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Experts' Views on Using History and Philosophy of Science in the Practice of Physics Instruction

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Abstract. This study examines the views of a representative sample of experts in physics, physics education and history and philosophy of science (HPS) on the incorporation of HPS based materials in physics instruction. The obtained spectrum of views addresses three areas: the rationale to include HPS, the most appropriate ways of doing so, and anticipated difficulties in such a new educational approach. The elicited views, interpreted and categorized, reflect the attitude of the community of science educators in Israeli colleges and universities with regard to the subject. The constructed profiles indicate low awareness of the recent changes in the understanding of learning and the role of HPS in the light of these changes. Such knowledge can guide the activities of those who devote their efforts to constructing and implementing learning materials utilizing HPS contents in science education.

1. Introduction

The question if today's instruction of scientific disciplines should include contents of history and philosophy of science (HPS), is dependent on one's chosen educational philosophy and values, and therefore has instigated continuous debates (Matthews 1994). Despite the intensive discussions that have been conducted for over a hundred years, ever since this idea was first articulated, HPS has seldom been implemented. This could be an indication of the complexity and controversial nature of the issue, and the necessity to invest theoretical efforts in its comprehensive analysis. Recently educational researchers had begun to study in depth the issue of the implementation of HPS in actual instruction, so as to provide a more solid theoretical and empirical basis on which to determine the usefulness of such an approach (e.g., Galili and Hazan 2000b). If HPS is to be implemented, it is of the utmost importance that we be aware of the view of those who will be most involved in its preparation and implementation. Such knowledge is required to assist curricula designers, theoreticians and practitioners in producing required HPS materials, as it allows for the consideration of any ideas they may have regarding such a program to improve it, while reducing the chance that any preconceptions or reservation they may have will undermine such a program.

As the subject is triangular in nature: the use of (1) the history and philosophy of science in (2) physics (3) education, we elicited and analyzed the viewpoints of experts in these three areas of knowledge. The subjects of the study, university or college professors, are involved in teaching physics and, to various extend, in the use and implementation of HPS based materials in actual teaching. The study aimed at providing a realistic picture of the views actually held by those involved in science education, instead of assumptions one might hold regarding such views. Although one may expect a considerable ideological versatility of viewpoints, ranging from strong arguments in favor of the historical approach to a clear rejection of it, only an explicit study can tell the "true" picture.

2. A Brief History of the Rationale of Using HPS

Our intention here is to recapitulate the emergence of the rationale for the use of HPS, and, to a lesser extent, the debate concerning the value of such a program (Matthews 1994).

Jenkins (1991), in tracing the arguments for the inclusion of HPS in regular teaching, began with the Duke of Argyle's call in the 19th century, to teach the *processes* of science as well as its products, by means of history of science. In 1917, the British Association for Advancement of Science (BAAS) released a claim to attain an integrity of education by using history of science (BAAS, 1917, p. 140):

> History of science supplies the solvent of that artificial barrier between literary studies and science, which the school timetable sets up.

Ernst Mach, advocating the inclusion of HPS in physics education, suggested a "genetic" approach to teaching, incorporating an explicit exposure to the historical evolution of understanding the particular scientific subject in its presentation to the learner (Matthews 1990). Mach praised history of science as a vehicle, in his opinion unique, to obtain a genuine understanding of modern scientific contents, to appropriately face new problems and prompt further progress in science. Lecturing to school teachers, he said (Mach 1886/1986, p. 347):

> A person who has read and understood the Greek and Roman authors, has felt and experienced, more than one who is restricted to the impression of the present. He sees how men, placed in different circumstances, judge quite differently the same things from what we do today. His own judgments will be rendered thus more independent.

At about the same time, Duhem, a prominent philosopher of science, developed his argument in favor of the same approach to teaching. He claimed an *analogy* between the development of scientific knowledge and the growth of individual understanding of nature. As in the contemporary debate regarding the role of common sense in the learning/teaching of science, Duhem wrote (Duhem 1954, p. 268):

> The legitimate, sure and fruitful method of preparing a student to receive a physical hypothesis is the *historical method*. To retrace the transformations through which the empirical matter accrued while the theoretical form was

> first sketched; to describe the long collaboration by means of which common sense and deductive logic analyzed this matter and modeled that form until one was exactly adapted to the other: that is the best way, surely even *the only way*, to give to those studying physics a correct and clear view of the very complex and living organization of this science. [emphasis added]

Sherratt (1982), reviewing British science curriculum in the first half of the 20th century, mentioned the following benefits of using HPS: (a) demonstration of *humanistic* and *cultural* aspects of science, (b) teaching about the *nature* and *methods* of science and (c) prevention of *over-specialization* by a sterilized, focused solely on the latest products, instruction. In addition, a great benefit, especially for teachers, was specified – intellectual enrichment through awareness of the legitimacy of alternative views and interpretations in science. The latter occurs in today's students as it did in science's historical past.

The eminent pioneer of the inclusion of history of science in education, Conant, advocated for a case study approach, and comprised a two volumes *Harvard Case Histories in Experimental Science* (Conant 1957). Cultural, historical and philosophical contexts of science can reduce, in his view, the barriers of *abstractness* and *hostile formalism* for learning, and provide the general student with a "broader perspective" and the sense of a "lasting value" of scientific information (Conant 1945, p. 155). Conant's materials for university students encouraged a similar approach in teaching secondary school science. Klopfer led the project "History of Science Cases for Schools" (1964–66). Despite certain indications of success, Klopfer himself considered his try to be one which: "rarely persists for very long time, and left little trace on the science education landscape" (Matthews 1994, p. 56).

