was suggested to the teachers who ran the course.

The principal focus of Study **D** was to show that an appropriate introduction to the history and sociology of science through the use of historical materials such as "*biographies, original papers, reports on STS in history or videos showing the making and growth of major concepts in P&C*" (Solbes and Traver 2003: 703), in a secondary school physics and chemistry course, can contribute to a better perception of science as well as a better appreciation of science by the students. According to the authors, the historical approach takes into account the idea of overcoming a purely empiricist image of science; promoting conceptual change – drawing parallels between historic ideas and students' preconceptions – comprehension of NOS and scientific activity; comprehension in relation to STS; the role of women in science, etc. The authors considered this historical approach in an integrated way, adopting a teaching and learning strategy during the research process, as suggested by Gil et al. (1991). However they did not share details of how this integrated strategy was implemented in the classroom.

Study **E** investigated the effectiveness of curricular materials that incorporated the history of science in dealing with force and movement units in three experimental groups with the aim of attaining a conceptual understanding and knowledge about NOS and a better appreciation of science by the students. A different strategy for teaching science history was used in each group: one considered the similarity between the students' alternative ideas and scientific concepts that encompass conceptual change – at which point the authors cited, amongst others, Wandersee (1985) and Seroglou et al. (1998); another strategy centred on discussions about how scientific knowledge is produced, with a view to better understanding NOS – here the authors drew heavily on the works of Abd-El-Khalick and Lederman ($2000_{a,\ b}$) amongst others; a third strategy used short personal accounts from scientists in a style unconnected to scientific concepts and NOS – here the authors drew principally on Egan's story form (1985, 1989)[4].

Study **F** looked to evaluate the effectiveness of the HOSC (History of Science Cases) instructional method in students' understanding of the NOS and the subject of physics. The study involved diverse groups of secondary school physics, chemistry and biology students, although the present research summary restricted the

[4] Even though the strategy presented by Egan is located, according to Matthews (1994), in the Storyline Approach, representing a middle road between the "add-on" and integrated approaches, the authors of Study E explicitly used scientists' life stories (in one of the didactic strategies) in a way that was disconnected from scientific concepts and NOS.

scope of the analysis to physics groups. During the four weeks in which the investigation was carried out the physics groups looked at Optics (Fraunhofer lines and speed of light) and Hydrostatics (atmospheric pressure). The teaching strategy involved reading and discussing history of science cases, utilizing historic texts along with original articles, experiments and exercises relating to the cases.

Study **G** analyzed the effects of historically informed instructional material on university physics students' ontological understanding of the concept of field lines, with a view to providing conceptual change. Reading and classroom discussions of historical stories surrounding Faraday's research on electromagnetism were used to compare the ontological status of field lines, as characterised by Faraday, with contemporary conceptions and had the aim of incorporating science history into the subject. Laboratory classes were held involving similar experiments to those of Faraday and there were also lessons in which problems were solved.

Study **H** aimed to determine the nature of traditional cosmological visions of Nigerian students with differing levels of education (including illiteracy) to ascertain whether certain demographic characteristics interfere in such visions and to analyse the impact of a university course containing HPS on these visions. As the HPS-based teaching strategy only involves university students, the present analysis only contains results pertinent to them. The study used a strategy of incorporating HPS into the subject through reading and discussions of a variety of historical texts including Greek cosmology, medieval astronomy and African cosmology; the idea being to stimulate students' rational thought processes and so increase the likelihood of their choosing a scientific explanation in preference to one from the African cosmological tradition.

Study **I** investigated the effects of a written teaching resource presented in dramatic form: a debate inspired by the history of the mechanics of vision, with a view to acquiring knowledge of how vision functions, improving the development of argument through speaking activities and making the students more conscious of their own cognitive processes. The study involved a strategy of teaching physics that integrated science history. This was based on Monk and Osborne's 1997 model of incorporating HPS in science teaching, which drew parallels between the historical development of scientific ideas and alternative routes for students to acquire knowledge of the mechanics of vision.

Study **J** aimed to evaluate the impact of an HPS-based course on teaching Brownian motion, and, at the same time, increase awareness of NOS within a group of undergraduate students of education. The study utilized an historical text written by the researcher himself, a book by Jean Perrin from 1916 and another didactic contemporary text to reappraise data relating to Brownian motion. The study used an integrated teaching strategy along with a reading and discussion of the texts; a production of a text by the students as well as an exercise that re-analyzed Perrin's data.

