Science Teaching: What Does It Mean?

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Abstract. This study considers the relationship between science, science teaching and the philosophy of science perceiving these three cultural phenomena as a semantic triad. This approach presents science teaching as being a form of a scientific reflection. The relationship of science teaching to the philosophy of science is advocated to be essential, revealing the conceptual meaning of science in the science curriculum and thus removing the semantic degeneracy taking place when the philosophy of science is ignored in science education. The study points at the bricolage as well as magic nature of the science curriculum preserving as long as science teaching preserves semantic degeneracy. Different types of meaning of Schwab's commonplaces were recognized. The study challenges the common view of the relationship between science, science teaching and pedagogy and suggests effective representation of individual knowledge of science educators.

Key words: theory of science teaching; semiotic approach to science teaching; the role of the philosophy of science in science teaching; denotative, conceptual, and connotative meanings of science curriculum; bricolage nature of science teaching; semantic degeneracy of science teaching.

Science Teaching: What Does It Mean?

> …contemporary scientific thought repeatedly returns to the problem of meaning. Psychoanalysis, structuralism, Gestalt psychology, some new trends in the literature critique, of which works of Bashlar may serve an example, investigate facts only to the extent that they mean something.
>
> (Barthes 1957)

Introduction

Bakhtin (1986) revived an old tradition of understanding a text by asking a question to which the text presents an answer[1]. In this vein we must first specify a question when we consider science teaching as a subject of a study. The question could be: *What is science teaching*? The answer depends on the current episteme (Foucault 1994) and might be provided, in various ways, by didactics, philosophy, synergetics, informatics, etc. In this study, we, however, will consider another question: *What does science teaching mean?*[2]

This presents a complex situation because meaning is an extremely wide term. Our approach, which will be defined, resembles that adopted in the Renaissance to account for Nature. Thus, Galileo considered Nature as a book written in mathematical symbols, and therefore a subject for elucidation, revealing its meaning. His approach was in contrast to that of gaining knowledge of a phenomenon by understanding its underlying causes – the approach of Aristotle.

The semiotic approach

Semiotics provides an established method for interpreting intellectual constructs (North 1995). In semiotics we are immersed in a world, which is a complex amalgam of signs. A small cloud in the sky is a sign manifesting a problem: "What does this cloud *mean*?" (It means a storm might be coming.) A sign does not exist by itself; it emerges during "reading", i.e. as a part of the process of interpretation ("Nothing is a sign unless it is interpreted as a sign", Peirce 1938, §2. 308). It results from the meeting of an individual (or a group) with the environment (cultural, social or natural) in the context of a problematic situation. When we observe the world around us, any thing and phenomenon could be associated with a sign which has a meaning for us. Thus, within generic view, science signifies progress, rational thinking and true knowledge. Similarly, a social sign is given to science teaching.

In this paper we regard science teaching as a sign corresponding to a phenomenon for which we seek the meaning. We apply an approach which is fundamental for semiotics, the semantic triangle (Frege 1892/1994), to the phenomenon of science teaching. We shall describe this construct.

The semantic triangle

In his seminal paper "On Concept and Object", Gottlob Frege (1892) introduced the idea of sign to a broad class of objects. The framework of his approach (which we will modify in the course of this discussion) was a special conceptual construct, later known as the *semantic triad of a sign*. He wrote -

> ...a sign by itself (be it a word, expression or graphical symbol) can be considered as related not only to the signified object, i.e. something that can be designated as a Denotatum of the sign (Beteutung), but also to something which I would like to call "the meaning" of the sign (Sinn)!; this meaning reflects the way in which the object is represented by the sign (ibid).

and:

> In the ideal case, the relationship between signs, meanings and objects should be arranged so that each sign corresponds to a single meaning, and each meaning to a single object. At the same time, one object may correspond to various meanings (ibid.).

Today we represent this semantic triad graphically in the form of a triangle (Fig. 1).