Harvard Project Physics Course (HPPC), developed under Rutherford, Holton and Watson (1970), is perhaps the best known project heavily loaded with HPS contents. This feature was justified by a need to produce a physics course with a *humanistic* orientation, attracting and motivating a wider range of students to study physics, in the way others study history and literature (Brush 1989). Assessment showed that in response to such instruction, students improved their attitudes to physics (Welch and Walberg 1972). Many of them were surprised to find *historical-philosophical* aspects of physics knowledge, which contrasted their image of physics as being strictly formal ("mathematical") and rigid theoretical construction. Yet, there was no solid evidence of any benefits of such an approach with regard to the subjects' content knowledge (Ahlgren and Walberg 1973).

Schwab's idea of teaching science as it really is, an inquiry of nature, inspired Connelly et al. (1977) in their "Patterns of Inquiry Project", to focus on historical examples of scientific inquiry. The new approach touched on the philosophy of science (scientific method), mastering of which required students' acquisition of critical inquiry skills, "to be able to assess the status of knowledge claims", as an illustration of "legitimate doubts ordinarily attached to scientific knowledge claims" (Connelly et al. 1977, pp. 6, 18). However, in practice, this educational approach, which took a lot from scientific epistemology, being not very compatible with the students' approach, soon found itself only another subject of scholastic training rather than authentic inquiry, as originally intended by Shwab (Duschl 1994).

DeBoer (1991, pp. 229–230) mentioned the role of teaching the *history* of scientific discoveries in providing a realistic view of science and its methods (philosophical aspect). This also includes, the role of intuition, luck and hard work, while conveying the idea that there is no simple formula that guarantees a discovery or success in science. At the same time, DeBoer reflected on teachers' refraining from the inclusion of historical contents, considering it time consuming, taking away the attention of the learner from the "study of scientific knowledge as it is now organized", and the *positive* presentation of theories "what is no longer thought to be true". All these may lead, in his view, the teacher to see the approach as unworthy of implementation.

The revived concern of *scientific literacy* in the 1980s (AAAS 1990) caused a renewed interest in using HPS. The new society, requiring its citizens to function in a technologically saturated environment and to decide both personally and collectively on scientific issues, presumes a certain level of general scientific knowledge regardless of one's professional occupation. This policy addresses the widest audience of students, not only those specializing in sciences. "Project 2061 – Science for All Americans" (ibid.) illustrates the new approach. It sees itself providing a range of para-scientific knowledge, besides pure specific contents. In a philosophical perspective, such a course has to elucidate the nature of scientific method and enterprise. With regard to the history, two objectives were mentioned – to illustrate the accumulative nature of scientific knowledge, and present major scientific achievements as historical events that comprise human culture, "milestones of the development of all thought in Western civilization" (ibid.). The "Science for All" project reflects the values of the educational paradigm Science-Technology-Society (STS), which aim at scientific literacy and demonstrates the unity of science, technology and society (DeBoer 1991, pp. 178–184). A number of scholars asserted the compatibility of HPS materials with the nature of the STS program (Duschl 1990; Matthews 1994; McComas et al. 1998).

Matthews (1994, p. 50) summarized the benefits of the inclusion of history of science in instruction, as they emerged in numerous publications since its first advocates in the 19th century:

- better understanding of scientific concepts and methods;
- connection between development of individual thinking with development of scientific ideas;
- cultural-intellectual validity;
- understanding of nature of science;
- counteracting scientism and dogmatism (common in science education);
- humanizing scientific contents, reduction of formalism;
- presenting integrative and interdependent nature of human achievements.

He also suggested to view the arguments opposing the use of historical contents in science education as a warning of their inadequate use, rather than their total refutation. Regarding philosophical issues related to science education, Matthews reiterated the vision of Mach in the following claims (ibid., p. 98):

- science presents an intellectual construction of economizing thought and experience with regard to the nature;
- science is fallible and does not provide absolute truth;
- science is historically conditioned intellectual activity;
- scientific theory can be understood if its historical development is understood.

Theoretical support for the use of HPS in education came from the latest development of the theory of learning, an implementation of the philosophical constructivism (e.g., Staver 1998; von Glaserfeld 1989). Thus, a simple, but profound, idea which stated that understanding of the world is determined by knowledge already possessed at each stage of development received a sound theoretical elaboration ("theory-laden" nature of reasoning used by scientists (Hanson 1958) and "p-prims" based reasoning of the science learner (diSessa 1993)). It provided an insight into Duhem's culturally incumbent claim regarding certain similarity of ontogenesis and philogenesis in the development of scientific knowledge reminiscent of Ernst Haeckel's nineteenth century "biogenic" doctrine, claiming recapitulation of evolutionary stages in the embrionic development (Moore 1993, pp. 411–418; Raven and Johnson 1999, pp. 1180–1181). The new vision of education made valid, and essential, alternative conceptions ("misconceptions") held by the students, as well as their ideas, beliefs, and epistemological commitments prior and during the formal learning (e.g., Nussbaum 1983, 1998; Nersessian 1989; Thagard 1990, 1992; Galili 1996). Educational importance was asserted to present science as an interplay of competing ideas, instead of the indoctrination of unique and correct theories. It was realized that instruction restricted to the "end of line" knowledge, could be the way to "educate" a computer, but does not work well with regard to humans. The claim of value of Mach and Duhem received theoretical support from modern science education research results.

