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Promotion of Cultural Content Knowledge Through the Use of the History and Philosophy of Science

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Abstract Historical excurse was suggested as a beneficial form of using the history and philosophy of science in the modules of learning materials developed within the History and Philosophy in Science Teaching project. The paper briefly describes the theoretical framework of the produced modules, addressing ontological and epistemological aspects of historical changes in physics knowledge with regard to several particular concepts relevant to school course of physics. It is argued that such excurses create Cultural Content Knowledge which improves the Pedagogical Content Knowledge in teachers and are appropriate to facilitate the meaningful learning by students. The modules illustrate the new aspect of the scientific knowledge not sufficiently addressed in the current science educational discourse—the constructive diachronic discourse that took place in the history. Historical excurse makes explicit the paradigmatic conceptual changes in physics knowledge and thus creates the *space of learning* in which the "correct" knowledge (type I) emerges in a discourse with the alternates (type II knowledge). Some of the previous conceptions show certain similarity to students' misconceptions which further motivates essential use of both types of scientific knowledge to support the meaningful learning of physics curriculum. The epistemological aspects of the developed materials illuminate the nature of scientific knowledge and its major features: objectiveness and cumulative nature. Teachers found the developed modules interesting, important but challenging their background and requiring special preparation.

1 Introduction

Using the history and philosophy of science (HPS) in science teaching has a long record and many researchers argued for its benefits to students and teachers of science (e.g., Brush 1969; Duschl 1990; Matthews 1994; Kipnis 1996). Importantly, the argumentation for using the HPS evolves with time, reflecting the cultural changes and research discourse taking place (Matthews 2000; Galili 2008). However, despite the intensive support for

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using the HPS in science teaching and articulation of its advantages (e.g., Matthews 1994, p. 38), the issue continues to be complex and controversial (Galili and Hazan 2001a), as it emerges from research reports (e.g., Monk and Osborne 1997):

> … even materials produced for teachers, for example, those produced in the UK … are not used. Attempts to produce restructured courses that put history at the center of the enterprise … have enjoyed only marginal success, as have those that have sought to introduce a more rigorous and current view of the philosophy of science … (emphasis added)

Physics teachers and physics researchers who lecture physics often refuse to significantly include the HPS materials beyond references, sporadic points and anecdotes, which are interesting, may remove the tension of formal instruction but are not essentially helpful to comprehend the complex subject matter. Serious opponents of using history state: indeed, why should we confuse students with obsolete views, surpassed problems, and premature epistemology of science?

Professional historians, in their turn, also criticize the historical presentations and materials for teaching produced by science educators, pointing to their voluntary selection, Whiggish and "bad" history. Indeed, the historical materials vary in a huge span of contents and aspects, all important for the history of science in variety of perspectives. Historical discourse is intensive and rich. Naturally, history consumers could be easily criticized for incompleteness and being not sufficiently informed of historical background and current research.

Concerning the philosophy of science, there is a widespread myth among teachers that science teaching can be neutral, "free of any philosophy" (Tseitlin and Galili 2006). The philosophers of science, in their turn, express their dissatisfaction with the philosophically superficial—and sometimes simply wrong—ideas on the nature of science, suspecting educators in insufficient competence in philosophy (Alters 1997; Matthews 2009).

However, even substantial and relevant critique cannot nullify argumentation of the vast potential of the HPS for science education, despite the numerous difficulties of actual application (Gauld 1991; Monk and Osborne 1997; Grimellini-Tomasini & Levrini 2004; Galili 2008; Höttecke 2009; Höttecke et al. 2010). Researchers point to the complexity of the subject which when ignored may cause troubles (Höttecke and Silva 2010). Intensive research, theoretical and empirical, is required to investigate what and how to employ regarding the HPS in science teaching, the conditions for their effective use.

The aim of this article is to illustrate several aspects of understanding this subject within a new perspective, named *cultural*. Within the HIPST (History and Philosophy of Science in Teaching) European project,[1] we tried not only to produce new teaching materials, but also elaborate on their relevance and even necessity in attaining better understanding of the subject matter, the scientific method (epistemology), and the beneficial impact of such materials for remedy of students' misconceptions in both realms. The modules provided concrete pedagogical suggestions. In doing this, we intended to match the features of the contemporary culture (its plurality, dialectic and dialogic nature) while presenting science as a human activity of construction of *tentative* but *objective* knowledge, the rational account of Nature.

It appears that a special framework of scientific theories, termed *discipline-culture* (Tseitlin and Galili 2005), legitimizes the use of the HPS based materials in education.

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[1] HIPST project comprised the effort of ten groups from seven European countries and Israel. They tried to promote using the HPS based materials in science education. The project was mainly concerned with the development and implementation of historical case studies for teaching and learning science. The official Internet cite of the project is at: http://hipstwiki.wetpaint.com.

The *essential* role of philosophy and history of science obtains semantic explicitness and thus contributes to the meaningful understanding of fundamental statements of physical theories (physics ontology) and of the scientific method (physics epistemology). Importantly, the developed materials address ontology and epistemology with regard to physical knowledge of the curriculum. This specific setting of application ontology and epistemology caused Schwab (1978) to introduce special terms—substantive and syntactic knowledge in correspondence.

Dealing with physics knowledge from the past one may distinguish between two types of the scientific contents, correct and incorrect, in view of the contemporary curriculum, and consider their importance for science learning.[2] We argue for the essential role of the incorrect conceptions from the history in the process of knowledge construction by students and the advantages of such use in a special form of presentation—historical *excurse*. In our choice of contents of physics curriculum to be addressed, we followed the strategy of addressing "critical details" of physics knowledge (Viennot 2004). The paper will briefly illustrate the produced materials and the specific rationale of each of the developed modules. Finally, we will briefly describe the feedback of practicing teachers of physics to whom we presented the modules in a series of meetings.

2 Theoretical Background

Those school teachers and university lecturers who resist to adoption of historical materials often explain that such materials address obsolete and simply incorrect contents in light of the curriculum that they have to keep with. Indeed, the scientific knowledge from the past often includes obsolete conceptions, views, values, language and terminology foreign to the modern learner (e.g., heavy religious load). Therefore, in science education, unlike humanities, we do not use the original treatises but their modern descriptions further selected and adopted to be presented in textbooks. For instance, in teaching and learning the fundamental laws of motion, required in physics class, nobody uses the original—Newton's *Principia* (1687/1999)—but the contemporary presentation of these laws, modified for the particular audience. Such are physics textbooks by Resnick and Halliday (1988)—for university students, Hewitt (2002)—for high schools, Reif (1995)—for teacher training, etc. All of them present essentially the same contents although very different from the original and to each other. If, however, a novice learner decides to read the *Principia*, he/she immediately faces essential difficulties. The concepts in use may confuse also an expert. For example, one may find that the First Law of Motion—the law of inertia—was not a special case of the Second Law as usually stated in physics textbooks today (Galili and Tseitlin 2003).

If so, why do we need to use the historical materials beyond mere curiosity and intellectual interest? It is a challenge indeed to answer this question. Although many practitioners ignore history of physics, many researchers advocate another view (e.g., Duschl 1990; Kipnis 1996; Seroglou and Koumaras 2001;[3] Galili and Hazan 2000b, 2001b; Grimellini-Tomasini and Levrini 2004; Galili and Hazan 2004; Mikelskis 2009). They claim that the HPS materials are more than historical documents and try to demonstrate their *relevance* for the modern teaching of science.

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[2] This, unlike the common perspective of historians, who use the terms right/wrong relatively to the time period considered.

[3] Review of the developments in using the History of Physics in Physics Education.

One perspective was seemingly simple to agree with: the HPS materials inform the learner about the features and nature of science as a human activity in which scientists seek the objective truth about the nature—the laws that govern its organization and explain natural phenomena. Conant (1957) collected the stories about bright individuals in science, who by their activities and discoveries facilitated the progress of our civilization. The materials were left to the student and teacher to be interpreted and related to the curriculum. This open nature of this and many other presentations of the history of science allowed the opponents to argue that the historical materials are more appropriate for extracurricular enrichment, not for regular teaching. Numerous historical materials were produced since then; yet, a great distance remained to the agreement of the need to include such materials into the regular teaching of science. Educators usually saw the HPS contents as being more appropriate for those who are interested and therefore being merely optional. Quite in accordance with the often prevailing pragmatic approach, the questions of "why this knowledge and not another?" and "was there another account for the same phenomena", which could provide the pleasure of understanding Nature, were seen as inferior to mastering the scientific formalism and training standard problem solving—"this is physics", they say. Indeed it is, we answer, but it is not the whole physics, as we all know.

In this regard, teachers point to missing by students the big picture in their learning physics which causes poor conceptual knowledge and inability to face and solve non-standard qualitative and quantitative problems requiring more than a known algorithm (e.g. Galili and Bar 1992; Galili and Hazan 2000a; Mahajan and MacKay 2000).[4] The HPS based materials enable learning of just this aspect of scientific knowledge—getting its big picture, familiarizing with the veracity and flexibility of the scientific method, its many faceted potential in the account of nature, revealing its laws and using the power of this knowledge for numerous purposes.

The constructivist paradigm of science education considers *conceptual change,* that is, construction instead of passive adoption of knowledge, to be the way of learning science (e.g., Duit and Treadust 1998). The goal of teachers became to encourage such a process to take place. Posner et al. (1982) elaborated the conditions for conceptual change in learning science: dissatisfaction with the knowledge currently held, combined with plausibility, intelligibility and fruitfulness of the scientific knowledge presented. To facilitate the transition, much research effort was and continues to be invested in revealing students' conceptions prior, during and after formal instruction. While reporting about the findings of this activity, researchers often mentioned the resemblance they found between students' naïve and novice conceptions, on the one hand, and those held by scientists in the past, on the other (e.g., Piaget 1968; McCloskey 1983a, b; Halloun and Hestenes 1985; Galili and Hazan 2000b).

These reports revived the already old thesis of similarity (recapitulation) between philo- and onto-genesis of knowledge (Piaget and Garcia 1989). At least, one may see that the *disequilibrium* taking place when an individual fails to answer questions and manipulate reality, which Piaget considered to be the driving mechanism of the *individual* development, could be compared to the tension growth leading to the scientific revolutions when the *collective* knowledge accumulates discrepancies causing crisis and eventually a "breakdown of the normal technical puzzle-solving activity" (Kuhn 1970, p. 69). The similarity does not presume identity, of course.