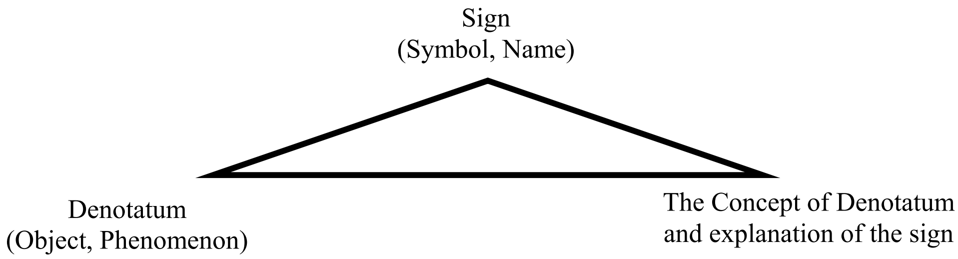

Figure 1. Semantic (semiotic) triangle.

Table 1 summarizes the meaning of the vertices in the semantic triangle.[3]

Table 1. Convention of the semantic triangle.

Sign (Symbol, Name)	represents, symbolizes the denotatum (object or phenomenon)
Denotatum (Object, Phenomenon)	the actual object or phenomenon
Concept	defines or explains the sign and gives meaning to the denotatum

We shall illustrate the above with the example of "a small ball" (Fig. 2) (Stepanov 1971).

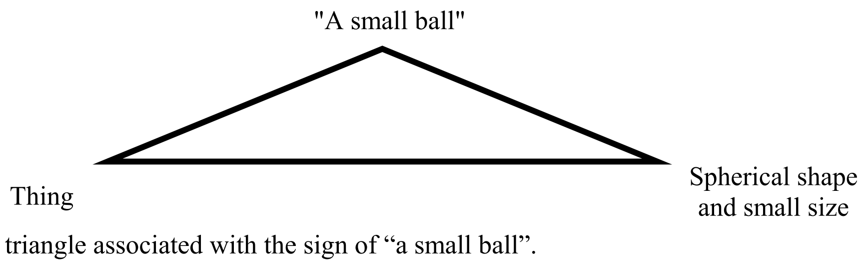

Figure 2. Semantic triangle associated with the sign of “a small ball”.

In this example, a real object is related to the word signifying it and to the necessary characteristics (spherical nature and a small size), which are needed to describe it conceptually.

However, although the concept describes and explains the meaning of the object, it is never complete. Frege illustrated this with the following example. If a, b, and c are lines connecting the vertices of a triangle to the mid-points of the opposite sides, then where *a* crosses *b* is also where *b* crosses *c*. The two terms: "the crossing point of *a* and *b*" and "the crossing point of *b* and *c* mean the same object but possess different meanings[4]. A full description of the object would have to include all possible meanings; this, of course, might be impossible. The relationship between a real object and its meaning can never be complete.

To clarify the idea of the semiotic triangle it might be helpful to consider cases where the relationships cannot hold. Frege mentioned the case of proper name: such as Aristotle where the object lacks a concept and the triangle degenerates into a line[5] (Fig. 3).

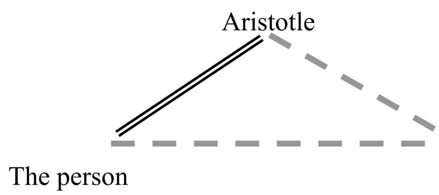

Figure 3. The degenerated semantic triangle for a proper name. The double line indicates a degenerate triangle and broken lines indicate missing relationships.

The semantic triangle of science teaching

Within the above framework we now consider a semantic triangle relevant to science teaching. To avoid obscurity, we must distinguish between the name "science teaching" and the phenomenon of "science teaching" that it signifies. The former serves as a sign for the latter, and the latter represents the object of the former.

In the case of "science teaching" as a name we obtain the semantic triangle of Fig. 4.

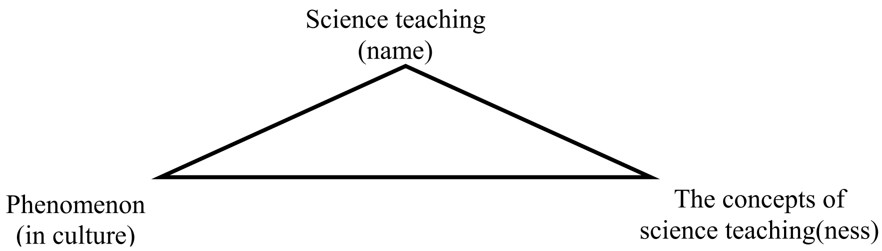

Figure 4. The semantic triangle for the science teaching as a *name*.