Although the presented lists of historical and philosophical merits could be supported and even further extended by other proponents (e.g., Herget 1989; Hills 1992), in reality, HPS incorporation in actual instruction of physics remained rare and, as such, deserves discussion.

In light of this background, checking the views on HPS implementation in science instruction, held by practitioners who are involved in such implementation, might reveal possible reasons for the limited success of this approach to education.

3. Data Collection and Processing

The study was carried out as a kind of "case study" aimed at the elicitation of views of experts, creating profiles regarding the utilization of HPS materials in regular instruction of introductory physics. The twelve experts interviewed represented three areas of knowledge relevant to the study: Subject matter – Physics (P); Physics Education (PE), and the History and Philosophy of Science (HPS). The sample was representative of Israel, the country in which the study took place. It included a significant share of the PE and HPS experts, recognized in Israel for their competency in the subject and participation, in one form or another, in attempts to implement HPS materials in physics instruction. Experts in physics education (PE) were represented by five practitioners, active and prolific in the research of physics education, development of leaning materials and experienced in college and high school teaching. The area of History and Philosophy of physics was represented by four active university professors, all of them interested in science education. The P-experts were three university professors of physics, all having extensive experience in research and the teaching of physics, as well as being seriously interested in physics education. All of the participants were professional researchers, faculty members of four leading Israeli academic institutions.

Each of the subjects was invited to express his views on the following issues:

- The rationale to use HPS materials in the regular instruction of science;
- The best ways of doing so;
- Difficulties anticipated in the use of HPS in science instruction.

All interviews were performed by the same interviewer, who was one of the authors. Each subject was interviewed with a semi-structured agenda for about 40–60 minutes. Although the general format of the interviews were kept the same, no restriction was placed on the subjects in expressing themselves in regard to providing further elaboration of one's claims.

The evaluation of the collected data was performed in stages. At first, propositions addressing the discussed issues of our inquiry were independently elicited from the protocols of the interviews, by both researchers creating the initial construction of the conceptual profiles of the experts. At the next stage, each researcher categorized the subjects' data based on his first interpretation of the data. The final spectrum of views was obtained after discussion between the researchers, which included a comparison of their first interpretations, so is to reach an agreement. The number of cases of disagreement of interpretation were extremely few, and only occurred with regard to definitions of sub-categories and the classification of a few propositions. This certain independence aimed at reaching higher reliability of the inferences made. The straightforward nature of the questions in this study, provided the content validity of the collected data.

4. Findings and Interpretations

The analysis of the collected data enabled us to reveal the rationale regarding the use of HPS materials in science instruction from various perspectives, as presented by our subjects. The views were clearly expressed causing no uncertainty of interpretation. The constructed profiles of opinions of the experts participated in the study constitute its major empirical finding.

Table I. Distribution of arguments for using (or rejecting) of HPS based materials in physics teaching

Arguments ⇒ Areas of expertise ⇓	Subjects of the study	Image of science		Fostering of learning			Discovery of science as a profession	Relevance and interest	Necessity for understanding science	Rejection of HPS materials		
Sub-categories		AI	CM	FF	DU	CC				FS	TS	SI
Physics	P-1			♦								♦
	P-2		♦		♦					♦		
	P-3										♦	♦
Physics education	PE-1	Ø										
	PE-2					Ø		Ø				
	PE-3						Ø					
	PE-4	Ø	Ø									
	PE-5					Ø						
History and philosophy of science	HPS-1						+					
	HPS-2	+				+		+				
	HPS-3		+									
	HPS-4								+			

AI – adequate image, CM – cultural merit; FF – fiction form; DU – difficulties of understanding; CC – conceptual change; FS – foreign scenery; TS – time shortage; SI – scientific incorrectness.

4.1. ARGUMENTS WITH REGARD TO THE MAIN GOALS OF USING HPS MATERIALS

These arguments were of several types (Table 1): facilitation of the proper image of science; fostering the learning process; discovery of science as a profession; relevance and interest; necessity for genuine understanding of science; and finally, arguments objecting to the use of HPS materials.

4.1.1. *Image of science*

This argument, mentioned by five of the participants, appeared in two forms. PE-4 refers to the necessity to expose the nature of scientific knowledge in instruction, and support the creation of its more *adequate image* (AI–Table 1) in students. As often observed, many students, especially in physics class, perceive scientific products as totally objective, representing the absolute truth about nature. HPS materials demonstrate the non-dogmatic, tentative and refutable character of scientific knowledge, which suggests understanding nature in the form of models. Those appear in history, one replacing, or being preferred over, another, and varying in the level of their adequacy. Presented together, models manifest science as a reflection of nature, but never its mirror image. PE-1 and HPS-2 emphasized the inadequate and often observed conception of science as a collection of dogma, stored in the Academic temple and lacking any dynamics, an accumulation of truth that gradually emerged with the years. HPS-2 says:

> In its contemporary form, physics teaching is heavily based on the drilling of problem solving which implements few "eternal" laws, creating the image of science as a frozen collection of quantifying statements (formulas) regarding nature. The history of science shows that, in fact, it is not the case. Science presents a permanently and turbulently changing system of concepts and conceptions, a mosaic of theoretical and practical contents, the result of continuously appearing new facts, inventions and theories.