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[4] For the recent conversation on poor understanding of physics by students for their lacking of a "big picture" (June 2010) see in PHYSLRN forum (PHYSLRNR@LISTSERV.BOISESTATE.EDU) the discussion "Discrete Skills vs. Big Picture".

Two these perspectives—educational constructivism and genetic epistemology relate between individuals to the history of science (Tsou 2006) and create the important perspective of relevancy of the HPS based learning materials. Such perspective essentially draws on the similarity of conceptual difficulties. This pragmatic view suggests considering specific historical ideas relevant to the contents presented in a regular science class. It is within this perspective that Monk and Osborne (1997) elaborated how those ideas may promote the required conceptual progression through a sort of *cognitive resonance* in the learners of science.

Duit et al. (2005) within the program of *educational reconstruction* stated the need to reveal relevant historical background for providing scientific clarification of the concept to be taught. Other authors suggested that acquaintance with historical examples could promote understanding the nature of science by making it concrete and meaningful (e.g., Kipnis 1998; McComas 1998, 2008; Matthews 2000).

Less numerous are reports of actual application of the HPS based learning materials (e.g., Kipnis 1992). Galili and Hazan performed a year long experiment of teaching optics course to 10th grade students using their textbook (2004) in which the subject matter of optics was interwoven with the pertinent history of science from the first accounts by Greek philosophers to the contemporary physics. Students demonstrated a significantly better knowledge both in the subject matter and views of the nature of science (Galili and Hazan 2000b, 2001b).

2.1 Science as a Culture

To identify our approach in using the HPS materials and the suggested concept of *cultural content knowledge* (CCK) we should address the issue of culture with regard to science. Much has been said regarding science as a culture (e.g., Bevilacqua et al. 2001). Latour (1987), among other social constructivists, distinguished between “Ready Made Science” and “Science in Making” and deliberately described the latter. Similarly, Ziman (2000, p. 24) defined:

> In effect, academic science is a culture. It is a complex way of life that has evolved in a ‘group of people with shared traditions, which are transmitted and reinforced by members of the group’.

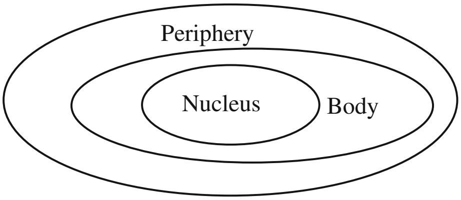
Close, albeit somewhat different view was stated by Aikenhead (1997) who suggested seeing science as a subculture of the Western culture and described:

> Scientists share a well defined system of norms, values, believes, expectations and conventional actions of a group.

This definition is extremely broad and may include behaviorist, spiritual as well as subject matter subjects. In practice, however, the “cultural” educational discourse addressed numerous attributes and features of science as a social activity, “way of life”. This realm is investigated by anthropologists (e.g., Marx 2009), but it is relevant to science education researchers who address such issues as students’ and teachers’ worldviews, the influence of social milieu, the impact of science on the society and the classroom culture—a well defined list of research questions (Cobern 1993).

Although in our products we mentioned these aspects too but they were not our major target. The focus of our approach was different and laid in the scientific knowledge itself—the subject matter. Our approach was close to description of the historical consolidation of certain scientific theory (Kipnis 2001) as well as displaying conceptual plurality in understanding of basic scientific concepts (Levrini 2002). Within this approach, the

Fig. 1 Discipline-culture structure



scientific contents are under close examination of the disciplinary discourse. It is this plurality[5] and the discursive nature of scientific knowledge that makes science a culture of a special kind (not necessary identified with the Western culture), different from great many other systems of knowledge seeking the truth about the world.

Lotman and Uspensky (1978) within their semiotic approach to culture considered it to be "a mechanism for organizing and preserving information in the consciousness of the community." They identified two types of culture, those arranged around contents or expression, rules or texts, in correspondence. Within this perspective, Tseitlin and Galili (2005) interpreted science (physics) knowledge—the culture of rules—as organized in the form of several fundamental theories. The cultural perspective on the totality of the scientific knowledge allows representation fundamental theories as *discipline-cultures* instead of regular *disciplines* commonly presented in teaching science. Scientific discipline usually focuses on certain theory and ignores alternatives both historical and contemporary. For example, the standard course on classical mechanics ignores its historical predecessors (say, Aristotelian mechanics) as well as successors (say, relativistic or quantum mechanics) and parallel disciplines (say, thermodynamics or electromagnetism). This presents the background of introduction of CCK into the discourse of science education.

2.2 Discipline-Culture Approach

The suggested in the previous study (ibid.) construct—*discipline-culture*—can represent certain physical theory in the form appropriate for providing the learners with the big picture of the discipline in educational context. Discipline-culture displays the *structure* of the disciplinary knowledge to be learned and thus fulfills the fundamental requirement of science education (Bruner 1966).

When the cultural framework is applied to certain theory, the learner is provided with explicit identification of three types of knowledge elements (Fig. 1). The first—*nucleus*—includes the paradigm of the considered theory, its central concepts and principles, ontological (such as the paradigmatic model of the theory) and epistemological (such as the adopted rules of knowledge production and validation). One may see this structure as a clarification making explicit those subject matter *presuppositions* which comprise the basis of any scientific theory. Seemingly, those were mentioned in general terms by Cobern (2000). In the course of regular teaching, they, however, are often skipped or passed without required attention and discussion. Not that they are not respected. Just the opposite is true, but lacking any controversy or tension of possible alternative, they are often swiftly left in favor of the "real stuff" to deal with—the application (the second type of theory elements).

The second type—*body knowledge*—includes constructs which result various applications of the central paradigm: solved problems, working models, explained phenomena,

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[5] In fact, *plurality* and *culture* share the same root in Hebrew, the language of the author.

experiments and instruments. Lakatos (1970) called the solved by certain theory problems "protection belts" with respect to the hard core of the theory (its nucleus, in our terms). Together, these two areas (nucleus and body) represent what is normally considered to be the *disciplinary knowledge*, corresponding to the certain part of a regular curriculum of physics course. Body knowledge often prevails even in school education, let alone the universities departments of physics, practically reducing learning to application of the correct knowledge in the form of solving standard problems by means of accumulated algorithms. This activity (hard and complex by itself) is currently emblematic for science education.

The third type of knowledge elements, often missed in educational context, represents the conceptions that contradict the nucleus, alternative accounts, ideas and concepts, alternative epistemology, either from the past or from the more advanced theories, as well as the problems and phenomena that the considered theory failed to resolve or explain. The elements of the third type comprise *periphery*. These knowledge elements locate the theory in the knowledge medium, display its limits of validity. However, even a question about such knowledge may surprise the teacher or curriculum designer.

All three areas together constitute the *cultural* representation of certain theory in physics.

Educational context and constructivist requirement suggest addressing students' misconceptions of the particular subject matter in the process of instruction. Misconceptions, apparently contradict the nucleus of the theory and hence they could be also placed in the periphery, together with the "logico-structural categories of students' worldview" (Cobern 1993), also in odds with the nucleus. One may still distinguish students' misconceptions from the alternative conceptions, ontological and epistemological, practiced in science (e.g., caloric in thermodynamics).

The reference to *culture* in the identification of this triadic structure is justified by the fact that cultural presentation includes alternative accounts for the same subject, those which argue with the nucleus and placed in the periphery. It is this feature that authentically represents the nature of scientific knowledge as well as matches the modern perspective on culture legitimizing several perspectives on the same subject—a pluralistic picture. The latter feature allows demonstration (visualization) of the dynamics of the scientific knowledge, both evolutionary and revolutionary changes taking place in science. Those manifest themselves in status exchange between certain elements of nucleus and periphery, the growing number of elements in certain area and so on. Within such framework of teaching the student may grasp the meaning of the paradigmatic changes that took place in the scientific knowledge and genuinely understand the contents of curriculum, realize to themselves the area of validity and limits of reliability of certain theory.

For example, culturally represented Classical Mechanics will be explicit in identifying its nucleus: Newtonian paradigmatic model (absolute space and time, void and point masses interacting through central forces), postulated laws, principles and definitions of the fundamental concepts. Besides displaying the body knowledge, such instruction exposes the periphery—the conceptual rivals of the Classical Mechanics: the principles of Aristotelian mechanics, as well as those of the relativistic and quantum mechanics. The teacher will find there the relevant misconceptions of the learners.

It is clear that the history of science serves as major resource of periphery elements. Furthermore, the considered triadic structure displays the relationship between the fundamental theories. Such representation includes separated nuclei and overlaid areas of body knowledge all together immersed in the periphery (Fig. 2). This account visualizes the *principle of correspondence* between physical theories, for example, between Classical

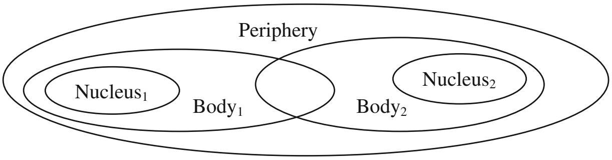

Fig. 2 Discipline-culture structure of two fundamental theories

and Relativistic Mechanics. Their nuclei are, in a sense, contradicting each other—incommensurable; each is located in the periphery of the other.[6] At the same time, the two theories may produce non contradictive results (such as the theory of relativity in the low velocities limit), which is represented by the area shared by the two bodies of knowledge.

Yet, being different, in the characteristic fundamentals, the scientific theories possess *family resemblance*, a powerful concept introduced by Wittgenstein (1953), though not regarding scientific theories. With regard to theories in science, it manifests itself in the shared or similar concepts, methodology, principles, mathematical formalism, etc. (also Irzik and Nola 2010). We thus may have arrived at the "big" picture of physics in cultural perspective—a family of a few fundamental physical theories.

2.3 The Role of the Philosophy of Science

The role of the philosophy for science in science education can be represented by semiotic tools (Tseitlin and Galili 2006). Within this perspective, the philosophy of science provides the conceptual meaning (the *concept* vertex) to the scientific contents—the *object* vertex in the semiotic triangle (Fig. 3). Science curriculum which represents the object (science) occupies the vertex of *sign* in the same triangle. This way, it is shown that the philosophy of science determines the contents of the sign—science curriculum. Indeed, we know that each philosophical paradigm—empiricist, rationalist, positivist or constructivist—originates the correspondent to it curriculum in science teaching, determines its contents and provides specific scientific worldview.

