Cultural Content Knowledge – The Case of Physics Education

Igal Galili
galili.igal@gmail.com

Science Teaching Department, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

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> There are very few, if at all, new things in this world. Therefore, the agenda of a person is to find a new, fresh interpretation of them.
>
> Giorgio Morandi (1890-1964)

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Abstract

If one thinks in terms of the commonplaces of science education which are, teacher, student, environment and subject-matter (Schwab, 1964), plurality and dialogism have introduced substantial changes in the first three commonplaces. The commonplace subject-matter has remained univocally focused on the scientific truth – an approach not in accordance with the nature of scientific knowledge. Given the issues raised about the effectiveness of science teaching and the need for scientific literacy amongst citizens, this paper attempts to provide a framework for introducing plurality and dialogism into subject-matter aligning the teaching of subject-matter with the nature of science. Science knowledge itself is considered as a culture and science knowledge is presented as a cultural structure in the process of science teaching. In accordance, the Cultural Content Knowledge (CCK) was introduced and exemplified (Galili, 2012). This paper is situated in physics but the approach can be applied to other natural sciences.

Introduction

In recent times, findings from science education research have essentially changed science curriculum. The discourse of physics education has provided new fundamental perspectives among which the features of plurality and dialogism might be taken as emblematic for our time. Indeed, if one thinks in terms of the commonplaces of science education which are subject-matter, teacher, student and environment (Schwab, 1964), among the substantial changes that have emerged in these areas, plurality and dialogism clearly take prominence.

Thus, with regards to teachers as a commonplace for science education, a central feature is Vygotsky's idea that the teacher's role is mediation of knowledge in students' learning, a process comparable with translation from a foreign language (Vygotsky, 1986). Either mediation or translation, this process includes plurality, multiplicity and dialogism by the very nature of these concepts. The multiple ways to mediate/translate scientific contents to the learner comprise what has been defined as PCK – pedagogical content knowledge by Shulman (1986). The teacher, thus, is obliged to possess much wider knowledge of the subject than a consumer does. For lacking a better term for such knowledge, one may try to name it erudition.

As to the students, one may relate to this commonplace the major change in the philosophy of educational constructivism currently prevailing as a 'theory of learning and teaching' (e.g., Fensham, Gunstone, & White, 1994). As the educational constructivism became a scientific research program in science education, it inspired studies which provided information on numerous "alternative conceptions" held by students and to be taken into account by their teachers (Driver & Easley, 1978; Driver & Erickson, 1983). Here too, variety and multiplicity entered into the knowledge relevant for the account of educational process.

After taking as obvious that multiplicity and variation are relevant to the third commonplace – environment (milieu) – we arrive at the fourth commonplace – subject-matter. Here the situation changes drastically. On the surface, there is *the* scientific truth about the world, and it is upon the teacher to teach it as a subject, whatever it is. The only variation allowed in this regard is to adjust the level of sophistication to the particular audience and keep with particular goals of the instruction. As a consequence of such understanding, the situation in 1964 inspired Schwab to reflect with respect to the commonplace subject matter as following:

> *Of the four topics of education – the learners, the teacher, the milieu, and the subject matter (that which is intended to be taught or learned) – none has been so thoroughly neglected in the past half century as the last.*

Clearly, much has been done in this respect since Schwab wrote his reflection. Within the activities in this direction one may mention the special effort of educators to clarify physics concepts (force, energy, mass, weight, image, etc.) and epistemological constructs (model, experiment, hypothesis, thought experiment, etc.). However, just with respect to the univocality of the scientific truth as presented to the students, there was no essential change in the school curriculum all the way through – keeping strictly with the disciplinary truth. This approach, however, appeared to be not representative of the nature of scientific knowledge, and it seems to be not effective in teaching science either. Here, we will address the attempts to deal with this important issue – the univocal nature of the subject matter knowledge, which can be related to the structure of scientific theory and its cultural presentation in the process of science teaching. In accordance, the Cultural Content Knowledge (CCK) will be introduced and exemplified (Galili, 2012).

Theoretical background

We start with the statement that provides the basis for the following discussion: *physics knowledge* presents a culture. Commonly we address physics *social activity* as a culture (e.g. Latour, 1987; Zimman, 2000). However, addressing physics *knowledge* as culture deals with content knowledge (CK) itself organized in a big structure of theories. But first, what do we say is culture and why is physics knowledge a culture?