Study **K** investigated the effects of a teaching intervention based on science history. A teaching strategy integrating science history was carried out in two instances: the first aimed to destabilize the students' alternative representations of image formation, and the second, reproducing Kepler's historical experiment, aimed to transform the students' portrayal of light emission and image formation

As evidenced above, these studies demonstrate a variety of objectives in relation to the use of HPS in physics classes:

- In seven studies, HPS was used to acquire conceptual knowledge (the majority of studies supporting the idea of similarity between students' alternative conceptions and historically conceptualized physical concepts).
- In five studies HPS was used to attain a better understanding of aspects of NOS (according to the authors, a better understanding of science, its processes and of scientists themselves, contributed to suppressing more naive views about science, and so contributed to a better understanding of the role of science in contemporary society);
- In four studies HPS was used to improve the attitude of students towards science (getting to know the history of science and scientists can help motivate students so they become interested in the study of science, especially physics)
- In two studies HPS was used to promote skills in structuring arguments (involving students in activities that recreate historical physics debates enables them to better develop their arguments).
- In one study HPS was used to develop metacognition (involving students in historical debates enhances their capacity to learn about their own thought processes)

Using the classification proposed by Matthews (1994) about how to include HPS in science teaching, the majority of studies (**A**, **B**, **C**, **D**, **G**, **H**, **I**, **J**) can be categorised as having an "integrated" strategy, that is, where the science content is studied in such a way that content and historical development overlap; study **F** used an “add-on” strategy in which a history of science unit was added to the science course using a traditional, rather than historical, teaching approach; study **E** utilized two forms of approach in different didactic proposals and study **K** used HPS in an integrated form with a strategy of teaching-learning whilst carrying out research in the classroom.

The didactic materials that incorporated HPS were texts in the form of historical narratives (in ten of the studies), biographies of scientists (one study), replications of historical experiments (three studies), lists of exercises with historically conceptualized problems (three studies), videos about the evolution of scientific concepts (one study) and short stories about scientists' lives (one study). Some of the studies used more than one type of the aforementioned didactic materials.

The teaching strategy employed in the classroom was not specified in three of the studies analyzed. Most (c. 70%) of the studies involved theoretical discussions supported by historical texts. A significant number of works (c. 60%) incorporated HPS in experiments in the classroom, reconstructing experiments from the history of the studied subject. In addition, two studies explored teaching strategies that focused on historically contextualised problem-solving. Since these strategies are not mutually exclusive, in some studies an overlap of strategies occurred in the didactic intervention. One negative aspect noted was that few of the studies justified the teaching strategies employed by elaborating on their pedagogical references.

The research designs presented a balanced portfolio, with 4 qualitative, 5 quantitative and 2 quali-quantitative studies. The preferred tools for data collection in the majority of the studies were questionnaires containing open or multiple choice questions (in 7 of the studies) as well as semi-structured interviews (5 studies), being similar to the findings of Bennett et al. (2007) in their review of the STS approach. In 3 out of 4 studies that used questionnaires regarding the nature of science, the questionnaire items, most of which lacked context, were selected from previously performed studies. In two studies, interviews were subsequently carried out on a reduced number of subjects in order to clarify data obtained via the questionnaires; in the remaining three studies, interviews were developed out of specific situations, two of which involved experiments. It is interesting to note that none of these studies used interviews as the principal instrument to elicit students' epistemological views.

None of the studies, whether dealing with epistemological visions or conceptual or cognitive skills, have subsequently re-evaluated the effects of their interventions. As establishing and maintaining (epistemological or cognitive) change can be inherently problematic (Chi et al. 1994) the impact of the results may be less than expected. Additionally, none of the studies used regular final examinations as research instruments. Whilst this would normally be acceptable given the scope of the research and/or the limited time of the interventions, nevertheless, it would have been interesting if Study **C** (which was the only one dealing with the effects of an HPS approach to student knowledge in the space of a year) also compared the control and the experimental group achievements with an instrument independent of the HPS approach. This would have allowed a true comparison of different approaches to conceptual achievements.

In terms of the length of interventions taking the HPS approach, only two studies (**C** and **D**) implemented them throughout the year whereas the others involved intervention periods that were more targeted, lasting a few months or for just one unit or course theme. An evaluation of the review articles' results should therefore take into consideration these short time periods when assessing the effectiveness of an HPS approach.