The discipline-culture approach further refines the role of philosophy. Indeed, it is the philosophy of science that determines the elements of nucleus for certain theory, elaborate its ontological and epistemological foundation. Thus, the nucleus of Newtonian theory differs from the nucleus of the theory of electromagnetism by the contents that essentially distinguish between the two theories. For instance, the ontological statements regarding the "interaction at a distance" oppose to the "interaction by contact", the time–space independence oppose to the time–space dependence, etc. These contents of the disciplinary nuclei are philosophical in nature, and they changed in the course of history. It is these characteristics of the nucleus that provide the physical meaning of the theory rather than particular problems solved by it. Once the statements of the nucleus are determined their alternatives are sent to the periphery, but never disappear. Thus, the scientific revolution of the seventeenth century introduced forced interaction at a distance (gravitation), through vacuum and sent the alternative—the interaction at a contact (Descartes)—to the periphery, for a while. Tension between these two ontological claims eventually brought to the radical conceptual change in which the concept of *field* was introduced in the electromagnetism, in the nineteenth century. This development can be represented as an exchange

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[6] This perspective can be related to *incommensurability* of the essentially different physical theories as introduced by Kuhn (1970).

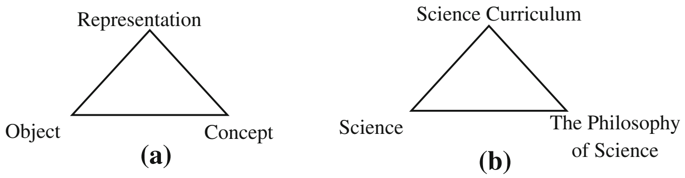

Fig. 3 **a** Generic semiotic triangle; **b** the semiotic relationship of science, the philosophy of science and science curriculum

of elements between the nucleus and periphery. The discourse between the two proceeded; action at a distance did not disappear and remained in the periphery in the form of alternative theories, old and new.

In epistemology, two philosophical framework, rationalism and empiricism, suggested different approaches to concept definitions in physics, nominal and empirical. In different periods each took place in the nucleus or periphery of physics theory. In the twentieth century the empiricism (positivism) placed the operational definitions in the fore, moving them from the periphery, where they were after Hellenistic physics, to the nucleus of the modern theories. This change can be illustrated by the changes of concept definitions of inertial mass (Mach 1893), simultaneity by Einstein (1905), and weight (Reichenbach 1927).

The ontological and epistemological elements of the nucleus represent the core statements (*genus*) of the considered physical theory. Although these contents are often missed in instruction, they are important for establishing the big picture of physics knowledge in the learner. In the modules that we developed, we addressed the relevant epistemological and ontological contents and described their changes in the course of history. This account matches the need of wider representation of the nature of science often limited to one approach (Duschl 1985; Alters 1997; Matthews 2009; Höttecke and Silva 2010).

2.4 Implication to Physics Education: Cultural Content Knowledge

Historical materials are used in education in the variety of forms (Seroglou and Koumaras 2001). The collection of case studies by Conant (1957) described in details the activity of prominent scientists and their major discoveries independent of any particular curriculum or interpretation. In the great scale of the *Harvard Project Physics* (Rutherford et al. 1971) and its predecessor, *Physics* by Taylor (1941), the whole physics course was immersed into historical narrative. This tradition continued in the impressive courses of Rogers (1960) and Glashow (1994), who emphasized historical roots of the fundamental concepts and conceptions. The courses, as mentioned by the authors, addressed the audience of non-physics and even non-science majors. Hecht (1994) elegantly infuses historical details in the narrative of the main text. Some university physics textbooks contain special boxes, which present historical information about the scientists whose names appear in physics laws and units: Newton, Faraday, Maxwell, Ampere, Volta (e.g., Serway and Jewett 2004). The boxes appeared on the margins and were independent in content from the main text.

The European project HIPST, small in scale, looked for the appropriate format of products that could contribute to science teaching in physics classes. *Historical cases* were chosen as a feasible and appropriate form to incorporate history and philosophy of science into teaching (Höttecke et al. 2010). However, the obvious limitations of a *case*—its focus on event, person, experiment, or instrument—posed a serious challenge to those committed

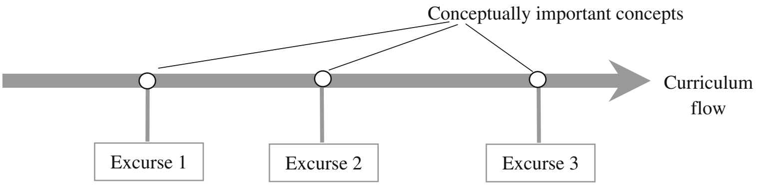

Fig. 4 Schematic presentation of incorporation of historical excurses into the existing curriculum

to the c*ultural* approach. Indeed, dealing with a particular case one may miss its relationship to the whole web of physics knowledge, its discourse—the cultural perspective. The latter suggests addressing conceptual dialogue: debate of scientists. Such dialogue may be *diachronic* and the scholar may differ in their conceptions, worldviews, methods and technology, as well as immersed in different social environments. To reach the cultural perspective, our group suggested *historical excurse* as an appropriate format of the modules to be developed. The excurses had to address conceptual points of the physics curriculum, especially important for understanding, teaching and learning certain subject matter (Fig. 4). This way several constraints of the project could be fulfilled: (1) *compactness*: focus on the *relevant* selected topics and materials; (2) *flexibility*: the modules allow application in different extent and purposes (teacher training course, extracurricular or regular teaching); (3) *conservatism*: the modules do not replace the adopted curriculum but facilitate and strengthen its understanding and meaningful learning.

Our historical excurses included comprehensive accounts of several subjects in content knowledge each expanded along a historical period. Special in its features, this genre may serve as an effective pedagogical tool of conceptual clarification. Excurse may include narrative parts in presenting history of the concept, limited quotations of the originals easy for reading. Furthermore, after presenting the historical narrative, the excurse separately addressed its ontological and epistemological aspects with regard to the considered concept and elaborated its curricular relevance. Questions, mostly qualitative, together with suggested activities enabled discussion and strengthened each excurse pedagogically.

As mentioned above, the criteria for choosing materials were based on the relevancy and content importance as established by researchers of physics education and matching our goal—promoting cultural content knowledge of the subject matter. In realizing this program we observed that the historical contents, usually used in education, elaborate and discuss the knowledge which is considered today as "correct". Such is addressing the history of lever and other simple machines used in various technologies. Similar respect is given to Archimedes' law of buoyancy, Eratosthenes' measurement of Earth radius, history of microscope and telescope, Cavendish's "weighing the Earth"; the discovery of electromagnetism by Oersted, and so on. The heroes of such stories are Archimedes, Eratosthenes, Galileo, Kepler, Copernicus and Newton, but never Aristotle, Ptolemy, Ibn al-Haytham, Descartes, Buridan, Oresme, and Grimaldi. The common in the former group is that they produced the knowledge proven later to be "correct" ("got it right"). Those of the latter group, however, if mentioned at all by educators, are solely criticized. We may label the first type—*Type-I* history, and the second—*Type-II* history.

Type-II history is indeed about the knowledge refuted in the following development of science. However, those scholars had important and sometimes pivotal contributions

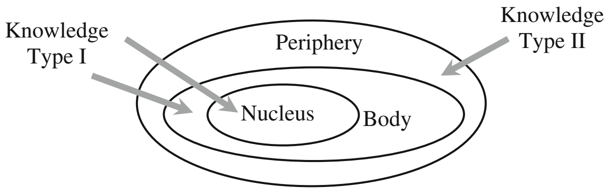

Fig. 5 Two types of historical knowledge and the areas of their affiliation within the discipline-culture structure of physical theory

providing their "shoulders" for the others to stand on.[7] They participated in the conceptual discourse of physics through time. For example, the cultural approach to teaching physics should adopt such items as the ideas of Aristotelian mechanics, Pythagorean theory of vision, impetus theory of the medieval physics, Ibn al-Haytham's theory of vision, and caloric theory of heat. Each of these topics belongs to the periphery of certain contemporary physical theory and challenges contents in the correspondent nucleus and body (Fig. 5). All together, they may establish constructive conceptual dialogue in the course of regular teaching.

It might seem that using Type-I materials is natural and that of Type-II—problematic and confusing. However, in closer view, the Type-I history, although interesting and enriching, seems to be not of unique importance. The historical materials of this type could be, in fact, replaced with equivalent modern addressing the same subject matter. Thus, many physics textbooks present simple machines (lever, screw, edge, pulley) without any history. It is frequent to present lever or buoyancy conditions without reference to Archimedes and the Geometrical Optics—without reference to Kepler. Teacher demonstrates the experiments and refers to the everyday experience. This policy might make the materials less interesting but preserves their validity. In effect, Type-I history is *not essential* in learning disciplinary contents.

The role of Type-II history of science is different and important to figure out. Some science educators decisively deny it for using in class, claiming its misleading and confusing influence on the students whose knowledge is not sufficiently mature to handle the obsolete contents (Galili and Hazan 2001a). Indeed, such ideas, refuted, often with great efforts in science itself, may confuse. Why mount "artificial obstacles", why to revive the old barriers already surpassed in science itself? There are several answers to this concern:

1. Controversy of the scientific knowledge (represented by the "wrong" knowledge) is an essential feature of the scientific activity in which the knowledge is produced. Controversy distinguishes the scientific knowledge from many others. Introduction of the historical debate into teaching converts teaching from transmission of dogma to the making an appreciated and justified choice. Controversy creates an adequate and authentic image of science. Therefore, revealing controversy in science grants maturity to the knowledge of the learner.
2. It is the debate of ideas that makes science attractive to many learners. Certain part of youth is interested in science as a living knowledge engaged in self-correction, comparative analysis, a fair competition of ideas, in which they, the novice, can participate, not only as consumers (e.g., de Hosson and Kaminski 2007). For this type of learners, the periphery knowledge drives their *major* interest in science. By excluding controversy of knowledge and debate of conceptual refutation, we often lose such students, repelled by dogma and algorithmic applications.

