On the involvement of History and Philosophy of Science in teaching Science – an approach promoting cultural content knowledge

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ABSTRACT

This study addresses the approach of representing physics knowledge as being comprised of few fundamental theories, each explicitly structured. Instead of a regular dual disciplinary structure, nucleus and body of knowledge, we expand to the third type of knowledge elements - periphery. The latter includes alternatives and problematic elements of knowledge from the historical discourse in the particular domain of knowledge. The inclusion of alternatives not only contrasts the nucleus of the theory but actually determines its meaning and the area of its validity. The periphery may include alternative conceptions of learners. It is the periphery that establishes the space of learning by conceptual variation which is required for meaningful learning. Altogether, this teaching approach seeks constructing cultural content knowledge (CCK) in the learner. Moreover, CCK determines the role and contribution of the history and philosophy of science in science curriculum as providing elements to the triadic structure and clarifying the relationship among the fundamental theories of physics. The CCK is exemplified with regard to the concept of weight.

Keywords

Theory based structure of knowledge, nucleus-body-periphery structure of theory, cultural content knowledge (CCK), cultural knowledge of the weight concept

Résumé

Cette étude porte sur l'approche de la représentation du savoir des sciences physiques comme étant composé de quelques théories fondamentales, chacune structurée explicitement. Au lieu d'une double structure disciplinaire fréquemment utilisée, le noyau et le corps du savoir, nous élargissons cette structure an ajoutant un troisième type du savoir, la périphérie. Ce dernier comprend d'éléments alternatifs et problématiques du savoir provenant du discours historique dans un domaine particulier du savoir. L'intégration d'éléments alternatifs non seulement met en contraste le noyau de la théorie, mais détermine effectivement son signification et son domaine de validité. La périphérie peut inclure de conceptions alternatives des apprenants. C'est la périphérie qui définit l'espace de l'apprentissage par variation conceptuel qui est nécessaire pour un apprentissage significatif. Cette approche de l'enseignement conduit en tout cas à la construction du Savoir Culturel du Contenu chez l'apprenant. En outre, le Savoir Culturel du Contenu détermine le rôle et la contribution de l'histoire et de la philosophie des sciences dans les curricula des sciences physiques en fournissant d'éléments à la structure triadique et clarifiant la relation entre les théories fondamentales des sciences physiques. Un exemple de cette approche est fourni par la notion du poids.

Mots-Clés

Théorie basée sur la structure du savoir, la structure noyau-corps-périphérie de la théorie, le savoir culturel du contenu, savoir culturel de la notion de poids

Introduction

Science, History and Philosophy of Science (HPS) are cultural products closely related and deeply interwoven. This unity was especially clear in the distant past, when science appeared as natural philosophy. However, with time, for the vast growth of the accumulated knowledge and the pressure of social environment, scientific disciplines appeared, the holistic curriculum split and became more pragmatically oriented. This development also matched the limits of individual abilities and variety of preferences. The accelerate growth of knowledge posed serious questions regarding feasibility of managing the great amount of knowledge. The situation possesses clear implications to education: what and how science curriculum could appreciate and should incorporate in order to adequately represent such amount of knowledge and leave a chance for an individual learner to grasp it in order to obtain a meaningful image of science as a whole – a big picture? Is it possible at all?

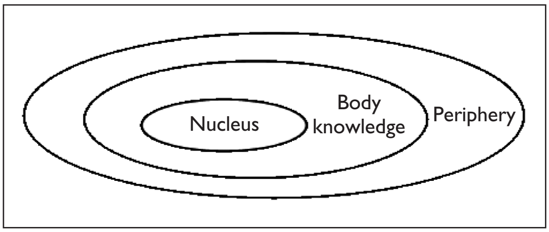
Another educational problem to be mentioned here is the problems of students in acquisition of conceptual knowledge of science. A great amount of research reports (e.g. Duit, 2009) indicate serious barriers on the way to reconstruct and understand scientific contents beyond the ability of solving standard problems often trained in classes in algorithmic manner. The abundance of alternative, erroneous misconceptions regarding the meaning of scientific knowledge was documented on behalf of students at all ages and levels of instruction. Teachers try their best to convey the correct knowledge, they speak "truth and only truth" and yet, students, generation after generation, again and again show the same misconceptions. Even in case of good students who manage quite well with learning material, they still fail in conceptual questions when those involve a novel situation (e.g., Galil & Bar, 1992). Misconceptions do not disappear.