The researchers developed the teaching sequences and also gathered and analyzed the data for all of the studies. Only one study (study **F**) took into consideration and analyzed teachers' conceptions about science. In 5 out of 9 cases the researchers were also responsible for the intervention itself (intervention responsibility being unclear in two of the studies). Although this procedure is not unusual in the area of science education research, it may bias the related findings of the effects of HPS on physics teaching by raising ethical issues surrounding the possible vested interests of researchers in reporting the success of their interventions. That said, the fact that researchers have responsibility for an intervention puts them in a better position to explore it further, although, in this case, the possibility of “extending” their findings would be limited, especially when problems relating to teachers' beliefs about science and classroom practice are taken into account (Abd-El-Khalick and Lederman 2000a).

It is worth noting that 7 of the 11 studies were interested in assessing the research subjects' previous knowledge of physics-related topics. In fact, when seeking to evaluate the effects of a specific intervention prior to the intervention itself, the methodological importance of understanding the research subjects' views on the topic in consideration is well-known. In general, this seems to have been taken into consideration in those research studies regarding the understanding of concepts. However, the same preoccupation is not evident regarding HPS, given that only 2 of the 11 works analyzed here sought to ascertain the students' prior ideas about elements of an epistemological nature. As has already been pointed out, the overall objectives presented in the research studies were to investigate the effects of didactic interventions that use HPS for improvement in understanding specific concepts of physics, views about NOS and students' attitudes to science, as well as in aspects of metacognition and argumentation and, for this reason, there is an urgent need to ascertain the extent of the research subjects' field knowledge, since it would be a methodological error to presuppose that research subjects either have no prior knowledge regarding these matters or that their knowledge is unsuitable.

3.3 Quality Analysis of the Studies

Following a general description of the studies, a quality analysis was undertaken, taking into account the following aspects in the articles analyzed: reliability of instruments (only for the quantitative studies); validity of instruments; reliability of results (only for the qualitative studies); validity of results, appropriate sample size, appropriate data collection techniques and discussion of study limitations (for both qualitative and quantitative studies). Given the diversity of meanings associated with concepts of reliability and validity, we note that the following criteria were used in this research which were similar to those found in Bennett et al. 2007; White and Arzi 2005; Munby 2003; LeCompte and Goetz, 1982:

- instrument reliability – criteria found in appropriate statistical methods used in quantitative studies, such as correlation factors;

- instrument validity – measures taken, as mentioned in the studies, in data collection processes such as piloting, language equivalence, use of instruments validated in previous studies or by any of the usual criteria (content, construct or related to criteria) etc.;

- reliability of results – criteria in qualitative studies related to agreement in analyses independent of the researchers;

- validity of results – measures to seek out and eliminate errors or biases, as well as alternative explanations to those described at the conclusion of the studies.

This quality analysis was undertaken separately by two of the study's authors via a thorough reading of the entire papers. Inter-rater agreement on the quality judgments over the 11 studies was 72%, and final results were achieved through discussion and consensus. Table 4 presents a summary of this analysis, showing which of the aforementioned items appear in the analyzed studies, as well as the quality concept attributed to each study. We attribute concept M (which indicates medium quality) when only two of the aforementioned items are found in the work and concept H (which indicates high quality) when three or more of these items are found.

Studies	Reliability	Validity	Instrument Validity	Appropriate sample size	Appropriate data collection technique	Limitations described	Quality of Study
A		✓				✓	M
B	✓	✓			✓	✓	H
C	✓	✓	✓	✓	✓		H
D		✓	✓	✓	✓		H
E	✓	✓	✓	✓	✓		H
F	✓	✓	✓	✓	✓	✓	H
G	✓	✓	✓	✓	✓		H
H	✓	✓	✓	✓	✓		H
I		✓	✓	✓	✓		H
J		✓				✓	M
K	✓		✓	✓	✓		H

Table 4 – Summary of quality analysis of studies. M indicates medium quality (where up to two items are found); H indicates high quality (where three or more items are found).

3.4 Observed Results from the Studies

Of the studies analyzed, 9 were categorised as concept H, being **B, C, D, E, F, G, H, I** and **K** (see table 5), with studies **A** and **J** being categorised as concept M. The results reported in the conclusions of the 9 high quality studies, were then summarized with the aim of eliciting the salient points regarding the didactic application of HPS in physics classrooms, thus enhancing the knowledge of researchers who work in this area.

Studies	Understanding concepts	Nature of Science	Argumentation	Metacognition	Attitudes towards science
B		✓	✓		**x**
C	✓	✓			✓
D		✓			✓
E	**x**	✓			**x**
F	**x**	✓			
G	✓				
H	✓				
I	✓		✓	✓	
K	✓				

Table 5 – Summary of results reported in the studies. ✓ Indicates report of favourable results; **x** indicates report of no favourable results.