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[7] This powerful metaphor represented the framework of scholarship adopted in Chartres (Bernard of Chartres) in the twelfth century (e.g. Hannam 2009).

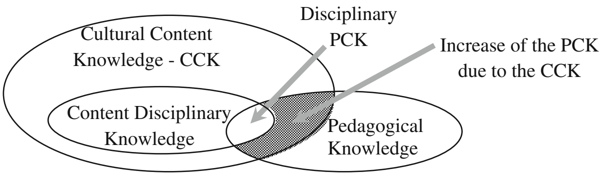

Fig. 6 Symbolic representation of the impact of the CCK on the PCK

3. The similarity between some obsolete conceptions in science and naïve conceptions of students, as reported by numerous studies, may be used in a remedial discussion (utilizing rich, often unique in quality argumentation developed by the bright minds of the past) leading to refutation of the alternative conceptions and ultimately, to the required conceptual change and/or cognitive resonance in the learner. In the following, we will illustrate such materials.
4. Certain elements of obsolete scientific knowledge are especially important. Those often present paradigmatic conceptions of the old theories. Such are, for example, the conceptions of motion by Aristotle (the need for the external mover for the body to maintain its motion) and that of Buridan (the internal mover—impetus—to cause motion of the body that possesses it). These conceptions from the periphery of classical mechanics establish conceptual variation of the central conception of mechanics and create the appropriate and required *space of learning* for the learner (Marton et al. 2004). The process of learning is different from loading computer with information; it presumes cognitive construction and reconstruction through *comparison between the possibilities*. This way people provide knowledge with meaning.

All together these answers claim that addressing periphery facilitates meaningful teaching and is *essential*. Periphery knowledge upgrades content knowledge of the discipline to the CCK, which is valuable for both: science learners (whether or not they intend to become physicists) and science teachers. Although in humanities the pertinent CCK is traditionally encouraged in students and presents a norm, in science education, CCK is often underestimated, neglected and ignored. Thus, it normally escapes teacher training programs and many learning materials. Such knowledge may be observed in old age scholars after their long enculturation via living in science. Our study argues for this knowledge already at the stage of learning science. This change is required by the young generation of students and teachers of science.

One can visualize (Fig. 6) the benefit of the CCK to the Pedagogical Content Knowledge (PCK, Shulman 1986)—the central concept of science education. The latter is usually represented by the overlaying of pedagogical and content disciplinary knowledge. In this representation, the impact of the CCK becomes obvious.

We will now briefly represent the implementation of the presented above considerations in five historical excurses that have been developed within the HIPST project.

3 Developed Materials

3.1 Structure of the Modules

All the developed in the project modules shared the common structure which included the following principal sections:

- Abstract
- Introduction
- Conceptual history of the considered subject
- Historical and philosophical background including nature of science
- Target group, curricular relevance and didactical benefit
- Activities, methods and media for learning
- Obstacles to teaching and learning
- Pedagogical skills
- Additional reading

The average length of five developed by our group modules was 50 pages of text including pictures, drawings and tables. The constituents of the modules reflected the fact that they addressed practicing and prospective teachers of physics, although high school students may benefit too from reading the materials. Historical originals were quoted and questions (usually qualitative) were provided to facilitate discussions. We related to the results of pertinent research in physics education (students' conceptions on the subject) published in international journals. In the following, we will briefly describe the developed modules.

3.2 Module 1. Understanding Classical Mechanics: A Dialogue with Cartesian Theory of Motion

This excurse displayed a particular segment of the history of mechanics closely preceded to Newtonian era of the classical mechanics. We considered Descartes' laws of motion followed by seven rules of collisions between two hard bodies. Descartes suggested these laws in his *Principles of Philosophy* (1644/1983), and they were thoroughly studied by Newton as a young student in Cambridge, who later replaced them with his own three laws, those we learn today at school. This was done by Newton in the famous *Mathematical Principles of Natural Philosophy* (1687/1999) which appeared to be a sort of conceptual debate with the *Principles* of Descartes. In this excurse, we displayed the laws of motion, rules of collisions together with their explanations from the original text of Descartes and analyzed all of them. The qualitative analysis was illustrated by numerical examples.

We demonstrated the failure of the third law of motion (the law of collision) and six (out of seven) rules of elastic collisions which refined that law. The major failures of Descartes were that he considered the quantity of motion to be *scalar value* (instead of vector) and distinguished between the state of *rest* and *motion* as essentially different states of matter. Thus, he ignored Galileo's principle of relativity and the symmetry of interaction between the colliding bodies in the sense of the third Newton's Law (action–reaction equality). The only exception of correctness was his first rule of collision, which possessed so high symmetry (two identical balls with equal velocities in frontal collision) that it preserved the rule correct even if the explanation given was wrong. Descartes knew that most of his claims provided incorrect results, but he did not know why (this was known to Huygens and Newton), and so he attributed the failure to the non-ideal conditions in reality.

The excurse proceeded to the history of refutation of Descartes' rules of collision, first empirically: by Jan Marci, John Wallis and Christopher Wren, and then—theoretically, by Christian Huygens (Dugas 1988; Losee 1993; Taylor 1941; Westfall 1989). We elaborated on the pioneer work of Huygens who, in his famous thought experiment, addressed the account of collision by two observers, one at rest, and the other in motion, applying Galileo's principle of relativity. Drawing on the previous empirical results (the coefficient of restitution), Huygens succeeded to deduce the law of conservation of the quantity mv^2 (labeled vis viva by Leibniz in 1695), later—*kinetic energy*, in the elastic collisions. Huygens' results regarding description of physical reality by different observers, as he introduced in his work, and his method of application of the relativity principle in mechanics, were ahead of his time to be interpreted in their full meaning. Only much later, they were appreciated as masterpieces of the classical mechanics (Mach 1893/1989).

As a rationalist philosopher rather than a modern physicist Descartes kept with his principles no matter what the reality showed to him. This strategy may serve as an example of great educational value. The excurse allowed high school students and physics teachers to follow the arguments of Descartes, who consistently applied rational reasoning keeping with the stated by him principles. It appeared that this feature by itself, although very important in science, is not sufficient to produce valuable knowledge. The need of continuous inductive-deductive cycle including experiment with controlled parameters was revealed. In it, theoretical reasoning and experimentation are interwoven, and this was missed in Descartes' method.

Reflecting the central ideas of Descartes regarding motion and collisions, we distinguished between the ontological and epistemological claims, analyzed them and showed which of their features passed the test of time and which of them—did not, what exactly was wrong and for what reason. The idea was to show that some claims of Descartes were refuted (moved to the periphery), yet there were important accomplishments which contributed and promoted the classical mechanics (its nucleus and body). Table 1 juxtaposes both. This separation encourages students' active comparison between the knowledge claims—our pedagogical strategy in using HPS. This analysis matched high school curriculum at conceptual and formal levels.

Furthermore, through considering the diachronic dialogue regarding collisions the teacher may demonstrate the important feature of the scientific enterprise. In fact, the

Table 1 Elements of knowledge introduced by Descartes and considered in the module

Remained adopted	Later rejected
Ontology	*Ontology*
The law of inertia (Descartes' first and second laws, combined and modified)	The law of interaction (Descartes third law)
Motion and rest are natural states (do not require causal explanation for preservation)	Rest—motion opposition. Rest and motion as absolute concepts. Addressing motion without reference frame (body) (Violation of Galileo's relativity)
Uniform motion is a state not a process (rejection of Aristotelian and impetus based understanding)	Motion as a scalar independent of direction, inability of decomposition
The idea of motion [momentum] conservation (upgraded to be vector quantity)	Holistic description of projectile motion (without decomposition on vertical and horizontal)
The idea of the centrifugal force (tendency, conatus) (Developed by Huygens, reconsidered by Newton)	Non-symmetrical interaction (unequal forces) between bodies; "overcoming" of one body over the other (Violation of Newton's third law)
The first rule of collision: Two identical hard bodies colliding with equal speeds separate with the same speeds after collision (understood as velocity reverse)	Rules of collisions (6 out of 7, except the first)
Epistemology	*Epistemology*
Physical theory as a hierarchical, reductionist system (basic laws and definitions following by their applications)	Neglecting empirical verification of theoretical statements, rejecting control experiment
Validity of mechanism in the conceptual explanation (for applications of fundamentals of the theory)	Neglecting hypothetico-deductive *cycle* in scientific research
	Metaphysical reasoning in physics arguments

Table 2 Ontological development in the nucleus of the theory of motion (summary)

Hellenic science	*Medieval science*	*Classical mechanics*
Natural motion – spontaneous, without agent	Natural motion – due to the gravity producing impetus	Motion (rectilinear and uniform) is a state
Violent motion – due to the force exerted by the external mover	Violent motion – due to the internal mover – impetus ("force of motion")	Motion (rectilinear and uniform) is equivalent to the rest (relativity principle)
		Change of motion is due to the external force
(Aristotle)	(Hipparchus, Philoponus, Buridan, Oresme)	(Galileo, Descartes, Newton)
Rest is a state; motion is a process		

researchers (Wren, Wallis, Huygens and Newton) did not simply start their studies "from the question" (as sometimes stated in presenting scientific method) but rather with learning the subject matter, the results and ideas of others whose work preceded to their own inquiry. In a sense, each new researcher joined the debate in the community discourse of scholars.

All together, the excurse provides students with a chance to familiarize the great debate from the foundation of the classical mechanics and grasp the principles of this great physical theory. Grimellini-Tomasini et al. (1993), who investigated pertinent students' conceptions of collisions, provided education relevancy to the considered materials—the treatment of collisions—by describing students' ideas and their difficulties (also, Sason 2005).

Furthermore, by displaying the historical introduction of the kinetic-energy conservation drawing on the inversion of relative velocities between the elastically colliding bodies the excurse, in fact, suggested a new approach to teaching energy in physics class. This idea also touches on the curricular question whether momentum or energy to teach first.[8] This module may support addressing a very passionate historical discourse on the account for motion in the context of collisions (e.g., Smith 2006). Momentum and kinetic energy both were involved in the same discourse.