Theoretical Framework

The two mentioned problems may have been related and could be resolved within certain teaching approach drawing on the knowledge borrowed from the history and philosophy of science, selected and prepared in a particular way. We suggest modifying the teaching focused on the traditional disciplinary curriculum which is often prevailed by standard problem solving and confirmation by laboratory work with supported by a detailed univocal manual. The suggested by us teaching should include, in major features, the relevant points from the scientific discourse, which would represent the construction of the presently taught subject matter.

Our theoretical framework is termed cultural for the reason that it introduces content discourse to the teaching context, polyphony of accounts for the considered subject. We may represent this content structure with the diagram of Figure 1.

Figure 1



The structure representing triadic codification of the knowledge elements of a physics theory in cultural perspective

A regular disciplinary curriculum is often structured in a dual manner: *nucleus* – for the fundamentals of ontological and epistemological nature, and *body* – for the knowledge drawing on that basis. Scientific discourse which presumes alternative conceptual accounts, together with epistemological alternatives of the nucleus, are incorporated in another area of the structure − *periphery*. It is the elements comprising the periphery that upgrade the curriculum from being disciplinary to what we call a culture-disciplinary type (Tseitlin & Galili, 2005). This way arranged knowledge of the subject matter we suggested to call cultural content knowledge – CCK (Galili, 2011)[1].

This format points explicitely to the ways by which the HPS materials are expected to contribute to the science curricula. It is done firstly, by distinguishing between the nucleus and the body of knowledge, which could be made, in principle, already in the disciplinary curriculum (but usually it does not happen). For emphasizing the nucleus, one needs the support of the philosophy of science. In particular, nucleus includes the paradigmatic model of the considered theory. In the case of Newtonian mechanics, for example, it would include the model of point particles in vacuum interacting by central forces and moving in absolute time and space. The epistemological principles of classical physics are also included there: the hypothetico-deductive method, empirical validation, operational and nominal concept definitions, etc. The contribution of the history of science is important especially in the restoration of the scientific discourse, in its major features, comprising the periphery. Thus, in the case of classical mechanics, the periphery may include the pertinent conceptions of Aristotle, Hippocrates, Buridan, Galileo, Descartes from the past, and of Einstein and quantum theory, from the present. Those together create a diachronic debate regarding the nature of motion.

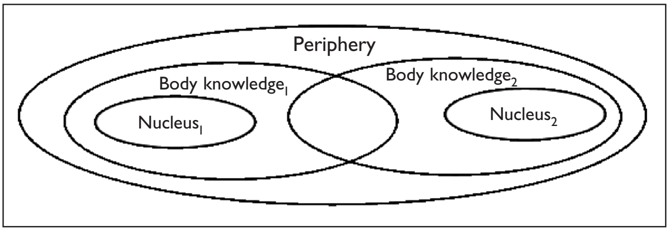
The important implication of this approach is the revision of the thesis of *incommensurability* between the different fundamental physical theories which is usually related to Thomas Kuhn (Kuhn, 1962/1970). The term – *incommensurability* – is taken from mathematics where it stands for the situation where two segments have no common measure, that is, their lengths cannot establish a rational ratio. This term becomes fuzzy and often not well defined when one transfers it to for using in humanities. It is not difficult to refine its meaning when it is applied to two physical theories. Two theories of physics which consider the same subject (otherwise there is no case for comparison) possess elements with different relationship. This is beyond the often presumed fact of sharing the commitment to the physics method (share the epistemology). The two may be compared in two perspectives: basic conceptions, the paradigmatic model (where they may contradict each other) and their products, the application of the basics. It is in products that the two theories may show different extent of closeness.

1 Lakatos (1978) used similar codification with regard to Scientific Research Program of a fundamental theory while ascribing different meaning to the components.

In terms of the triadic code of nucleus-body-periphery, one may consider the common example of Copernicus-Ptolemy theories confronted in their perspective to the world order. The two theories contradict each other in their paradigmatic models located in their nuclei. Therefore, each nucleus is located in the periphery of the other theory. However, the two theories may partially overlay in their bodies. People can use both theories to account for the motion of celestial bodies and receive compatible results. This relationship may be represented by Figure 2.

Therefore, we may talk about two theories in physics that their nuclei are contradictive but their bodies may be compatible. In fact, this situation may represent the principle of correspondence between two theories in the history of science. It is, in fact, important to use this perspective in education when addressing relationship of two theories such classical and relativistic mechanics. In some sense, nuclei, they *contradict* each other ("incommensurable") and in another sense they are and should be *compatible* ("commensurable"). It is in the latter sense, that one may state that "classical mechanics presents a special case of the relativistic one".

FIGURE 2



Representation of the relationship between two physical theories that contradict each other with respect to their fundamentals while remain compatible in considering some physical subjects.