Culture is very inclusive as it includes all artifacts, the products of human activities in general and so whatever is produced by people could be considered manifestations of their culture. To narrow the meaning and clarify what we mean by culture we identify the following features as creating the specific image of a culture appropriate to the scientific knowledge of physics. Such knowledge:

- presents a discourse
- interprets nature, not only describes it
- is selective in establishing correctness by special rules
- is comprised of several fundamental theories (mechanics, electromagnetism, etc.)
- has its ethos, norms, standards, values and spirit.

It is in light of all these we conclude: physics knowledge presents a culture.

If so, one may ask, what type of culture is established by physics knowledge? The answer can be provided by the classification introduced by Yuri Lotman (2010: 19) who distinguished between two basic types of culture. The first is the "culture of texts". It considers itself as a cluster of cases, traditions, texts. The shortest way to present this type is to exemplify it by such domains of human intellectual activity as history, philosophy, art which all could be referred to as cultures of texts. The second type is the "culture of rules" (or "grammatical cultures", as Lotman called it). They present clusters of products following certain norms and rules. In this class, one can find such domains of knowledge as natural sciences, technology, and law. The knowledge in these areas is arranged in fundamental theories. In physics, they are: mechanics, electromagnetism, thermodynamics and so on. While the first type of culture does not possess clear standards of correctness as a sign of belonging and keeps with tradition as such a sign, the second one does adopt the status of being correct and places the law as its basic principle. Such culture establishes clear demarcation constraints. We will expand on that in the following.

If physics knowledge is a culture of rules, one may now proceed and ask how people learn such cultures. This important perspective may be addressed in the way in which Lev Vygotsky (1986) considered learning foreign versus native languages, where learning a foreign language is from the outside and learning one's native language is spontaneous, from the inside. One may develop an analogy of learning scientific versus spontaneous concepts (Galili & Lavrik, 1998). Similarly to language, the culture of rules can be learned from inside and outside. These types of learning are different. Students learn scientific concepts similarly to foreign language through some version of direct instruction during short time periods. Scientists, however, keep learning science as long as they are active. They face nature, investigate it and try to make sense of it in terms of a theory. They maintain learning culture from inside, whereas students learn science, superficially, facing texts and in vast broadness. Students learn culture from outside. It is known to education researchers that learning from outside is very different to learning from inside.

Summarizing the two points made above we may infer that:

Learning science by a student is learning culture of rules from outside.

Keeping in mind the difference between the scientist and the learner of science one may imply a special need of students to be *provided* with the explicit knowledge of codification and structure of science. One cannot leave these features to be discovered or constructed by the learners simply because, if not for any other reason, they do not have sufficient time to reveal, figure out the codes, structure, concept definitions, for the whole cluster of knowledge that they have to master. This idea corresponds to the need for an advance organizer as formulated by Ausubel (1968). Some physics educators express the same requirement in other words: the learners need a *big picture* of the material they are learning.

Big picture – structure of theory

Lacking representative, hierarchical and functional structure of knowledge presents major obstacle to the novice in physics who encounter with a great abundance of information multiplying itself in extreme speed during the course of learning. Recall that physics being a culture of rules is arranged in fundamental theories. Tseitlin and Galili (2005) suggested a potential structure for a fundamental theory in physics. It comprises three areas of knowledge elements forming a triadic structure: nucleus, body and periphery (Fig. 1).

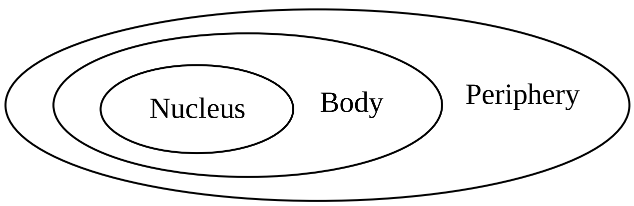

Figure 1: The structure of a theory

Nucleus incorporates the central principles – the paradigm of the theory, its fundamental laws and concepts of ontological and epistemological nature. The *body* incorporates various applications of the nucleus: solved problems, explained phenomena, algorithms to treat various situations, results of performed experiments, accounts of apparatus and machinery constructed based on this theory, and so on. *Periphery* incorporates all kinds of opponents to the nucleus, its rivals from the past (historical predecessors), present (alternative ideas in science and learners' misconceptions) and future (the theories which will surpass the claims of the nucleus from the further development of physics). We note that this structure of a fundamental theory includes experiments, in contrast to the usual opposition of *theory* and *experiment*. This is because scientific experiments are always designed within particular theories and are consistent with the theories.