3.3 Module 2. The Pre-Newtonian Theory of Motion

This module also addressed the high school students and physics teachers. It deals with the account of motion—the major content of mechanics. Seeking the "big" picture of the subject, the excurse addresses the ontological discourse regarding the nature of motion (Clagett 1959; Crombie 1959; Gliozzi 1965; Koyre 1968; Pedersen and Phil 1974; Grant 1996; Drake 1999).

The text identifies three major steps in the conceptual understanding of motion during which the correspondent contents of the nucleus changed. Table 2 presents them as they were in the theory of Aristotle (Hellenic period), the theory of impetus (Hellenistic and medieval periods), and the classical mechanics (in the seventeenth century). The module illustrated these contents by quoting from the originals by Descartes (1644/1983), Galilei (1638/1914), Newton (1687/1999) and other scholars.

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[8] See, for example, the debate in PHYSLRNR electronic forum—Physics Learning Research List, on May 2011.

Table 3 Epistemological development in the nucleus of the theory of motion (summary)

Hellenic science	*Medieval science*	*Classical mechanics*
Contemplation of nature seeking law like regularities	Logical analysis based on the principles and rules (resolution and composition)	Introduction of controlled variable experiment
Establishing basic principles (experience based)	Theological metaphysics (creator and designer of the world)	Hierarchical reductionist theory for a certain domain of reality
Logical analysis seeking for the causes of natural phenomena	Reasoning by principles, logic and authority	Combining rational and empirical approaches in a research cycle
Hypotetico-deductive cycle	Invention of formal tools for conceptual and mathematical accounts of motion	Nominal and operational concept definitions

In parallel to the ontological claims regarding motion, we addressed the epistemological development in the science of motion from Aristotle to Newton. Table 3 presents these changes in the nucleus of the theory of mechanics. These epistemological aspects facilitated the adequate understanding of the status of the ontological views at the correspondent times. The validity of epistemology often remained in shade when the consumer is focused on applications and remains unfamiliar with the fundamental presuppositions that allowed such application.

By making explicit the changes of both types, the excurse makes possible to illustrate and discuss the nature of the progress in the scientific knowledge, continuous, yet, not a simple accretion. The community of scholars kept a constructive diachronic dialogue, discussing the same subject, introducing new concepts and modifying the old ones, often in the same contexts. This process was illustrated in presenting the contributions of Galileo, Descartes and Newton.

The excurse dismisses the frequent neglect of the mediaeval science (the "Dark Ages") by demonstrating significant accomplishments in the theory of motion which essentially facilitated the achievements of the later scholars.[9] Many of such achievements are relevant to school curriculum: invention of pendulum, method of virtual displacements, kinematic relativity (the precursor of the dynamic relativity of Galileo), the precise characteristics of motion—velocity and acceleration (instant and averaged), classification of motion (uniform and uniformly accelerated types) and its accounts: graphical representation of motion, mean speed theorem, calculation of distances, thought experiment of falling bodies, and others. Many of them are traditionally attributed by physics teachers and textbooks to Galileo who in fact adopted them from the previous scholars such as Buridan, Oresme, Bradwardine, Swineshead, Heytesbury, Benedetti (e.g., Pedersen and Phil 1974; Hannam 2009). These contents, besides contributing to the disciplinary learning, may surprise and cause cultural enrichment. However, the major impact of the applied excurse is expected in the improving of understanding of the basic concepts of the theory of classical mechanics (Tables 2, 3), easily missed in a strictly disciplinary instruction applying these concepts.

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[9] Lacking background in the history of science, science teachers are often ignorant regarding the cultural legacy of the medieval scholars. Pejorative attitude to the medieval science is often behind the claims "Galileo was the first scientist" and "the church impeded science".

The relevancy of the pre-Newtonian views of motion (Type II knowledge of the periphery) for teaching mechanics was demonstrated in numerous researches which revealed high school students' misconceptions similarity to the historical conceptions: force-motion relationship ("motion implies force"), impetus like views, etc. (e.g., Viennot 1979; Whitaker 1983; McCloskey 1983a, b; Halloun and Hestenes 1985; Galili and Bar 1992). Science educators may take an advantage of this similarity of onto- and phylogenies even without stating exact recapitulation. In particular, the excurse displayed the arguments by which the erroneous views of motion were refuted in the later progress. They could be used again, this time to overcome students' erroneous conceptions.

Furthermore, seeking the empirical refutation of impetus the excurse suggested an original activity, which by modern means (electrical or magnetic field that counterbalance the gravitational force at the highest point of an object thrown upwards) can distinguish between the predictions drawn on the impetus theory and those made by using Newtonian views. This activity, either as a real or thought experiment, is especially important since many situations in the regular experience could be reasonably well explained by means of impetus which thus prevails in the naive knowledge.

3.4 Module 3. The Story of Optical Image

This excurse elaborated the genesis of physics knowledge regarding optical image and vision. The subject is usually studied at the beginning of high school. The history of optical image started with the period when several theories tried to account for optical image—classical Greece. Some of the conceptions introduced then coexisted for years, remaining a subject of a continuous conceptual discourse (Conford 1937; Ronchi 1970, 1991; Pedersen and Phil 1974; Lindberg 1976; Russo 1996; Park 1997). The excurse followed the evolution of understanding from the Hellenic theories (Pythagorean active vision, Atomists' eidola, Plato's hybrid understanding, and Aristotle's transmission by means of the medium), to the Hellenistic theory of Euclidean rays of vision, and the medieval ray theory by Ibn al-Haytham (11th c). These theories of Type II history preceded to the theory of Kepler (17th c), currently taught at schools as Geometrical Optics. In parallel, the history of light ray—the central optical concept employed to account for vision and light—was traced. In its course, the status of ray changed from the effective cause of vision, in the Hellenistic and Medieval physics, to a mere descriptive tool, in the Keplerian geometrical and Huygens' wave theories of light.

The important conceptual debate took place between the intromission and extramission theories of vision, during more than 1,500 years, until the extramission theory was refuted by Ibn al-Haytham in the eleventh century. His own theory served, however, as an intermediate stage before Kepler's account within the theory termed—Geometrical optics, for the intensive geometrical procedures used to represent image formation (Table 4; Fig. 7).

Table 4 Ontological changes in the intromission theory of optical image

Holistic **eidolon** (Atomists) or **medium perturbation** (Aristotle) transfers from the object into the eye of the observer	⇨	Points of an object are mapped to the points of the image by single **rays** of light (Ibn al-Haytham)	⇨	Points of an object are mapped to the pints of the image by light **fluxes** (Kepler)

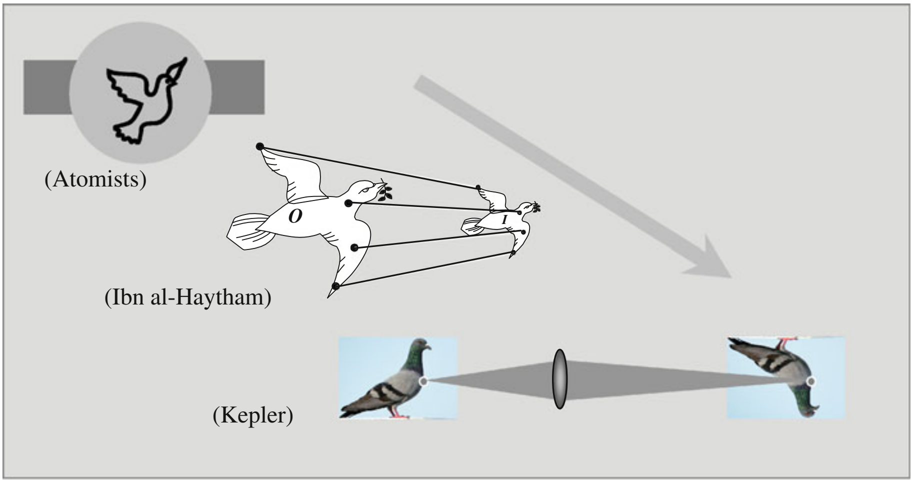

Fig. 7 Transformation of the conception of optical image transfer (corresponds to Table 4). The mechanism of image transfer of Aristotle's—a perturbation of the medium transferring the impression of the object into the eye—was skipped here although it belongs to the intromission conceptions too. It was different from Atomists' conception: moving through space eidolon enters the eye. In the big debate between intro-mission and extra-mission conceptions of vision (Lindberg 1976) Atomists and Aristotle stood, however, on the same side

Addressing optical image in the module utilized art representations of image transfer and its transformation in a plane mirror. This approach was discussed previously (Galili and Zinn 2007).

The relevance of these contents for physics education was demonstrated by several researches that reported and analyzed misconceptions students held regarding vision and optical image (e.g. Guesne 1985; Rice and Feher 1987; Bendall et al. 1993; Langley et al. 1997; Galili and Hazan 2000a, b). The schemes of knowledge that students hold regarding optical image show certain similarity to the conceptions of scientists in the past. Thus, prior to instruction, students often show holistic understanding of optical image creation and transfer through space (similar to Atomists), whereas novice learners of optics often show misconception which corresponds to the image transfer by means of a single ray per image point (similar Ibn al-Haytham's account for vision). It was checked that addressing the old theories of vision in instruction (Type II knowledge of the periphery), that is to say, applying cultural curriculum, had significant remedial effect on students' misconceptions (Galili and Hazan 2000b).

This excurse possesses an important additional potential. Exposure of the conceptual development of the scientific knowledge regarding optical image touches on the nature of science with respect to its usual identification as a "sub-culture of the Western culture" (e.g., Aikenhead 1997; Aikenhead and Jegede 1999). The excurse shows that after the first steps in Hellenic and Hellenistic societies, scientists of non Western societies of Muslim countries significantly contributed to the optical knowledge and even led the scientific research in the early Middle Ages (Al-Kindi and Ibn al-Haytham). This educational innovation was possible due to the cultural appeal to the periphery and presents a special modification of school curriculum. The latter is prevailed by images of the Western culture (no scientists from any other place), as if only they contributed to the contemporary science that changed through time. At schools we continue to promote the old image of science.