ARGUMENTATION

We may now return to the two problems that we placed in the beginning of this paper. With regard to the great amount of information and knowledge in physics which accumulation continues to grow in acceleration, we may suggest the organization of physics curriculum in terms of fundamental theories possessing triadic structure. Despite of the huge amount of material in physics, the number of big theories which control these products is low, and they should, thus, provide the organization of scientific knowledge. The central role of the theories in physics knowledge should be explicit and emphasized. The physics curriculum should be structured in terms of few such theories incorporating the rest of the contents: principles, laws, concepts, conceptions, models, explained phenomena, experiments, technological appliances and so on. The theory based structure of science allows providing the learners with a big picture of physics.

The second problem we mentioned was regarding the difficulties on the way of the learners to the assimilation of the scientific knowledge which is commonly accompanied with multiple alternative conceptions produced by the learners trying to make sense of the reality and the knowledge they face in physics class. The answer to this problem may be also provided by adoption of the approach of CCK regarding the subjects of physics curriculum. The CCK draws on the exposure of the scientific discourse on what is taught and learned. As mentioned, this approach implies addressing the periphery of the considered theory, the conceptual alternatives. Why is this educationally important? Why to address the knowledge which appeared to be incorrect? Is there a danger to confuse the learners whose knowledge is fragile and non-mature? There are several answers to these questions which expose the rational of CCK as a framework of physics curriculum. One may summarize them as following.

Displaying the scientific discourse presents the real nature of the scientific method. The instruction which remains silent about the alternative accounts, in fact, promotes an erroneous vision that a "pure" experimentation, thoroughly performed with a more advanced technology creates a more advanced scientific knowledge – the image which is a far cry from the true situation in which theoretical accounts in accord with different theoretical conceptual systems continuously compete. History of science provides a plenty of examples of theory laden experiments that facilitated a choice made between different theories. It is important to reveal to the students that experimental results make sense only within certain theoretical framework and such framework is normally not unique. For example, in the debate for establishment of special theory of relativity the results of Michelson-Morley experiment were explained in several ways not only by Einstein's theory but by a several theories with which Einstein theory was in a very tough competition (e.g. Miller, 1997).

Moreover, scientific discourse presents the method by which the scientific community seeks and reaches objectivity of the collective scientific knowledge. Missing such discourse in teaching may lead to the dubious claims about the subjective nature of scientific knowledge often addressing individual perception and background of certain discoverer. Such misleading confusion may place science to the status similar to astrology, alchemy or religion. It is indeed a challenge to show how possibly subjective views of individual scientists lead to the consolidation of the objective knowledge of science (e.g., Popper, 1978, 1981; Holton, 1985). Scientific discourse which may provide elements affiliated to the periphery of certain theory plays in this process a central role.

Another argument in favor of addressing periphery in teaching is related to the certain similarity observed between some historical conceptions held by scientists and dismissed later on, in the course of history, on the one side, and the misconceptions developed and held by students, on the other. It is not too speculative to state that presentation of the discourse and the arguments for and against the considered conception possesses an additional value if such conception resonates with the conception held by the student. This was observed by us in a yearlong experiment of teaching optics to 19^{th} grade students using our historically based course (Galili & Hazan, 2004). During this year we displayed and discussed a series of historical conceptions such as holistic image transfer, active vision, image transmission by means of light rays (Alhazen's theory) and other historical ideas which closely remind the misconceptions popular among students. We explained the success of our experimental groups in comparison with control groups by the impact of considering correspondent historical conceptions and a cognitive resonance with them (Galili & Hazan, 2000).

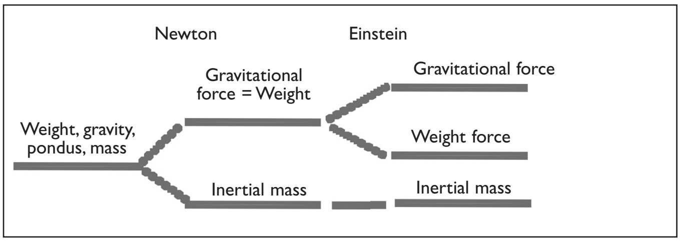
Finally, we will mention a strong argument on behalf of educational psychologists who claim that in order to reach effective learning one should use variation of the goal concept and encourage the comparison by the learner who through appropriate analysis will discern and prefer the correct option and dismiss the alternatives. This process takes place in the space of learning created by the relevant conceptions (Marton et al. 2004). Clearly, the elements of periphery provided by historical alternative accounts may support teacher in creating the appropriate space of learning for the concept serving as a subject of instruction.