This argument may reminiscent of the claims by Driver et al. (1996).

Another argument (P-2, PE-4, HPS-3) addressed the *cultural merit* (CM–Table 1) of HPS materials which, in a broad sense, combine humanistic and scientific values. Education, in their view, should reveal the real, not sterilized, picture of science, which cannot neglect humanistic aspects of the scientific enterprise. Such exposure can serve as a bridge between science and humanities, more appropriate to the culturally oriented education, and is especially necessary within the introductory courses.

4.1.2. *Fostering the learning process*

P-1 considered the merit of the HPS materials as often having a *fictional form* (FF–Table 1) of stories or anecdotes. Their contents, being far from strictly scientific, include social ecology, human passions, struggles, feelings, thoughts, hesitations, mistakes, and problems. As such, their potential appeal is much higher than those in regular instruction, as the awakened intellectual interest might further trigger interest in the scientific contents.

HPS materials are of special value for teachers in revealing the nature of *difficulties in understanding* (DU–Table 1) particular subjects in science. In the view of P-2:

> Exposure of the difficulties scientists experienced in the past, their hesitations, mistakes they did, and the ways they succeed to change the whole world of their conceptions, can provide an insight into students' understanding of the subject matter and thus contribute to teachers' competence and awareness of students' problems.

PE-2, PE-5 and HPS-2 argued that presenting science as a story of conceptual revolutions can positively affect learning, by encouraging students to perform similar *conceptual changes* (CC–Table 1) within themselves regarding their knowledge about the world. Individuals' personal difficulties in understanding while learning, are often compatible with those occurring in the course of the evolution of scientific views. History reveals that scientific progress cannot be reduced to a linear formal-logical development, but required innovative conceptual changes. One may experience personal solidarity with such changes, as if they are happening in his/her mind. The arguments used by scientists in the past, for or against specific theories, may remain valid and persuasive for the contemporary learner, as they often address cognition in perspectives other than logically correct deductive explanations. HPS-2 said:

> Individual's development of understanding of nature resembles the historical development of science. Historical examples can help students to perform the transition between different scientific paradigms. Thus, Galileo wrote for people who hold Aristotelian views, and in accord brought the best arguments required to persuade such people in replacing particular theoretical views. Since students often hold Aristotelian views, these same arguments can be relevant also in a physics class.

This thesis of parallelism, in accord with the constructivist perception of learning, suggests the anchoring role of historical materials in the construction of individual knowledge.

4.1.3. *Discovery of science as a profession*

PE-3 and HPS-1 brought up the importance of introducing science as a profession, which might provide a motivation quite different from seeking general knowledge and success in school. Exposure to the "kitchen" of science could help students decide whether being a scientist in the future fits their life interests. This can motivate them as interested learners. HPS materials are indispensable in providing authentic information about science as a profession. They, in a sense, enculturate the learner into the community of scientists. The noble nature of science as a human activity, its proclaimed goals of seeking progress and prosperity for all people regardless of race, gender or beliefs, the high passion and devotion of its "warriors" and "heroes" as they confront nature to unravel its "secrets", the inherent democracy of science – all these, despite the complexity of reality, clearly emerge from the history of science. High-school is the last opportunity to provide our youth with the knowledge that could guide them to chose to be a scientist. For example, HPS-1 said:

> In my opinion, the aim of an Advanced Placement physics course in high school is to enable students to decide if they want to be physicists. The school has to introduce the learner to the special activity called physics as it appears, as a process, an establishment of knowledge. Normally, our high schools fail in this. It is less important if the student will obtain more factual knowledge from physics, and it *is* more important if he or she had an opportunity to experience physics in action: asking questions, planning experiments and analyzing suggested answers. History of science illustrates all these in a natural environment, as they really happen.

4.1.4. *Relevance and interest*

HPS materials, in the view of PE-2 and HPS-2, have a high potential for conveying to the learners a broad picture, combining aspects scientific, technological and social in nature. This is often referred to in education as the STS approach to science teaching. These aspects demonstrate to the learner that science is inherently related to the widest spectrum of relevant and interesting issues, aspects which remain isolated from science in its traditional classroom presentation. HPS, however, naturally combines the mentioned three areas, create an integrative picture intriguing the learner, and motivating his learning effort. The social and technological implications of scientific subjects, presented in a historical background, may highly increase the number of learners of sciences who otherwise would never show interest in science. HPS-2 emphasized that:

> STS-HPS combined approach, by being interesting and relevant to many students, can contribute to their deeper understanding of pure scientific contents. Those, being considered in their historical setting, become clear and plausible, especially to those with a lower ability of abstraction.

Importantly, "relevance", as was emphasized by both experts, should not be understood as restricted to an actual every-day experience of the learner himself, but presumes a wide area-of-contents, which commonly attract natural curiosity of both young and adult students. Among such areas are space exploration, warfare, economical competition, ecological threat, etc.