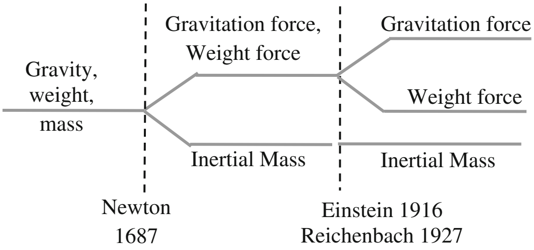

Fig. 8 Conceptual evolution of the weight in physics history

In this regard, this excurse may suggest another option—to identify the special status of science as a culture close to Popper's concept of the *third world* (Popper 1972, 1978). Within this view, science presents a universal type of culture which belongs and characterizes all people regardless their cultural identification. Being a universal culture it is easier to be adopted, appreciated and genuinely supported by the great variety of learners across the world.

3.5 Module 4. The Story of Weight and the Gravitational Force: Marriage and Divorce

The excurse to the history of weight concept was prepared for high school students and physics teachers. It goes across the whole history of physics from its dawn to the modern period. In this big span, one may identify three periods of weight conceptualization (Fig. 8):[10]

1. Weight is the faculty causing the body to be heavy and fall;
2. Weight is the gravitational force acting on the body and different from its mass, and;
3. Weight is the result of (standard) weighing of the body, that is, the force that the body exerts on the measuring apparatus. Weight is distinguished from the gravitational force.

One observes here that the definition of weight changed through the history showing complexity of the concept and the subtleness of the subject matter involved. It is these historical changes that create the required *space of learning* (Marton et al. 2004) to be used in the instruction. Comparison between different interpretations of the same concept—weight—presents educational advantage of this historical excurse. While following the genesis of this concept and the parallel changes of the related epistemology the learner reveals the full picture of physics knowledge which makes his/her knowledge meaningful.

The excurse follows the history from the pre-Newtonian holistic understanding addressing a whole cluster of features related to an object, which one may express today as mass-gravity-matter (the medieval notion of "pondus" could be also informative), to the Newtonian invention of the gravitation—the attraction force between each two material bodies and his identification of this force with weight (the *gravitational definition* of weight). Newton stripped weight from other qualities previously affiliated to weight, and first of all, from the inertial mass as he defined it. The story ultimately arrives to the modern physics and the new split, this time it was between the gravitational force and weight (by the new *operational definition* of weight). This step drew on the recently adopted in physics principle of equivalence of Einstein (Reichenbach 1927/1958).

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[10] We skip here on the important development of weight concept during the Middle Ages.

All together the conceptual evolution presented in Fig. 8, looks as sequential removing the conceptual degeneracy that took place along the progress in physics knowledge.

The excurse refines this evolution and informs the learner about the ontological and epistemological changes that caused variation of weight definition. Weight in modern physics was reinterpreted due to the cardinal change in the epistemology of physics at the end of the nineteenth and the beginning of the twentieth centuries—the introduction of the positivistic philosophy. Within this vision, Mach performed revision of the classical mechanics and *operationally* defined mass (Mach 1893/1989). He, however, ignored the concept of weight (the subject which required the principle of equivalence that he did not possess).

Weight was treated later, after introduction of the Theory of General Relativity by Albert Einstein. Hans Reichenbach (1927) did that while applying the new approach consolidated in the philosophy of science. Starting from positivism of Mach it arrived to *operationalism* defined by Percy Bridgman (1927)—a distinguished physicist who entered the epistemological discourse of science. His claim was that the operational definition (and only such) determines the meaning of any physical concept by means of a unique measurement. The contemporary philosophy of science established later a more balanced requirement: to be well defined any physical concept should be provided with two definitions: theoretical (nominal) and operational (epistemic) (Margenau 1950). This perspective establishes a special value of the excurse to the history of weight: it demonstrates the norm of concept definition in physics and also discharges the myth of teaching physics "without philosophy" (Tseitlin and Galili 2006). The historical account of weight displays and protrudes the ubiquitous importance of epistemology in science.

As seen, the issue is not new, neither for physics, nor for philosophy. However, in science education, a system with huge inertia, the transition to the operational definition of weight proceeds very slowly and has not yet accomplished despite of the wide spread confusion of students/teachers and the importance of conceptual clarification by means of concept definitions in physics instruction (Galili 2001; Galili and Lehavi 2006; Leong and Chin 2009). In light of this situation, the excurse to the history of weight may not only well illustrate the role of the philosophy of science in education, as depicted by the semiotic triangle (Fig. 3b), but also lead to a conceptual change in many physics curricula. A special educational feature of this discourse is that it is still continuing. One may observe a split between the textbooks, that is to say, between those authors who keep with the Newtonian definition (e.g., Young and Freedman 2004)—the majority in the US, for instance, versus those, also in the same country, who define weight operationally (e.g., Orear 1961; Marion and Hornyack 1982; Keller et al. 1993; Halliday et al. 2000). The beneficial way to clarify the concept seems to present it in a cultural way: in its historical genesis. Such presentation, together with analysis and discussion may lead to the conceptual learning and necessary change in physics education.

The relevancy of the subject to physics pedagogy was reported in several studies. The common confusion of students regarding weight and gravitational force (beyond the confusion of weight and mass) can be traced to the instruction in accordance with the Newtonian definition of weight (e.g., Galili and Kaplan 1996). In a way, education recapitulates the history of physics following the same path of development: from the pre-Newtonian all-inclusive concept of mass-gravity-weight at students of earlier ages (Galili and Bar 1997) to the Newtonian gravitational understanding of weight as the gravitational force exerted on the body, but not its mass (Galili and Kaplan 1996), and finally to the distinguishing among weight, mass and the gravitational force as three different concepts (Stein et al. 2009). Teaching the operationally defined weight is simple enough to be taught already at the level of junior high school and its incorporation provides remedy to prevent the weight misconceptions (ibid.). Also, teaching by means of a historical excurse to the history of weight will further enhance the impact by providing wider perspective on the method of physics and worldview of science making students' knowledge more mature, valid and reliable.

3.6 Module 5. The Story of Inertial Force

This excurse is special by the fact that its subject matter deals with the topic which is traditionally problematic even to mention in physics curriculum at schools—*inertia* and *inertial forces*. The module addresses mainly the population of physics teachers of high schools who usually face these concepts in their naïve form in students' ideas. School curriculum usually ignores this subject and address close, but not the same: *inertial mass*. *Inertia* is reduced solely to *inertial mass*, making the rest of students' ideas—misconceptions. High school students are expected to administer physics descriptions without inertial forces. While in physics class at school *inertial force* is a misconception, it is widely used in the everyday life and practically by all textbooks in engineering—the situation that is hardly acceptable by any reasonable educator.

Although the notion of *inertia* was introduced by Kepler only in the seventeenth century its roots go back to the medieval science. The seeds of inertia could be recognized in the concepts of impetus and gravity. Mach (1893), who by the end of the nineteenth century revised mechanics trying to purify its concepts by putting them on the empirical bases, ignored inertial forces. This was not occasional, of course, and perhaps shared the reason with the contemporary curriculum designers who ignore those forces too—these forces are considered "fictitious", not real, actually not required by an inertial observer—the only legitimate observer in the classical physics of the nineteenth century. Much changed in physics since then.

The required clarification of the subject may come through examination of the rich history of inertia concept that we made using the originals (Kepler 1618; Galilei 1613, 1632, 1638; Descartes 1644, 1976; Huygens 1659; Newton 1687; Euler 1736; D'Alembert 1758; Einstein and Infeld 1938) and the secondary resources by scientists and historians (Lagrange 1783; Sommerfeld 1952; Drabkin and Drake 1960; Drake 1964; Jammer 1961; Cohen 1971). The excurse reconstructs the diachronic discourse of scholars regarding inertia and inertial forces which could be visualized by the representation which keeps with the idea of nucleus-periphery structure of a physical theory (Fig. 9).

The unfolding story starts from Kepler's breaking with separation between the heavens and sub-lunar world. Inertia for him was the faculty of *resistance to motion* of the weightless planets (celestial objects), much like weight for Aristotle in the violent motion of terrestrial objects. From there, the excurse proceeded through the *indifference to motion* of Galileo and rejection of any force related to motion by Descartes to *vis inertia* of Newton who radically modified Keplerian inertia to the force acting on the body during any change of its motion, in proportion to the rate of that change (Cohen 1971; Galili and Tseitlin 2003).

The excurse discusses the outstanding contribution of Christian Huygens who prior to Newton introduced his vis centrifuga. The special status of the latter was too novel at his time—the account of reality from the point of view of the person on a spinning wheel. This perspective was not understood until Einstein's epistemological revolution which legitimized the account of reality by any observer. Why this great delay in recognition? Was it because the approach of several observers applied by Huygens was not elaborated by him

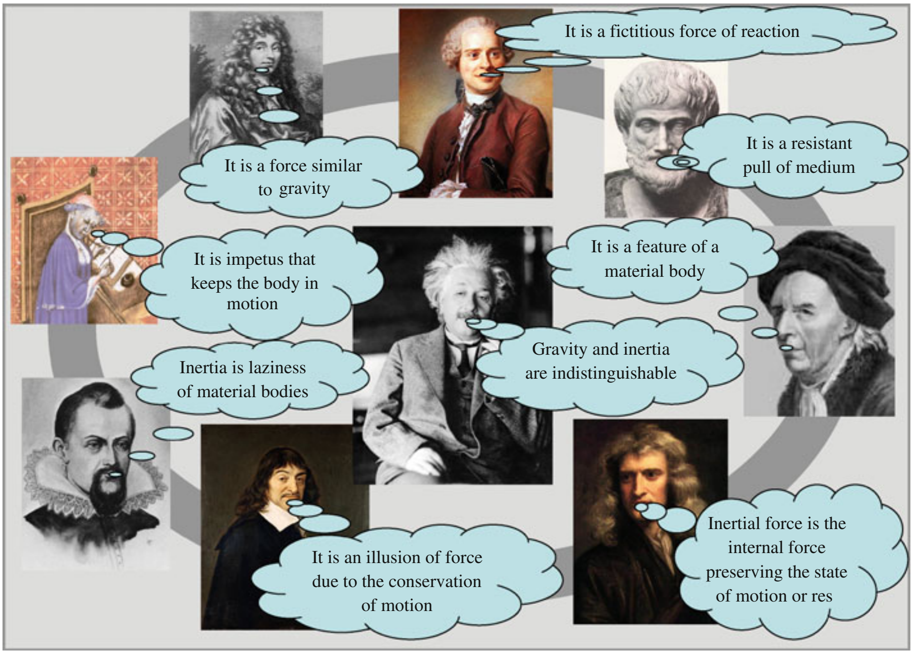

Fig. 9 Representation of conceptual evolution of the inertial force in a diachronic discourse on the subject of inertial motion and inertia

within any new *philosophical framework* (Huygens did not distinguish between inertial and non-inertial observers) and therefore was abandoned for about 200 years by his fellow scholars who shared the Newtonian worldview. Such question emerged in this excurse emphasized the fundamental importance of philosophical framework in physics.