Currently, the generic curriculum in physics is normally restricted to the contents of the first two mentioned elements: nucleus and body. The nucleus-body structure represents *disciplinary* curriculum as it is common in numerous physics courses in schools and universities. Adding the periphery makes the knowledge of physical theory *cultural* and creates *discipline-culture* that represents cultural content knowledge (CCK) of the subject matter in a particular domain (Galili, 2012). This approach was applied in a special course of optics for high school students (Galili & Hazan, 2004, 2009) and in the HIPST European project (HIPST, 2010). Its impact was checked in a teaching experiment (Galili & Hazan, 2000).

An important aspect of discipline-culture is an adequate representation of the relationship between the theories which replaced each other in the course of history. Thus, it is often stated that the theory of relativity replaced classical mechanics and the latter became a special case of the theory of relativity. This statement is seriously deficient from the educational perspective. In fact, such a claim represents the relationship between the numerical results obtained by both theories in their account for a particular situation. As to the basic principles of the two theories, they are essentially incompatible which corresponds to the well distinguished nuclei of these theories (each located in the periphery of the other), while the body areas partially overlay providing the area where both theories produce compatible results solving problems and providing accounts for the same situations (Fig. 2).

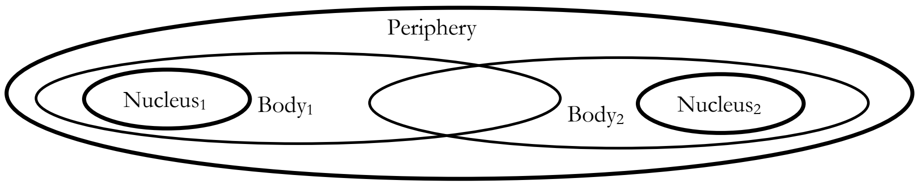

Figure 2: Discipline-culture structure of two fundamental theories in physics.

CCK about conceptual revolutions in physics

Discipline-culture structure can represent fundamental changes of theories in the course of the history of science. For example, representing cosmology the teacher may start with presenting the triadic structure in which the nucleus corresponds to the Aristotelian paradigm of the geocentric universe. The body knowledge of this theory will be represented by such conceptions as those by Eudoxus, Ptolemy, medieval scholars, etc. The rival ideas of this theory could be represented by the early views of Philolaus (early Pythagorean) prior to Aristotle and the developments made by Aristarchus after Aristotle. They will be placed into the periphery of such a scheme. With time, however, new ideas emerged due to the bright scholars who attacked the geocentric structure of the universe – those by Nicolas of Cusa, Tycho Brahe, and, of course, Copernicus, among others. They, however, were not successful in causing radical conceptual change, were ignored, and remained in the periphery. During the 17th century, the attacks on the nucleus were much more effective. The efforts of Galileo, Kepler, Descartes and Newton, among others, caused the revolution. This process can be represented by exchange of location between the Heliocentric and Geocentric conceptions in the triadic scheme of Fig. 3. The former moved to the nucleus and latter – left to the periphery, while the elements of the body were simply replaced by the new products of the scientific enterprise constructed within the new cosmological paradigm – the new contents of the nucleus.

Although the same process may be described without such visualization, providing a schematic imagery of the process possesses representational advantage for meaningful learning of this subject, resulting in the CCK. The important feature of this image is representing the continuous discourse maintained by scientists across the time, regardless of social structures, different disciplinary tools (mathematics equipment) and worldviews. The major concepts did not disappear or appeared just to cause an immediate revolution. They are preserved in the periphery maintaining a discourse with the rival conceptions. Presentation of this debate in education introduces *plurality* to the subject-matter commonplace of education. The focus of such historical perspective is on the science via the exchange of concepts and development of ideas via discourse, rather than keeping a catalogue of names, dates, historical, or philosophical perspectives.