4.1.5. *Necessity for understanding science*

This argument was mentioned by only one of the subjects, an expert in science history and philosophy (HPS-4). He advocated incorporation of HPS materials, claiming that such materials are not only to be considered important in physics instruction, but should be recognized as necessary for stimulating conceptual understanding of any scientific content. This argument, originally employed by Mach and Duhem (see above) with regard to the education of future physicists, attains here a universal validity, as being appropriate for a wide population of learners. A meaningful understanding of any scientific issue, presumes that the individual knows the historical evolution of such understanding, and that contemporary knowledge serves only as the currently final page, incomprehensible without previous pages. HPS cements the whole bulk of physics knowledge, molding it in a single structure. This makes HPS knowledge a requirement of the modern curriculum. As he (HPS-4) put it:

> The currently accepted knowledge of physics is inconceivable in isolation from its whole, like a branch cannot be understood in isolation from the tree. Thus, the concepts of space, motion, or life, cannot be meaningfully taught and learned, except in historical and philosophical discussions guided by appropriately prepared materials. For the same reason, scientific papers

commonly start from a more or less comprehensive survey of the background in the area to be considered in the particular study.

4.1.6. *Rejection HPS in regular instruction*

Arguments for rejecting of HPS materials in regular instruction of a physics course were presented by the physicists of the sample (it did not, however, prevent two of them from also raising arguments in favor of using HPS). Three kinds of arguments were mentioned to support the view to refrain from using HPS. The first one addressed the *foreign scenery* (FS–Table 1) that often appears in HPS materials. As P-2 noted:

> The historical scenery, such as names of scientists, their sex, race, social origin and status, frequent in HPS materials, appears strange and even foreign to the eye and ear of a contemporary student. For instance, a strong religious motivation of many prominent scientists in the past, rather than helping, may impede the contemporary understanding of the subject. Repelling influence may not only impede understanding, but strongly decrease student interest and motivation.

Another reason to refrain from using HPS materials, given by P-3, was the additional time required to cover more material, the regular plus HPS, in the instruction. This time is not available in the contemporary science curriculum, which is usually already overloaded with a variety of contents, and suffers from a *time shortage* (TS–Table 1).

Finally, the argument of vagueness and inaccuracy, often, even *scientific incorrectness* (SI–Table 1) of the knowledge from the past was also mentioned by P-1 and P-3. In their view:

> Much of the old scientific knowledge, though contributing to the course of historical progress, clearly does not match contemporary scientific views. It is primitive, and often simply mistaken. Inclusion of such in the instruction of novice learners, presents a risky game. Although it may attract the expert, it may cause serious confusion for the learner, who cannot discriminate between the scientifically right and obsolete theoretical claims. To distinguish between such, requires scientific maturity not available to the novice.

4.2. VIEWS ON THE WAYS TO IMPLEMENT HPS MATERIALS

We classified these views in the following categories (Table 2):
- Reproduction of historical experiments;
- Acquaintance with original texts;
- Infusion of stories and anecdotes;
- Systematic integration of HPS contents in the course;
- "Dates and Names" approach.

Table II. Distribution of the suggested ways to implement HPS based learning materials in physics instruction

Modes of implementation ⇒ Subjects' areas of expertise ⇓	Subjects of the study	Reproduction of historical experiments	Original historical texts	Infused stories	Systematic integration	"Dates and Names"
Physics	P-1	♦				
	P-2			♦		
	P-3					♦
Physics education	PE-1			Ø		
	PE-2			Ø		
	PE-3				Ø	
	PE-4	Ø				
	PE-5			Ø	Ø	
History and Philosophy of science	HPS-1	+				
	HPS-2		+			
	HPS-3			+		
	HPS-4					

4.2.1. *Reproduction of historical experiments*

P-1, PE-4, and HPS-1 suggested to reproduce or schematically describe important experiments in the course of instruction. One of the subjects (P-1) stated:

> The historical experiment should be presented, not as an interesting event, but as a scientific solution given in the past to a real problem which students should appreciate and consider reasonable. The science laboratory, basically, should not be used to confirm already known laws, but to test hypothesis and facilitate explanations of problems under consideration. An experiment may either support the explanation or reveal its falseness. Historical experiments can be used to illustrate such an approach.

4.2.2. *Acquaintance with original texts*

Another way to utilize HPS materials is to expose students to the authentic scientific texts, original publications presenting results of scientific research. Those can be presented as amendments to the regular teaching materials. HPS-2 said:

> Original scientific texts will represent authentic research in real science, and demonstrate conceptual changes as described in these texts. To attain such effect, instructors should carefully chose documents which can illustrate the

> relevant changes in the considered scientific conceptions, and which can be appreciated by students.

4.2.3. *Infusion of stories and anecdotes*

P-2, PE-1, PE-2, PE-5 and HPS-3 argued for infusion of HPS materials in the form of interesting stories or anecdotes possessing instructive value. In this view, which was the most popular in our sample, a story with a relevant content directly addressing the idea of a specific instruction, is especially useful. Such an approach does not presume systematic integration, but an occasional use, when the chosen piece exactly fits the idea promoted by the teacher.

4.2.4. *Systematic integration of HPS contents in the course*

A systematic incorporation of the HPS materials as an integrative part of the instruction and the use of learning materials which support it, are perceived as comprising the body of the course (PE-3 and PE-5). Such integration obviously presumes extensive preliminary work, invested in serious study of historical materials by the designers constructing the new kind of learning materials:

> The incorporated HPS materials should be relevant, and match the goals of the instruction at each of its stages. They should be integrated in a way that appears natural to the student, reducing to the minimum the impression of an artificial addition. Only then, may we expect the required beneficial outcomes of using HPS.