Seven (**C**, **E**, **F**, **G**, **H**, **I** and **K)** of the nine studies had the objective of evaluating the effects of HPS in learning the subject included in the didactic intervention. Studies **E** and **F** reported that there were no differences between the experimental and control groups regarding the learning of physics concepts. The other studies reported positive conclusions in terms of learning as an effect of the didactic use of HPS, while study **H** did not indicate the occurrence of conceptual change, but rather of a change in the research subjects' preference for the scientific concepts, without relinquishing the prior concept. Study **C** also made no reference to the occurrence of conceptual change – given that it did not take into account prior student knowledge – but only compared, at the end of the HPS tuition, the benefits of this tuition for the experimental groups as compared to the control groups. Thus, studies **G**, **I** and **K** concluded that there was a conceptual change, although **K** reported a resistance to this change in the group studied.

We can thus infer that a majority of studies that focused on this area reported favourable results, although there was no consensus about the positive effects of the didactic use of HPS in terms of concept learning. Similarly, there was no agreement about the occurrence of conceptual change, although it should be noted that there is considerable volume of literature criticising the conceptual change approach (Mortimer 1995; Millar 1989; Matthews 1992b; Marín 1999), which means that this lack of agreement cannot be linked to the didactic approach under consideration – the use of HPS – but to the possibility that this change may occur, whichever teaching approach is employed.

Studies **B**, **C**, **D, E** and **F** sought to investigate the effects of the didactic application of HPS on the research subjects' understanding of NOS in their respective pieces of research, while study **C** also explored these effects in relation to STS. All the studies, without exception, presented entirely favourable results. This shows that in the teaching of physics the use of HPS-based approaches may in fact foster a more mature student vision in respect of their understanding of NOS. Thus, physics curricula and/or teaching that include in their objectives provision for the students' better understanding of NOS, may find an effective ally in HPS.

The same studies, with the exception of **F** which investigated the effects of the didactic use of HPS in regards to NOS, also investigated those effects relating to the subjects' attitudes to science. The reported conclusions, however, do not concur. Studies **C** and **D** report positive conclusions concerning the students' interest in scientific undertakings, scientists and established theories, as well as in the processes of the evolution of science in relation to STS. Study **B** concluded that, even following a didactic intervention based on HPS, the students insisted on receiving affirmations about the 'status' of absolute truths from the teacher, thus demonstrating little interest in the demystification of science. In study **E** it was reported that, although accounts of scientists' lives aroused the students' interest, discussions about the scientific method without the use of these accounts, reduced their interest in science. Thus, according to these research studies, it is not possible to confirm that approaches in physics teaching based on HPS lead to an increase in students' interest in science, suggesting that more careful investigation is needed in this area.

Only 2 studies (**B** and **I**) were concerned with the effects of the didactic use of HPS on the research subjects' level of argumentation. Each of these reported favourable conclusions regarding improvement in the quality of the students' arguments, both in terms of debating skills and in favouring more abstract explanations. This confirms findings from the literature dedicated to this line of research – that the adoption of science teaching strategies which promote argumentation is an essential element in science education because it offers many benefits including that of providing students with the opportunity to engage with the culture of science and allowing the development of meta-cognitive features as well as the development of different forms of thought (Abi-El-Mona & Abd-El-Khalick 2006; Erduran et al. 2004; Albe 2007; Munford and Zembal-Saul 2002; Jiménez-Aleixandre et al. 2000a,b). However, the fact that only 2 studies explored this aspect also confirms that this approach is rarely adopted in science teaching classrooms (Abi-El-Mona & Abd-El-Khalick 2006) and especially, in the teaching of physics, demonstrating the necessity for more research to be undertaken in order to evaluate the potential of HPS resources in promoting argumentation.

We should point out that only one study contained results relating to metacognition. Study **I** reported as one of its conclusions that the teaching-learning sequence based on HPS employed in the research made the students more aware of their own cognitive processes, enabling some of them to analyse those elements that supported changes to their spontaneous ideas. This demonstrated both the potential of a teaching approach supported by HPS for metacognition (Seroglou and Koumaras 2001), as well as the need for greater research effort to investigate this matter.