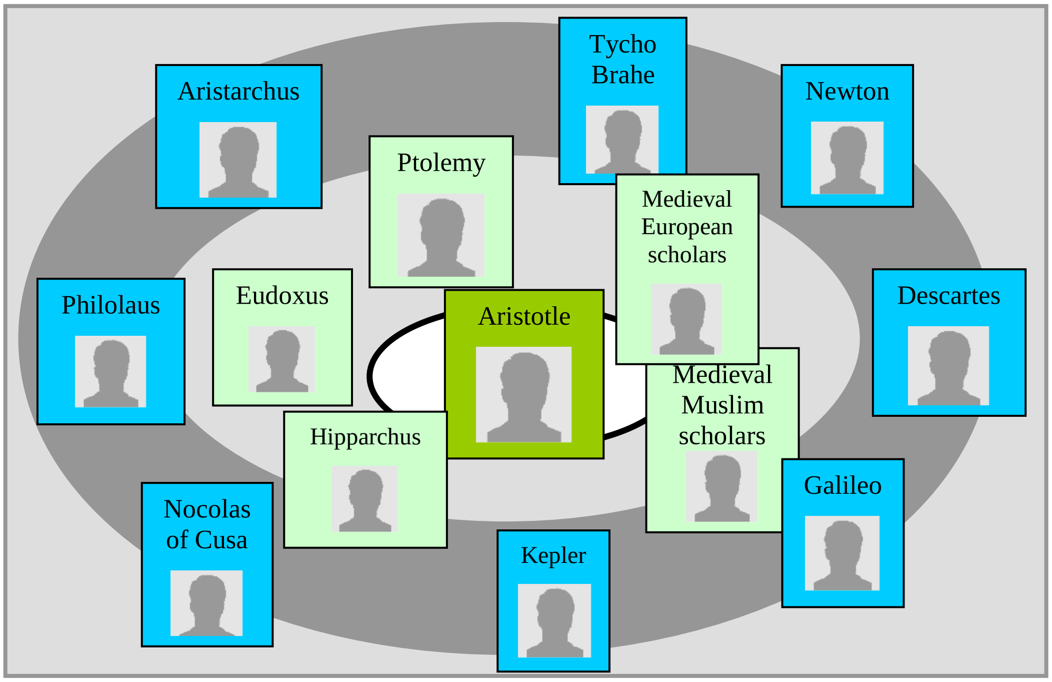

Figure 3: Discipline-culture structure of the geo-centric cosmology of Aristotle.

Cultural curriculum

Seeking construction of CCK in students apparently implies two major changes in the curriculum: (i) explicitly distinguished nucleus and the body, and (ii) inclusion of periphery containing the elements of knowledge of special type. The two changes are different in nature and seemingly might cause different reaction, support or resistance.

The demand for clearly discerning the nucleus of the presented theory might seem to be a step introducing unnecessary rigor. Indeed, one may manage with standard problems in mechanics without clarifying the paradigm of Newton, let alone other concepts within the nucleus. Absolute infinite space, independent absolute time, point masses, central forces, and instant gravitational interaction – these concepts comprising Newtonian paradigm seem of rather "philosophical" than "practical" importance, distant from the pragmatic goals of an introductory course. However, it is this core of knowledge that identifies classical mechanics as different from, say, electromagnetism or quantum theory. Clarification of nucleus in each fundamental theory of physics informs the learners of why physics cannot be represented as one all embracing theory. Such understanding will reveal the nature of physics knowledge consolidated in a *family* of few fundamental theories, distinguished by essentially different nuclei and maintaining a dialogue in the activities of practitioners who observe them all and make decisions as to which one to utilize or involve in each particular context. This is the big picture physics educators would like to engage learners with and the scientific literacy sought by many in introductory courses of physics.

The second demand, however, might cause even greater resistance. The inclusion of *wrong* conceptions from the past or even more modern ones which surpass the currently taught – the periphery – might seem causing unnecessary complexity and confusion among the novice students. Why do that? Several answers follow.

1. Inclusion of alternative conceptions (from the history of science) in disciplinary learning creates an authentic image of science for students. All too often students taking a specific course have no idea of physics as comprised of well developed fundamental theories not only each applied in different field of exploration but also different in conceptual validity. CCK helps in creating such a perspective.

2. Inclusion of alternative (wrong) conceptions in teaching implies inclusion of conceptual dialogue, revealing arguments that were used to refute the alternatives in order to establish the ideas included in the nucleus of the particular fundamental theory. Addressing the debate with the alternatives makes the physics course intellectually provocative, interesting and human. These factors are generally accepted as important.