An extreme version of this approach to teaching subject matter in its historical continuum, was given by only one of the two mentioned subjects, experienced in teaching astronomy.

4.2.5. *"Dates and Names" approach*

P-3 expressed an approach, quite common in many textbooks. It implies the use of references to inventors and discoverers as a recognition of a cultural debt, a "tax" of politeness, to those discoverers of laws and inventors of technical contrivances who significantly contributed to the scientific progress. This policy is seen as a form of cultural tribute and literacy. It is strictly focused on the contributions which appeared "positive" in the course of scientific progress. Thus for instance, no significance is given to philosophical views held by the same scientists of the past. Those were perceived as foreign in science classes.

Table III. Distribution of difficulties anticipated in the implementation of HPS based learning materials in physics instruction

Difficulties ⇒ Area of expertise ⇓	Subjects of the study	HPS content knowledge of teachers	Teaching style and methods of assessment	New learning materials	Relevance of the HPS materials	Institutional difficulties
Physics	P-1			♦	♦	
	P-2	♦		♦		
	P-3					
Physics education	PE-1	Ø			Ø	
	PE-2		Ø	Ø	Ø	
	PE-3	Ø	Ø		Ø	
	PE-4	Ø	Ø			
	PE-5	Ø				
History and philosophy of science	HPS-1	+				
	HPS-2	+				+
	HPS-3	+		+		+
	HPS-4	+				

4.3. DIFFICULTIES ANTICIPATED IN ATTEMPTING THE INCORPORATION OF HPS MATERIALS

In the view of many, the implementation of HPS implies essential qualitative changes in teaching. As such, various difficulties may be expected and seemingly are unavoidable, and our subjects anticipated the following (Table 3):

- New content knowledge of teachers in the area of HPS;
- Change of teaching style and methods of assessment;
- A need for new learning materials;
- A need to keep HPS contents relevant to the students;
- Mismatch with institutional traditions and standards of teaching sciences.

4.3.1. *New content knowledge of teachers in the area of HPS*

Most of our sample, and especially experts in science history and philosophy, emphasized the fact that the regular training programs of pre-service physics teachers seldom, to say the least, provide a required knowledge in history and philosophy of science (Table 3). Although such a deficiency can be in principle fixed by self and in-service education, teachers need to be encouraged and supported in their efforts, especially in their first steps. In a realistic perspective, the requirement new knowledge, albeit beneficial and enjoyable, will present a barrier for introducing a new curriculum. Quoting HPS-3:

> Within the new approach, teachers may find their knowledge and expertise, accumulated over many years of learning and practice, insufficient again . . . Many were never formally instructed in HPS. This is especially true with regard to the philosophy of science. In such cases, teachers need to learn on their own, and then to apply it as novices in their classes. This is not at all simple.

One of our science educators (PE-5) asserted:

> The main problem is teachers' training. The teacher should have knowledge in HPS, and he/she must recognize the importance of its use in class. There are no problems with students: the historical subjects are adequate regardless of the students' age or level.

4.3.2. *Teaching style and methods of assessment*

The introduction of HPS materials in regular physics instruction implies another challenge to the teacher, beyond extending knowledge content. HPS contents inevitably invite a change in the previously adopted teaching style, new sort of assignments as well as assessment. The nature of the new contents is usually more qualitative and phenomenological; a simple "right-wrong" formal logic is seldom applicable to evaluate the meaning of facts and events. This might be quite at odds with the views and expectations of both students and teachers in a science class, especially when an "instrumentalist" view of science knowledge reigns. Thus, it can be a very new the idea stemming from the history of science, that new theories are not always due to new experimental data (Kuhn 1970). In accord, a need for a new, valid and reliable instrument of assessment which would be sensitive to more than a pure scientific dimension, is obvious. It was not surprising that experts in science education were sensitive to this issue (PE-2, PE-3, PE-4). PE-3 said, for example:

> Science teachers will need to change their teaching style, as well as the methods of assessment they usually employ and are comfortable with. As I see it, the new ways of evaluation of students' knowledge will be reminiscent of those in use in humanistic disciplines.

4.3.3. *New learning materials*

It is a widely adopted constraint that curriculum should not venture far beyond the available instructional materials. New contents obviously imply new materials. As stressed by P-1, P-2, PE-2, HPS-3, the creation of appropriate teaching materials, is a precondition for any progress, even for positively motivated teachers. The problem of creating adequate learning materials incorporating HPS materials, is for years on the agenda in English speaking countries, e.g. Harvard Project Physics. In Israel, there are presently no textbooks supporting such an approach to teaching science. There is the unique collection comprised by Sambursky (1960), somewhat similar to Cohen and Drabkin (1948) and Clagett (1959). However, all of them are out of print, as well as not sufficient to match the rising expectations of physics educators, being comprised of historical materials not necessarily addressing issues in the school physics curriculum. Moreover, the originals in the history of science, as they are, are usually not appropriate for direct use in a regular class. Besides the odd conceptual world, the original historical and philosophical texts, being committed to a different cultural code, were written in a different style, employed archaic language, all of them make it difficult to understand today by an unprepared reader. Our subjects (PE-2) voiced the concern:

> There are no adequate historical materials which would fit the school audience. Preparation of such learning materials would surely demand great efforts, for they must equally match the demands of the discipline, and be clear enough for our students. Books written by historians, or original texts of scientists, are equally not sufficiently good for school instruction. As they are available now, they can only be used as supplementary to other, specially prepared materials.