Finally, it may appear strange that a review of the use of HPS in physics teaching did not take into account an analysis of the experiences of the Harvard Project Physics (HPP), probably the most well-known instructional material for HPS-informed physics teaching. History may explain this absence. The criteria we have used to screen the bibliographic data bases emphasized the use of HPS in physics teaching. When HPP first appeared and was analyzed in the late 1960s and early 70s, the expression HPS was not widely used in science teaching. For instance, Holton (1964), presented it as a "connective approach" and the lexicon of the time referred to HPS as having a "humanistic approach" (Welch 1973). In fact, HPS in science teaching only matured under this title in the late 1980s and early 90s. Thus the criteria adopted in our review did not allow us to include studies on HPP within the chosen sample. However, any review of the use of HPS in physics teaching would be deemed a failure if it did not include a reference to such an experience. For this reason, we refer the reader to the relevant literature for an assessment of this experience.

"*The most compelling single summative assessment study*" on humanistic approaches to science teaching "*was the complex, multi-faceted, randomized research design for*" HPP, according to Aikenhead (2003: 60). This study, coordinated and reviewed by Wayne Welch, was an extremely sophisticated quantitative study, carried out over four years at a national level in the US, with experimental and control groups. On the advantages of the HPP course, Welch (1973: 375) reported: "*students in HPP find the course more satisfying, diverse, historical, philosophical, humanitarian, and social; their questionnaire responses suggest a belief that mathematics is not essential to understanding physics; the historical approach is interesting; the book was enjoyable to read; their class finished the text; and they hoped the book would not be changed*." However, concerning conceptual learning Welch also concluded that the results "*showed no significant difference between the HPP and non-HPP groups.*" This conclusion was challenged by Aikenhead (1974), who undertook a revised analysis of the tests and arrived at different conclusions. Indeed, after "deleting the frivolous and incomplete answer sheets, Aikenhead recalculated the gain scores and found the HPP group had significantly out-performed the non–HPP group" (Aikenkead 2003: 60). Today, Aikenhead's revision of the HPP tests may still be considered a caveat for the kind of data that should be used in quantitative assessments. Even without Aikenhead's revision, the balance of assessment is widely favorable to the HPP experience.

4. Conclusion

The first point to consider is that the procedures used in this study seem to be a reasonably effective way of undertaking a systematic review of literature that refers to the didactic use of HPS in science teaching, and in particular, physics teaching. The research summary reported here allowed us to outline, with the aid of tables and graphs, a general overview of research studies on this subject, published in internationally renowned journals and also to gather critical information in a secure manner, which may be of value to this area of research.

The vast majority of the studies selected for analysis support the idea of similarity amongst students' spontaneous understanding of scientific concepts and the historical development of these concepts, with the aim of attaining a conceptual change, despite the large amount of criticism found in the literature about this type of approach. In spite of the presence of a variety of teaching strategies based on HPS, comparatively few of them provided the pedagogical references to justify the use of these strategies, and few were concerned with assessing the students' prior knowledge of HPS.

The studies analyzed present various ways of how to utilize HPS in the teaching of physics: in relation to teaching objectives (learning concepts, NOS, attitudes, argumentation and metacognition); in relation to teaching strategies (integrated with the subject of physics, integrated with another teaching strategy and non-integrated); in relation to didactic materials (historical narratives, biographies, replicas of historical experiments, historically contextualized problems and stories of scientists' lives).

Of the 11 studies analyzed, 9 were considered to be of high quality according to the criteria set by the present study, which is a favourable indicator for this area of research. The results reported the occurrence of positive effects in the didactic use of HPS in the learning of physics concepts, despite there being no consensus about this, and they also indicated a lack of agreement about the occurrence of conceptual change. Greater research efforts are therefore needed to investigate these aspects, especially when the aforementioned limitations in research procedures are taken into account. In the same way, no consensus was found as to how HPS promotes improvements in the students' attitudes to science, which also leads us to conclude that this subject needs further investigation. On the other hand, this type of approach appears to promote a more mature vision in respect of the students' understanding of NOS, which should be taken into consideration when planning curricula and/or physics teaching strategies. Favourable results were also found when looking at the effects of the didactic employment of HPS on the areas of argumentation and metacognition, despite the dearth of studies in the analysis dealing with these areas. This demonstrates that potentially important areas are being explored which warrant a higher position on the HPS-based physics teaching research agenda.

In conclusion, despite the limited number of studies included in the final analysis, the actual scope of the survey, as well as the selection and exclusion criteria and the in-depth analysis guided by the research question, allows the authors to consider this research synthesis a reliable indicator of the state of art of this particular area of research.

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