Numerous researches have uncovered that students' misconceptions may remind historical conceptions adopted in science in the past. Thus, the force-motion relationship, understood as cause-effect, reminds the Aristotelian conception of violent motion. Similarly, students' ideas of *active vision* fit the then leading ideas in optics adopted by Euclid, Ptolemy, Al-Kindi and other scholars from the past. If so, addressing their ideas in the class may lead to so called "cognitive resonance" in the learners. Therefore, debates on such ideas in science classes could promote effective learning of the knowledge represented in the curriculum.

3. Finally, the inclusion of the opponent conceptions creates contrast with the nucleus and thus, by emphasizing the difference, makes learning more meaningful. Cognitive psychologists (Marton et al., 2004) stipulate meaningful learning with providing the learner with certain *variations* of the target concept to be learned. In other words, one should create a so called *space of learning* in which the learner discerns the required understandings of the target concept.

   For example, teaching Newton's laws of mechanics can be contrasted (or varied) with the ideas of the previous Aristotelian dynamics, Medieval Theory of Impetus, as well as Einstein's Special Theory of Relativity. In teaching biology, one could enrich the teaching of the modern theory of evolution introduced by Darwin and Mendel (whose principles are represented in the nucleus) with the alternative conception of evolution by Lamarck and the explanation of archeological findings by the theory of catastrophes by Cuvier. Teaching classification of elements in chemistry – the periodical table of Mendeleev – could be contrasted with the alternative principles of elements classification from the history of science, used by Aristotle, Paracelsus, Lavoisier, Mayer and so on.

Students' typology

Given the identification of the three knowledge elements within physics knowledge organization (nucleus, body, periphery), the problem of being a good or bad student in science, according to the perspective of C.P. Snow (1962), changes. Instead of this black-and-white evaluation of students' being apt for learning physics, teachers may think about their students in terms of three possible preferences that people may demonstrate and, in accordance, be more successful if provided the corresponding type of teaching and materials for learning.

In particular, some of our students in physics classes may demonstrate a clear preference for the knowledge about "the laws of nature" (e.g., Peierls, 1956), which represent the regularity and cause-effect relationships in the real world that we live in without much attention to their applications or problem solving. Such students show a sort of "philosophical" bias in their interests. The other group of students demonstrates a clear preference for the knowledge of various implications of the general laws and principles in reality and their multiple uses in problem solving, modeling, constructing machines, gadgets, devices and so on. These students seem pragmatic, practically biased and could be taught in accordance (e.g., Bueche & Wallach, 1994). The third group of students may show a special interest to the reasons that we possess the particular kind of knowledge as it is, why just this and not the other (e.g., Holton, 1952).

One may classify these predispositions in interest as "philosophers", "consumers", and "revolutionists" respectively. Of them, teachers usually prefer the second type (consumers) as easier for evaluation and simpler for instruction. However, it is not too risky to anticipate that the "philosophers" will become at least literate in science citizens, badly needed in the contemporary society, and the "revolutionists" might cause major changes in physics some day, changing the normal science that we practice today. In any case, this perspective refutes the "two cultures" perception of Snow (1962) and expands the potential population of learners of sciences to the highly important groups of students usually missing in the pragmatic environment that focuses predominantly on the consumers, active in problem solving.

Excurse to the history of a concept

Facing the question of the appropriate form apt for representing the cultural knowledge with regard to physics fundamental theories we suggest the genre of excurse. This compact form of learning materials represents the ideological genesis of certain physical concept in an unfolding story. However, this is not a "regular" history of science and neither is it a philosophy, in the meaning of scholarly treatise. The goal of the excurse is to reconstruct (in major features) the scientific argument that produced certain concept in its current form. Such excurse represents a diachronic discourse in which scholars of different periods participate in a continuous debate. The target concept is reconstructed, thus, providing the learner with the CCK about the subject. Excurses allow to be integrated into the regular curriculum flow at the appropriate point where addressing the concept controversy is especially relevant. This use of history of science is still different either from those renowned textbooks, which are entirely written in historical perspective (e.g., Mach, 1893; Taylor, 1941; Rogers, 1960; Rutherford et al., 1970) or those that present fragments of history in marginal boxes. Those preserve their validity but such contents are rarely used in teachers' practice for several reasons (Monk & Osborne, 1997). We will illustrate the rationale of historical excurse by particular examples from the materials prepared within the HIPST project in 2010 (Galili, 2012).