4.3.4. *Relevance of the HPS contents*

Our subjects (P-1, PE-1, PE-2, PE-3) also expressed a specific concern with regard to the HPS contents to be used in regular instruction with respect to their relevance to the learners. It is the relevance of HPS learning materials that may encourage students to overcome the possible strangeness of historical materials for the contemporary learner, as mentioned above, and prompt their successful use in learning, bridging over sometimes significant cultural, scientific, social and technological gaps between the scenery and heroes of HPS texts, and the reality of our students. The call for relevance is not new in education. However, with regard to the HPS materials, it obtains a special meaning. Their relevance does *not* necessarily mean correspondence to everyday experiences or the possible application of the new knowledge, but answering questions which intrigue our students, *regardless* of their "practical" value. In turn, students' motivation can stem either from natural curiosity or from that initiated by the questions arising in the course of instruction. The following quote (PE-3) expresses the anticipated consequence of a lack of relevance, as perceived by teachers and students:

> HPS contents are not perceived as mandatory in a science course. Students, as well as teachers, might not see their relevance or importance with respect to the traditional contents of the course, rather a sort of "decorative", supplementary part. In practice, this attitude might lead to a gradual omitting of the HPS topics, even if they are truly related to the considered subject.

This implies, in the view of our subject, that teachers should demonstrate and make explicit the relationship between the HPS materials and the scientific agenda of the course, providing the students with the perception of conceptual relevance.

4.3.5. *Institutional difficulties and old standards*

Two kinds of social, or, as put by HPS-2 and HPS-3, "institutional" difficulties were mentioned. Teachers who are going to apply the approach of involving HPS contents in physics instruction, may find them to be serious obstacles. This view (e.g., HPS-3) ascribes an important role to the ecology of the teacher in the community of educators in his or her institution (school or college):

> Adequate atmosphere in the teachers-room is another necessary condition for success. HPS teaching in physics classes apparently expands on the areas identified as nonscientific, and blunts the differences between sciences and humanities. This may cause "collisions" of contradictory perceptions with their colleagues, educators of different disciplines. One should worry that such interaction, not lead to competition, that it will be constructive and encouraging, rather than destructive and impeding. If the atmosphere in the teachers-room is separatist, and teachers are interested solely in their own narrow discipline, HPS instruction in physics class might fail.

No less important, is the role of the administration in the institution (e.g., HPS-2):

> As long as the navigators and supervisors of school education encourage customary instruction of isolated disciplines, it will be very difficult to introduce any interdisciplinary activity in science courses. Such an initiative will be considered a deviation from the traditional curriculum, and be rejected before it starts. Such a rigid educational policy might impede any innovation which suggests the merging of areas of human activity.

5. Summary

This study investigated the views employed by three groups of professionals directly related to physics education. Following the revealed spectrum of views several inferences may be made with regard to how experts perceive using HPS as an approach in the regular instruction of physics.

The prominent feature of the data was that despite certain positive attitudes (when HPS contents were considered as a factor which can foster the process of learning and understanding scientific contents of the instruction), all P-experts proposed arguments to refrain from using HPS in their teaching, stating the foreign scenery of such contents, time shortage of instruction and scientific incorrectness of many historical ideas which were subsequently refuted in science.

One may more adequately interpret this viewpoint against the background of teaching science in Israeli high schools. To describe the current situation in simple terms, one finds sciences an elected part of the high school program, selected to be a matriculate discipline by only half of the student population (in contrast with seven non-science disciplines, mandatory for all students.) Physics, is chosen by less than 10% of the students. Furthermore, the majority of those who registered in one science class (i.e., physics) do not study any other (i.e. chemistry or biology). This causes a profound negative discrepancy of science classes in the school schedule. In this situation, the idea of introducing HPS contents (despite the subject-matter knowledge interwoven in it) is perceived by many physics teachers as a dilution of the subject-matter by humanistic contents, and thus, causing further disbalance between the sciences and humanities.

At the university level, the situation changes but the result, with regard to HPS, remains the same. The concept of higher education in physics is solely perceived as mastering physics as a profession. This orientation, as was expressed by our P-experts, prescribes a heavy accent on factual and instrumental subject-matter knowledge. Since the amount currently required to reach professional competency is so large, HPS contents are often perceived as excessive, a mere cultural debt or decoration, which may make the course "interesting", but at the expense of fully covering the curriculum. As such, they are dropped from the inflationary growing list of important subject-matter items.

One could add that university physics training programs do not require courses from the HPS, leaving it to be a subject of self- education. This situation contributes to a confrontation in the modern society between the two cultures, technocratic (rational) and humanistic (values oriented), explicitly observed in our educational system.

Given this background, one should consider if the recent growth of knowledge regarding our understanding of the learning process, should not create change in the above described situation. The following may illustrate a need for possible changes.

1. Are students' views about the nature of science an important issue? Recent studies indicated that besides the general importance of an adequate image of science required by citizens of a scientifically literate society (e.g., McComas et al. 1998), it has been shown that these views held by learners can serve as major determinants of what they learn in physics courses and how well they learned it (e.g., Halloun and Hesteness 1998). HPS naturally incorporates basic knowledge regarding the nature of science, allowing for its internalization without its explicit inclusion into the formal curriculum.