Following this history, one reveals that the notion of “fictitious force” appeared with regard to the *d’Alembert force* in the eighteenth century. The force was considered to be no more than a mathematical trick, “not really a force” quite in agreement with the Newtonian paradigm of *interactive* nature of forces. The situation changed only in the twentieth century, when the idea of description of reality by various observes, or in other words, in different frames of reference, entered to the modern physics. The epistemological progress was articulated by Bridgman (1927), and it legitimized inertial forces within the *operational framework* of physical concepts. However, as often happens, the name *fictitious* remained causing great confusion regarding the “reality” of such forces.

The diachronic conceptual discourse (Fig. 9) on the inertial force was suggested as a mediating concept for meaningful learning about inertia. It illustrated the non-linear nature of knowledge accumulation regarding certain concept in scientific progress, far from being simple or “Wiggish”—a sequential replacement. Instead, the presented debate revealed complementary contributions within various worldviews and epistemologies that constructed the present understanding of inertial forces.

The high relevance of inertial forces for physics course was established in several studies on high school students’ conceptions (e.g., Gardner 1981, 1984; Galili and Kaplan 2002). The finding that weak and strong students equally often employ inertial forces regardless the instruction was indicative. Students frequently use them to account for various physical situations. In accordance with the dictum of educational constructivism, this extreme popularity obliges teachers to address inertial forces in their instruction, not merely dismiss them as erroneous. In fact, the legitimacy of inertial forces is warranted by the operational definition of force adopted in modern physics as well as in modern pedagogy of physics (Arons 1990; Reif 1995).

The major complexity of the subject is, however, due to the strong linkage existing between inertial forces and the issue of multiple observers as adopted by modern physics for more than a 100 years but remains outside of regular school curriculum. The framework of multiple observers, by transgressing the description of the world soley by inertial observers, matches the modern cultural perspective.

4 Teachers' Perception of the Developed Materials

As already mentioned, the developed materials mainly addressed physics teachers and hence, their perception of the developed modules was of central importance for us, especially in light of the novel character of the cultural approach. Within the activities of our group in the project, teachers participated in three national meetings and several workshops. Several findings in this regard were especially important to determine the final form of the developed materials.

Firstly, we were reminded that the major difficulty of using the HPS-based materials in actual teaching is due to the fact that teacher training programs, as well as disciplinary programs at physics departments of universities, do not require courses in the history and/or philosophy of science. Therefore, practicing teachers normally lack background knowledge and hold strong naïve views of the subject of HPS. This implied that the meaningful cooperation with teachers had to start after the first version of the materials was constructed and teachers were invited to react, comment and ask questions facing concrete products. This interaction took place at the national meetings and workshops. The collected by us reflections were used in the subsequent revision of the modules.

Teachers wrote to us:[11]

> There is no tradition of teaching physics with such materials…. They require deep understanding… I will have to learn much first by myself before to bring them to the class to ignite my students. I am still not there.

Yet, at the same time:

> But they [the materials] are very much relevant, interesting, provides meaning. They are interesting to hear, they bring "taste" to the class instruction. They are refreshing and opening your mind, provide a big picture of how people arrived to the theories, how it happened from the thoughts of more than one person. We want our students to think in big [wide perspective], not only solve problems. This is also more interesting and in fact there is no other way to produce future scientists.

Secondly, many teachers expressed concern about the lack of time for "extra materials" in the already dense and crowded physics curriculum. Indeed, high school instruction in our country is currently oriented to the matriculate examination requiring solving standard problems rather than expressing theoretical disciplinary knowledge and knowledge of the history or philosophy of physics. This fact brought the question of whether the knowledge of the HPS is relevant for the success at the final test students have to pass. Teachers said:

> The major problem is lacking time. In the framework of high school physics course there is no place to stop and spend more time for discussion on any topic. We need to run and mainly focus on the

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[11] All the quotations were translated by us from Hebrew.

> material that will be tested. It is a pity, but perhaps one can infuse some drops of these materials at relevant points…

In accordance to this view, our decision was to focus on the concepts of central importance in the curriculum and, in a sense, adopt our materials to such pragmatic consideration.

A special concern was mentioned with regard to presenting historical materials:

> Presenting these materials may increase the direct teaching [lecturing] and reduce the time reserved for individual solving problems and personal creativity. There is a need to find a balance in teaching between listening the story and student activity, otherwise the most interesting stories may again become boring after some time.

Regarding the cultural structure and addressing several theories in their account of the same subject, we received the following reflection:

> I liked very much the structure and the idea that different theories have different nuclei, and they "maintain" cultural discourse. Indeed, culture comes [in Hebrew] from "numerous". … I liked to see how different theories were connected. For instance, it was about reproduction of light ray by superposition of light waves [Fresnel zones treatment of light expansion].

Some teachers were skeptical and suspicious when they found materials not familiar to them in the subject matter, those addressing wrong theories and conceptions from the past (Type-II knowledge). The concern was that such alternative ideas often look rather reasonable and not obvious for refutation. Therefore, teachers thought, such theories could confuse students, and the teachers may face the problems that they created for themselves.

In response to this concern, we displayed the results of physics education research that demonstrated students' misconceptions similar to the historical conceptions and outlined the idea of knowledge recapitulation in the evolution of scientific knowledge (e.g., Piaget 1968; Galili and Hazan 2000b). It was understood, then, that whether or not the teacher addressed certain "wrong knowledge", the mind of students was already "contaminated" with many wrong ideas, some very similar to those in the history of science, spontaneously produced by the learner in his/her account of reality. This information softened the resistance and replaced it with pragmatic interest and curiosity regarding the ways by which scientists refuted those plausible but incorrect conceptions. Thus, with regard to the mentioned problem of optical image one teacher stated:

> The image in Camera Obscura can be very useful in explanation of optical image, using the paradox [mentioned by Aristotle and solved by Ibn al-Haytham] of transfiguration of the observed image depending on the size of the opening [of the camera].

Despite of the lack of background, teachers showed a special interest to the philosophy of science. One teacher wrote:

> Philosophy displays the reasons for all [materials] we teach, the way people thought and produced claims, made inferences. … Without learning philosophy physics [knowledge] is similar to the revelation of commandments given by God to Moses on Mount Sinai. [There were immediate problems of acceptance and lack of understanding among the people of Israel who had to adopt the codex without any reasoning]

Similar appreciation of the philosophy of science was observed in teachers reflecting to the argumentation in favor of the operational definition of weight and its separation from the gravitational force. Dealing with the philosophical requirement of operationalism teachers raised the question why Newton did not see the problem. In a vivid discussion the teachers revealed to themselves the epistemological differences between Newtonian and contemporary physics: the unique observer of Newton versus multiple observers in contemporary physics. The standard declaration that physics knowledge changes with time was refined drawing on this concrete example.

All together, the teachers sympathized to the cultural approach. One teacher summarized:

> I liked to know how different were solutions suggested by philosophers [to the same problem or question] until scientists arrived to the present understanding.

Another teacher wrote:

> Much thanks for the great intellectual pleasure this special workshop caused to me.

5 Discussion

In presenting the modules we have already addressed various content specific aspects which are on discussion in physics education research. Here we add few points of summarizing character related to the *historical excurse*, the product of our activity in the project. One may realize that these points are very much interwoven. Yet, they deserve mentioning as separate points.

5.1 Making Science

We may start with mentioning that the genre of historical excurse revealed special advantage in demonstrating the nature of science as a product of intellectual activity, a special culture and a way of knowledge construction. Familiarizing with historical excurses one may, for example, refine a rather misleading claim that scientific inquiry "begins with a question". Our excurses testify that scientific inquiry of scientists rather starts from learning by an individual the previous discourse, the accumulated scientific knowledge on the subject considered. As it is very well known to the practitioners, people do not spontaneously produce research questions. Similarly, scientists did not spontaneously possess skills of scientific inquiry when they face a problem to solve. In a way, making science is not straightforward common sense applications (Cromer 1993; Wolpert 1994). In order to pose a scientifically meaningful question and further explore it in a *scientific* research—confirm and refine, or refute and replace—one needs to be introduced into specific discourse (related views and ideas) regarding the considered subject. Research questions are usually inherited and/or constructed in the course of inquiry. The *National Science Education Standards* (NRC 1996) put this important claim of the *complex* nature of science in the following form:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. (emphasis added)

Historical excurse presents a sequence of events and studies, and reveals to the learner the narrative of a certain inquiry. Familiarity with the big picture is essential, for it enables the learner, as well as the researcher, to ask *relevant* questions. Historical excurse displays a diachronic discourse on the particular topic performed by different people in different times and by means of various methods. In a way, excurse may unfold several *scientific research programs* (Lakatos 1970) applied to the same question. Thus, for instance, Ibn al-Haytham thoroughly learned the heritage of Greek and Hellenistic scientists before he could question and investigate light, vision and image creation (Module 3). He answered the *same* questions which bothered other scholars and addressed their claims to be scrutinized and debated. The progress in *science* is, thus, a continuing ascending construction of *spiral* nature: returning back to the same subject at different levels, rather than localized independent projects of questions–answers as often presented in introductory physics courses and studies.

Considering history of physics in a sufficiently wide scope, one may learn to appreciate the features of cyclicity and continuity, combined and preserved in science development, hermeneutic in nature. The complexity of this process manifests itself in the continuous back and force interaction between theory and experimentation: the repeating inductive-deductive cycle, introduced by Aristotle in its initial form: observation-explanation, replaced in more modern science by the repeating hypothesis-experiment framework (e.g., Losee 1993). The best way to show the importance of this aspect of scientific activity is to show what happens when one neglects it. We showed that in Module 1, discussing Descartes' theory of motion and collisions.