CCK of motion

The theory of motion is a subject of many historical studies, and it is presented in numerous books on the history of science. At the same time, this theory is the major content of mechanics courses. To design an excurse to the theory of motion one needs to be familiar with both. However, the resultant material – the excurse itself – should not fully represent the entire history: it is impossible and unnecessary for the regular curriculum of physics course. The appropriate goal is to represent the conceptual genesis of the scientific account of motion apt for facilitating teachers' and students' activity in physics classes.

For this purpose, one should identify and elicit the major steps in the variation of people's comprehension of motion. Among them were: the dichotomy of natural and violent motions, force-motion conception of Aristotle for the violent motion, the conception of impetus, kinematic relativity of motion (middle ages), the conception of Galileo: motion indifference and dynamic relativity, force-motion conception of Descartes, conservation of quantity of motion and the removal of rest-motion opposition, motion laws of Newton, space-time motion conception by Einstein. This excurse required numerous resources not quoted here. The excurse establishes conceptual diachronic discourse regarding the physical account of motion. This discourse creates a special space of learning in which the understanding of motion required in physics course is constructed through its historical variation.

CCK of weight

Weight is among the oldest concepts in natural science. The excurse to the theory of weight may include the conceptions of Aristotle (weight as an intention to fall, not as a force), the medieval split of gravity to natural and accidental, Descartes' weight as caused by the external push of medium, Newton's weight as the gravitational force, distinguished from inertial mass, operational definitions of of physical concepts (Mach, 1883) leading to the separation of weight from the gravitational force (Reichenbach, 1927) after introduction of the principle of equivalence by Einstein. This set does not represent the entire history of weight, but the important steps in the refinement of the concept of weight. Perhaps an even more reduced picture in this regard can be provided by a subset shown in the diagram of Figure 4. It shows a gradual removal of "degeneracy ", if one uses the terminology of atomic spectroscopy, with regard to the weight concept. This historical process allows a class discourse in the cultural curriculum.

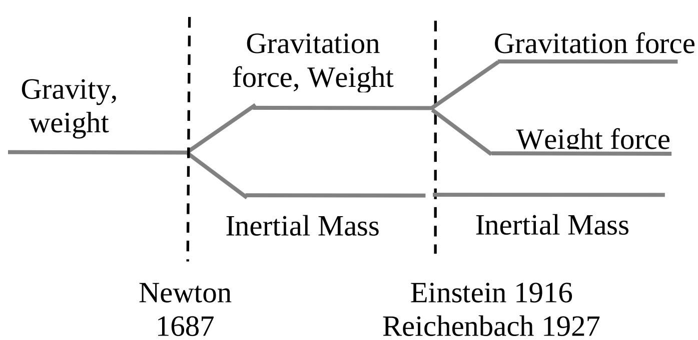

Figure 4: Conceptual refinement of the concept of weight in the course of the history of physics.

The diachronic discourse on the nature of weight surpasses a mere use of history of science by inclusion of the epistemological development of physical methods that eventually arrived at the recognition of the essential importance of the operational definitions of physical concepts. The relevance of this excurse is especially high given that only some of national curricula have performed the transition from the Newtonian to the modern definition of weight. Many countries still keep with the gravitational definition of weight and researchers continue revealing numerous alternative conceptions amongst students who face the environment very different from that observed by Galileo, Descartes and Newton (e.g., Galili, 2001; Galili & Lehavi, 2003). This excurse describes the historical evolution of the understanding of weight creating the pertinent space of learning in which the modern concept emerges through its variation.

CCK of image

Another example of the CCK oriented material is an excurse to the history of optical image. This excurse starts from considering the original conceptions of vision developed in Classical Greece (Pythagoras, Atomists, Plato, Aristotle). These ideas were further refined in Hellenistic physics (Euclid, Lucretius, Stoics, Ptolemy), inherited and promoted in the medieval Muslim period (Al-Kindi, Alhazen), medieval and Renaissance Europe (Grosseteste, Leonardo, dela Porta), and finally bring the learner to the solution of the problem – physical explanation of vision provided by Kepler in the 17th century (Lindberg, 1976).