The presented argumentation in favor of importance of periphery, as the essential element of the CCK approach, may imply a general inference regarding the involvement of history of science in educational process. It is a commonplace to address the history of science in its elements which present steps of constructing the "correct" knowledge, adopted by us today. Such are, for example, the measurement of Earth's circumference by Eratosthenes or the laws of lever by Archimedes. Such references to the names and historical facts are indeed important in general sense of culture and present the ethos of science. However, in the perspective of conceptual understanding of science, interesting and enriching as they are, they cannot be identified as *essential*. One can imagine students who succeed in learning of certain elements of physics knowledge without knowing their true inventers, and their historical background. There are, however, other types of history fragments, those presenting incorrect conceptions and concepts involved in the scientific debates and historical arguments but subsequently dismissed. They often contrast the correct conceptions in the aspects critical for correct understanding of the adopted concept. Such were, for example, the theory of motion by Aristotle and the theory of impetus. Their use is less easy for teachers who might not know about them from their own professional training but the awareness of them is essential for students' genuine understanding of motion as they face in the classical mechanics of Newton. This perspective led us in our participation in the European project HIPST (2008-2010). There, we created special units – *excurses* – which reconstructed the historical scientific discourses regarding several concepts important in physics education (Galili, 2011).

The case of Weight concept – the importance of philosophy of science

We have reviewed the involvement of the history of science as framed within the CCK approach. Now we turn to the involvement of the philosophy of science, addressing mainly the epistemological nature of scientific knowledge, the way science adopts knowledge. From several aspects of that, we will mention a special role of the operational definitions of concepts. The essential importance of the operational definition was realized with entrance of modern physics of the 20th century (e.g. Bridgman, 1952). Further development recognised the necessity to provide both operational and nominal definitions to physical concepts (Margenau, 1950). Here, we use the shortest way to illustrate the impact of this philosophical issue on education though considering the concept of weight (e.g., Galili, 2001, 2011; Galili & Lehavi, 2003). This concept is a subject of learning at all levels of physics curricula, yet, it is taught differently by different teachers in different countries. The situation in the US physics textbooks is representative. The texts split between two kinds. One defines weight as the gravitational force (e.g. Sears & Zemansky, 1982; Young & Friedman, 2012) and the other defines weight as the force causing weighing results (e.g. Hewitt, 2006; Knight, 2013). This dichotomy in weight definition implies, for example, different accounts of physical situations in a free gravitational motion ("falling"), the state of weightlessness. The long history of weight reveals the major steps in the correspondent conceptual discourse. In a simplified way, this long history could be represented in the diagram of Figure 3.

FIGURE 3



Schematic representation of the development of the concept of weight. Two conceptual splits are related to the establishment of classical mechanics by Newton (Newton, 1687/1999) and modern relativistic mechanics by Einstein (Reichenbah, 1927/1958).

The major understanding of the problem draws on the revolution in physics epistemology: from classical rationalism (even if involving experimental verification) to the positivistic revolution, the transition from classical to relativistic and quantum theories. In particular, physics knowledge embraces now multiple observes (the accounts in different frames of reference) and the framework of drawing inferences restricted to the local measurement. This change brought to the fore the principle of equivalence in physics and recognition of the fact that weight as a result of measurement by weighing cannot univocally testify for the gravitational force. The two concepts – weight and gravitational force – split, but this split was not always copied in the system of education. We will not expand more on this problem here (Galili & Lehavi, 2003; Stein & Galili, 2014) but mention the fact that currently the authors make their choice between the two options but they refrain from presenting both options in a dialogue, actually ignore "the other way". This would be the cultural way to treat the problem when one exposes different philosophy behind each of the approaches, in the historical discourse. We believe that awareness of such conceptual discourse, the arguments launched by physicists and philosophers of science, as exposed in researches, might change the situation to better for the students who widely hold numerous misconceptions regarding weight and weightlessness as numerously reported in educational studies.

Conclusion

We believe that the presented framework of the account for physics knowledge in terms of theories structured in terms of nucleus-body-periphery is important for science education as providing a big picture to the students and teachers. It also makes explicit the suggestion of the way in which the history and philosophy of science may contribute to the curriculum of regular learning at schools and educational programs for prospective teachers of science.

We may additionally mention here the recent study which suggested another implementation of the CCK approach to teaching in the form of summative lecture subsequent to the regular teaching (Levrini et al., 2014). The authors applied this method to the knowledge of optics in the secondary high school. They documented the positive impact on students' views on science, the nature of scientific knowledge and its organization in theories. However, much research effort is still required to check the impact of the CCK on students' and teacher' content knowledge of physics. We hope it will be done in close future.

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