5.2 Cumulative Nature

Closely related another benefit of historical excurses is their demonstration of the *cumulative* nature of physics knowledge and continuity of the scientific progress. The controversy of this view may be traced to Kuhn's (1970) thesis of science history as comprised of periods of incommensurable paradigms (or the parallel claim in humanities by Foucault (1970) of periods of different cultural epistemes). Indeed, replacement of one theory with another (an incommensurable nucleus, new concepts and frames of thought) may be interpreted as a break in continuity of science. This view is, however, partial and ignores the whole picture. Cultural approach demonstrates the idea of continuity by leaving no nucleus isolated. The rival ideas and conceptions are not deleted in the physics history (collective mind) as well as in physics teaching (in the suggested pedagogy), but placed in the periphery representing as if preserving dialogue with the nucleus. Despite of the different epistemologies and worldviews, a virtual diachronic discourse on various aspects of the subject matter continued. This image of scientific knowledge creates a big picture showing knowledge *accumulation*, which yet does not imply simple addition, but integration of ideas and data on the subject of concern.

Such was the way of knowledge about motion, developed through the whole history of physics. Modules 1 and 2 together described this process across the time segment of 2,000 years. In it, Philoponus and Buridan, in a way, debated with Aristotle; Descartes—with medieval scholars and Galileo, and Newton—with Aristotle, Buridan, Galileo, Kepler, Descartes and Huygens. Similar discourse took place over the concept of optical image (Module 3), the concept of weight (Module 4) and the concept of inertial force (Module 5). They all demonstrate the possibility of scientists to proceed with the same research subject, adopt the knowledge from the past and tackle it again and again, arguing by alternative interpretations, methods and tools.

In fact, scientists never forgot their dependence on the previous accomplishments and warned the novices against simplification of the new achievements as discoveries ex nihilio, in isolation from the previous scientific products. For instance, in the interview with the *New York Times*, in April 1921, Einstein said (Jammer 1999):

> There has been a false opinion widely spread among the general public that the theory of relativity is taken as differing radically from the previous developments in physics from the time of Galileo and Newton, that it is violently opposed to their deductions. The contrary is true. Without the discoveries of every one of the great men of physics, those who laid down preceding laws, relativity would have been impossible to conceive, and there would have been no basis for it. Psychologically it is impossible to come to such a theory at once, without the work which must be done before.

This and other confessions of scientists may place to the correct context certain interpretations of science progress which might create an impression of discontinuity of "science in action" (e.g. Latour 1987). Other scholars may describe debate over scientific issues and/or in a particular period and setting—a historical case (e.g., Shapin and Schaffer 1985). Such descriptions of the scientific enterprise may be locally valid and sociologically informative, but they cannot be but secondary for one who reconstructs what happened in the particular scientific content discourse in a wider scope and longer run (thus, scholars debated plenum versus vacuum not only in Britain of the seventeenth century). This order of things was illuminated in our excurses with regard to several physical concepts. Their goal was to elaborate the perspective of continuing progress for the purpose of learning and teaching physics at schools.[12]

Exposed solely to the disciplinary formalism and lacking CCK of the subject, students may remain unaware of the *conceptual* scientific tradition. Therefore, they cannot but become the teachers who keep strictly with the "correct" disciplinary curriculum and neglect any background of its claims. Regardless their opposite and sincere intentions—this is indoctrination of knowledge. Naturally, their students, in mass, will do the same. This reality presents a vicious circle of cultural ignorance.[13] Providing teachers with CCK regarding central issues of physics may break the circle and change this unfortunate reality in science education.

5.3 Objectiveness of Science

The next to mention benefit of historical excurse is promotion of understanding science as a human construction of *objective* knowledge about Nature (AAAS 1993). On our days, it became common, in science education in particular, to emphasize the opposite—the "*subjective* nature of science". The adherents of this view argue by the fact that individuals are biased and reflect in their knowledge specific social environments, personal background, worldviews, imagination, etc., which thus introduce subjectivity into the their scientific products. Others might mean by "subject" the whole community of researchers. Therefore, *subjective* actually means for them human made. The latter is, however, not the original meaning of subjective in the philosophy of science, representing individual, idiosyncratic knowledge, depending on personal perceptions and conceptions.

It may appear as a claim: "Science has a *subjective element*", which seemingly addresses certain features of the *form* of scientific articles. Indeed, considering our modules, one may point to the fact that Descartes' theory of motion reflected his strong personal religious beliefs (Module 1) and similarly, Newton's worldview, also deeply religious and individual, penetrated into his concept of inertial force (Module 5). If, then, one remains silent about the objectiveness of the science *content* on the first place,

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[12] In the history of science, the assertion of continuity of the scientific knowledge was stated not once by Sarton (1947), Grant (1996), Bala (2006), Hannam (2009) and others.

[13] For the marvellous visualized image of such see M.C. Esher's *Ascending and Descending* (1960).

the claim of subjective elements easily becomes: “Scientific knowledge *is subjective*”.[14] This claim places science in the same category with magic, astrology, religion (miracles), politics and personal interpretations, which presents a serious drawback in science education. To prevent this distortion of replacement of the essential with accompanying, the HPS based materials should take a wider scope that reveals, for example, that the mentioned subjective features of form did not remain in the scientific theories. The subjective features were abandoned in the following discourse of the scientific community and in no way appear in our wide use of the classical mechanics.

The presented excurses, by their comparative and wide temporal perspective on the scientific discourse, allow the learner to argue for the objectivity of scientific knowledge. The learners observe consolidation of the *collective* knowledge of the science community that goes through purification and modification in a long run, through debate of individuals holding different ideas and frameworks of thought, becoming more and more adequate to the features of the world outside. Thus, the resultant knowledge of *classical mechanics* enabled great technological achievements—a reliable test of objectivity: people walked on the Moon regardless various individual details in the knowledge of the people who created the knowledge required for such enterprise.

At the same time, different scientific theories vary in their areas of validity. For example, *Classical mechanics* is essentially different from *Quantum mechanics.* Related by the principle of correspondence (Fig. 2) and family resemblance, both mechanics present human made pictures of the reality. Possessing nuclei valid in different areas of physical parameters, they produce dissimilar statements, which are considered in science both objective and correct in a well defined sense.

Furthermore, in science education, it is important not to confuse various *aspects* of scientific knowledge with its *genus* (NRC 1996; Bunge 1996). Confusion of *objectivity* with *universal and unconditional correctness* of knowledge seemingly leads to misconceptions about the nature of science. The prominent contemporary physicist addressed this issue (Weinberg 2001):

> We [scientists] believe in the objective truth that can be known, and at the same time we are always willing to reconsider, as we may be forced to, what we have previously accepted.

As shown in our excurses, the scientific claims (principles and laws of physics) are independent of race, nationality, religion, personality, state of mood and worldview of those who *apply* them: reproduction of the conditions is followed by reproduction of the same results—verification. This is the objectiveness of the scientific knowledge. Popper (1972) depicted consolidation of the collective scientific knowledge as the process in which the objects of the *second* world[15]—the knowledge of individuals possibly subjective—create the objects of the *third* one shared by the community of scientists—the world of objective scientific theories:

> For scientific knowledge simply is not knowledge in the sense of the ordinary usage of the words ‘I know’. While knowledge in the sense ‘I know’ belongs to what I call the ‘second world’, the world of ‘subject’, scientific knowledge belongs to the third world, to the world of objective theories, objective problems, and objective arguments.

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[14] To make my claim *objective* I avoid personal citing in this matter. My intention is solely to call for attention and the need to correct the deformed in education.

[15] The first world is the world of real objects.

In no contradiction to objectiveness, the scientific knowledge remains dynamic, unfinished, and tentative—a special type of culture which reflects Nature, not replaces it.

Finally, it is not enough to declare that the scientific knowledge is discussable and allows corrections and refutations; the teacher should be equipped with concrete examples presented in an intelligible, visually appealing and plausible form. The historical excurse allows illustrate the dialogue among several theories, expressed in terms of nucleus-periphery interaction and exchange of knowledge elements in case of scientific revolutions. Historical excurses demonstrate the dynamics in which theories were corrected, refuted and replaced. This feature distinguishes scientific knowledge from other types of knowledge: religious, mystic, and traditional.

6 Conclusion

In the development of the HPS based materials within the HIPST project, we have arrived at a new format of using the HPS contents in teaching physics—a historical excurse. Science educators may apply it aiming at construction by the learners of the conceptually meaningful knowledge regarding important topics of physics curriculum. Developed within this format modules were discussed with school teachers at workshops and meetings. The accumulated responses provided basis for belief that application of the modules may promote Cultural Content Knowledge of physics in students and teachers. Historical excurses, rich in physical contents, can facilitate meaningful learning of ontological and epistemological aspects of physics. The excurses provide the learners with a big picture and possess advantages over isolated episodes from the history of science by being inclusive regarding the construction of the knowledge to be learned.

We argued that addressing deliberately chosen scientific articles, albeit refuted in science history (Type II knowledge), could reveal the meaning of the knowledge to be mastered today—Type I knowledge. It is the combination of both types that makes the knowledge *cultural*. Both types together better represent the genesis and meaning of conceptions in science. Inclusion of the alternative conceptions *in science* for improving teaching and learning physics is a step similar to the constructivist reform *of science education* that suggested revealing and addressing the alternative conceptions of students as a tool for their remedy. This holds equally with regard to the content knowledge as well as syntactic one (the scientific methodology).

By presenting a big picture of scientific discourse on certain subject, which goes through different periods of history and different personalities of scholars who contributed to the scientific progress, *historical excurse* might serve as an effective tool to demonstrate the *objective nature of science* (physics in particular) in its *contents*, and thus to facilitate understanding of its essential difference in this aspect from other types of knowledge which are subjective.

Addressing the CCK in teaching *not* necessarily implies *significant* increase of instruction time but rather the change in the nature of curriculum and pedagogy—the teaching style. The expected impact of our products—to be further checked—seeks restructuring students' knowledge from the spontaneously created structure of the *knowledge in pieces* (diSessa 1993), or *scheme-facets* (Galili and Hazan 2000a, b), to the cultural knowledge of science organized in scientific theories each possessing triadic structure of *discipline-culture*.

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