Vivid discussions across time regarding the nature of optical image demonstrate the objective core and cumulative nature of the scientific knowledge interwoven with subjective views and different theoretical frameworks in the course of the progress. The requirement of the space of learning can be matched in such a debate of ideas regarding the optical image (Fig. 5). Physics educational research provides information about certain similarities and parallelism between students' and historical conceptions in optics. Thus, prior to instruction, many students show the holistic conceptions of image popular in early science, while the students after instruction often reproduce the understanding similar to that developed by Alhazen in the 11th century (Galili & Hazan, 2000). A required remedy of this misconception was observed in students' knowledge after the teaching addressing the historical conceptions of optical image seeking the perspective of CCK (ibid.).

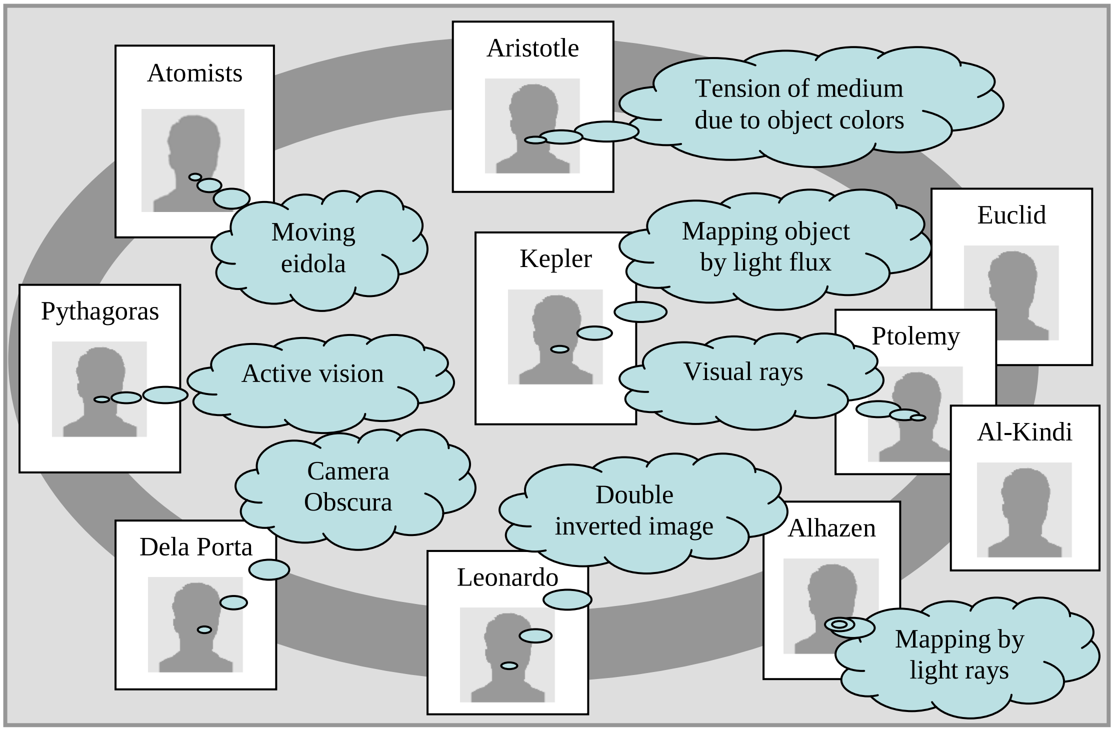

Figure 5: Symbolic representation of the diachronic discourse regarding the concept of optical image.

Conclusion

Cultural content knowledge of the considered concept or physical theory includes its conceptual genesis and in this way promotes meaningful learning of the subject matter in various dimensions. CCK replaces the linear curriculum of science teaching (as well as the simplified linear representation of the history) introducing a special teaching strategy – discursive reconstruction of knowledge which draws on the ideas of the bright minds from the history of science. This step does not replace learning science with learning its history, the focus is preserved in the disciplinary knowledge.

Furthermore, CCK renders a balance between the knowledge of the big picture and the problem solving in physics. The cultural curriculum is not limited to a qualitative account and includes the regular spectrum of physics formalism used in problem solving. However, the teaching seeking CCK makes physics (science) more dialogic and human, combing the objective essence of the subject matter with subjective features introduced to it by individuals in different periods of intellectual climate. This mode of teaching makes science interesting, causing curiosity and heralding scientific ethos, human values and worldviews.