2. Individual constructs knowledge in a complex process. It is common understanding now that in this process new ideas interact with those previously held and are reconsidered and evaluated using available cognitive tools. The process is interpreted as a conceptual change. This perspective was first introduced by historians and philosophers (Kuhn 1970; Lacatos 1970) with regard to science as a

whole. Later, the same approach was applied to conceptualize learning progress in students (Posner et al. 1982).

While the old conception granted HPS contents a power of demonstrating science as an inquiry process, the elucidation of its nature and integration with various social issues, the modern rationale does not reject these claims, but states that the list of pro-arguments can be extended to the cognitive aspects of the influence of the HPS materials. This extension alone reinforces the rationale of HPS infusion in regular science instruction.

It was found that while learning, an individual may reproduce considerations which lead scientists in the past to think about changes in the theories by which they had explained reality. Reviving such historical contents while encountering a particular subject, may cause a cognitive solidarity within the learner. In such cases, the exposed scientific development may be especially appealing to the learner, as if being in "resonance" with his or her thinking. Under such circumstances, one may expect a high effectiveness of instruction, inducing a conceptual change in the learner.

This conception implies a need for a two fold approach. Firstly, one should determine students' naive and alternative knowledge in the area of instruction, for example, students' knowledge of light and vision (Bendall et al 1993; Galili and Hazan 2000a). Secondly, one must locate valid materials in the history of science, which may serve as a remedy for the particular misconceptions, for example, the erroneous theory of image transfer by Alhazen (Lindberg 1976). Then, the obtained information needs to be synthesized so as to design and produce a new practical instructional unit (Galili and Hazan 2000b).

Another example waiting for the necessary synthesis would be (step one) the students' intuitive conceptions about force-motion relationship (Viennot 1979; McCloskey 1983) and (step two) elaboration of the historical theory of impetus (Clagett 1959, pp. 505–525; Dugas 1988, pp. 47–50). At present, no textbook provides such a synthesis for instruction.

Both mentioned examples represent comparatively recent developments in science education research, and could if had been known to our P-experts, cause them to make a different evaluation of the role of HPS in teaching. Moreover, our study showed that the awareness of such a two-fold approach was rare, even among our PE-experts.

The fact that the argument for the necessity of HPS knowledge was mentioned by only a single subject (HPS-expert) is indicative. It was the historically first argument, already elaborated by Aristotle, who stated that we had to know how any subject had been previously understood to meaningfully render its present conception. Mach revived this claim by addressing such an approach (sometimes called "genetic") and applied it constructing science textbooks (Mach 1893, 1913). In the past, this claim was accepted by many culturally oriented scientists and philosophers. Presently, however, the neglect of history in instruction is shared by many scientists. The newly comprehended justification of HPS use as a factor fostering conceptual change in the learner, may restore the lost respect of this educational paradigm.

Following much research effort, a significant amount of knowledge has been accumulated regarding the application of HPS. This knowledge also includes the how and what to do in HPS based instruction – the correspondent pedagogical content knowledge (Shulman 1986). Yet seemingly, it has not reached a very large audience, both designers and consumers, in comparison with traditional educational methods. Thus, very probably, the limited success of the attempts made in the past to implement HPS in teaching was due to the inappropriate format of such implementation. The few available English resources (e.g., Conant 1957; Connelly et al. 1977; Holton and Brush 1985), as well as being out of print, do not provide a sufficient list of topics, and are obsolete in style, form and some interpretations. The project recently adopted by the Israeli National Center for Education to develop a high school textbook in optics totally based on HPS materials and addressing the widest student population, brings hope for improvement, at least on the local scale. The responsibility of designers are high – inappropriate format or contents of the textbook may nullify even the best curriculum and the best intentions.

It is indicative that episodic infusion of stories and anecdotes in regular instruction, together with historical experiments, were the forms mainly mentioned by our subjects as appropriate for HPS implementation. These intuitively plausible ways, though known for years, have disappeared from the most currently available physics textbooks (according to two our P-experts). Attempts to develop a complete physics curriculum based on a systematic incorporation of historical materials are rare (Kipnis 1993; Galili and Hazan 2000b). Besides different contents, a history based course may have a different form of organization, emphasis of presentation, types of the end-of-chapter questions and problems, and of course, assessment. Such a change in the nature of the learning materials may manifest a change toward addressing a wider student audience with broader cultural interests. We anticipate that the appearance of new quality materials of this type, and their successful use in actual instruction, may cause a shift in the views of physics educators when they are informed about their success.

As a concluding remark, we mention the need for applying in-service teacher training (e.g., Eylon and Bagno 1997) specialized on pedagogical content knowledge with regard to the HPS. There is a necessity to disseminate the new knowledge about the role of the HPS in education among all science educators, as the older views regarding HPS, even when supportive, may not be sufficiently convincing. Seemingly, the major impact should come from the experts in science education, who are knowledgeable in the results of research in the area of HPS-implementation, as well as about recent studies of learners' knowledge of science (structure and contents of students' knowledge, pre- and misconceptions, constructivist perception of conceptual change). The contribution of experts in subject matter and those in the area of the history and philosophy of science, might and should be complementary. Failure of this might preserve the paradox between the sound benefits raised for HPS implementation and the few practical successes occurring in such activity.

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