Conceptual dialogism is a common value in the philosophy of science. CCK oriented curriculum introduces the same value in science education through inclusion of the polyphony of relevant interpretations and ideas, yet without eliminating the evaluation of knowledge in terms of correct and incorrect from the modern perspective. The immediate reward of such curricular approach might be the transition of instruction into teaching, and training into learning.

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References

Ausubel, D. P. (1968). *Educational Psychology – A Cognitive View*. Holt, Rinehart & Watson, New York.

Bueche, F. & Wallach, D. L. (1994). Technical Physics. Wiley, New York.

Driver R. & Erickson G. (1983). Theories-in-action: some theoretical and empirical issues in the study of students' conceptual frameworks in science *Studies in Science Education* 10, 37-60.

Driver, R. & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, 5, 61-84.

Fensham, P., Gunstone, R., & White, R. (eds.), (1994). *The Content of Science: A Constructivist Approach to its Teaching and Learning*. London: Falmer Press.

Galili, I. & Hazan, A. (2000). 'The influence of a historically oriented course on students' content knowledge in optics evaluated by means of facets - schemes analysis'. *American Journal of Physics*, 68 (7), S3-15.

Galili, I. & Lavrik, V. (1998). 'Flux concept in learning about light. a critique of the present situation'. *Science Education*, 82 (5), 591-614

Galili, I. & Lehavi, Y. (2003). 'The importance of weightlessness and tides in teaching gravitation'. *American Journal of Physics*, 71(11), 1127-1135

Galili, I. (2001). 'Weight versus gravitational force: historical and educational perspectives'. *International Journal of Science Education*, 23 (10), 1073-1093

Galili, I. (2012). 'Promotion of Content Cultural Knowledge through the use of the History and Philosophy of Science', *Science & Education*, 21(9), 1283-1316, DOI 10.1007/s11191-011-9376-x

Galili, I., & Hazan, A. (2000). The influence of a historically oriented course on students' content knowledge in optics evaluated by means of facets – schemes analysis. *American Journal of Physics, 68*(7), S3-15.

Galili, I., & Lehavi, Y. (2003). The importance of weightlessness and tides in teaching gravitation. *American Journal of Physics*, *71*(11), 1127-1135.

HIPST (2010). History and Philosophy in Science Teaching – European educational project in 2008-2010. Retrieved September 20, 2012, from http://hipstwiki.wetpaint.com.

Holton, G. (1956). *Introduction to Concepts and Theories in Physical Science*. Addison-Wesley, Reading, Massachusets.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers through Society*, Cambridge, MA: Harvard University Press.

Lindberg, D. C. (1976). *Theories of vision form Al-Kindi to Kepler.* The University of Chicago, Chicago

Lotman, Yu. (2010). *What people can learn*. Book Center Rudomino, Moscow (In Russian).

Mach, E. (1893/1989). *The Science of Mechanics.* The Open Court, La Salle, Illinois.

Marton, F., Runesson, U., & Tsui, A. B. M. (2004). The Space of Learning. In F. Marton, & A.B.M. Tsui (Eds.), *Classroom Discourse and the Space of Learning* (pp. 3-40), Lawrence Erlbaum, Mahwah, New Jersey.

Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education*, 81(4), 405–424.

Peierls, R. E. (1965). *The Laws of Nature*. Charles Scribner's Sons, New York.

Reichenbach, H. (1927/1958). *The Philosophy of Space and Time*. Dover, New York.

Rogers, E. M. (1960). *Physics for Inquiring Mind.* Princeton University Press, Princeton, NJ.

Rutherford, F. J., Holton, G., & Watson, F. G. (1970). *The Project Physics Course.* Holt, Rinehart, & Winston, NY.

Schwab, J. J. (1964). Problems, Topics, and Issues. In S. Elam (ed), *Education and the Structure of Knowledge* (pp. 4-47), Rand, McNally, Chicago.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4–14.

Snow, C. P. (1962). *The Two Cultures and the Scientific Revolution.* Cambridge University Press, Oxford.

Taylor, L. W. (1941). *Physics. The Pioneer Science.* Dover, NY.

Tseitlin, M. & Galili I. (2005). Teaching physics in looking for its self: from a physics-discipline to a physics-culture, *Science & Education*, 14 (3-5), 235-261.

Vygotsky, L. (1986). *Thought and Language*. The MIT Press Cambridge, Massachusetts.
Zimman, J. (2000). *Real Science. What it is, and what it means.* Cambridge University Press, Cambridge, UK.