At the same time but from another point of view, the *phenomenon* of science teaching itself serves *a cultural* sign (upper vertex), and we seek to identify the other vertices (Fig. 5).[6] To reveal these other vertices is to define the meaning of the phenomenon science teaching and thus, to answer to the question: "what does science teaching mean?"

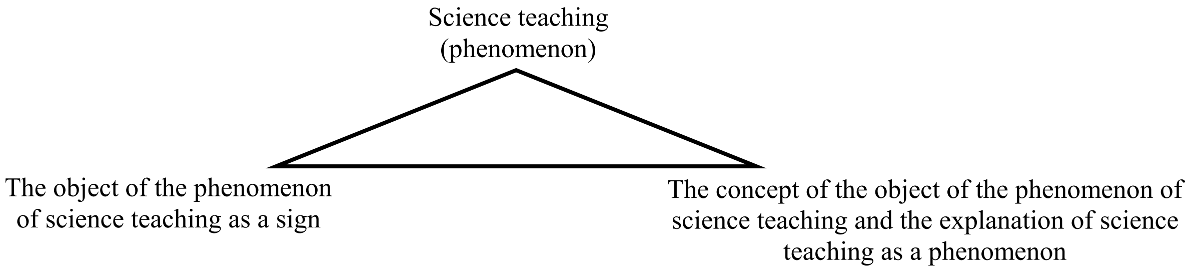

Figure 5. The semantic triangle where science teaching is a *cultural sign*. This triangle provides the answer to the question "what does science teaching mean?"

Following the above definitions, we suggest that *science* itself serves the object of *science teaching*. Indeed, science teaching presents the image of science in education. This identification helps us to reveal the concept vertex in the triangle. For this role, we suggest the *philosophy of science*, which describes the rationale of science, its ontology and its epistemology, as well as the logical apparatus and other components which provide science with a structure and framework. This triad may explain why scientists at all times have gravitated to educational and reflective activities[7]. The attraction, as they sometimes confessed, was often (if not mainly) due to more than a desire to disseminate knowledge. They felt that only in the context of science teaching could address the concept of science (philosophy of science) and they make clear to themselves.[8]

The philosophy of science helps determine what science should be presented and how it should be presented. It manifests itself in various curricular decisions: the choice of relevant content, determining the balance between theory and experiment, the selection of problems to be solved, the choice of scientific methodology, the place of the history of science (if any), the nature of laboratory work, the role of computer simulations, etc. All these considerations regarding the triad of science, science teaching and philosophy of science correspond to the way in which Frege defined the relationship between the object, its sign and its concept (Fig. 6).

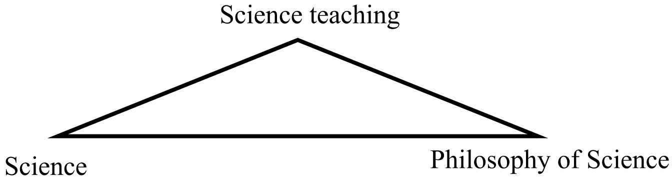

Figure 6. The semantic triangle for science teaching as a *phenomenon*.

In this context the philosophy of science is one of the meta-languages of science. We practice science teaching (the sign) as a label of science (the object) reflecting the ways in which science can be interpreted (concepts). From this point of view we can reveal multiple curricula corresponding to various trends in the philosophy of science.[9]

The semantic triangle and commonplaces of Schwab

In presenting the above semantic triangle for science teaching we have ignored such aspects as teachers' knowledge and training, students' knowledge and cognition, cultural and social environment. These aspects relate to the four commonplaces of Schwab (1966): teacher, student, teaching content and teaching environment. Although we have used the general term "science teaching" in our semiotic triangle, it was the content of the syllabus that was identified with the object. We have ignored the realization of a curriculum in class and other aspects related to teaching science.[10] Our triangle, which represents science teaching and of which the concept vertex is occupied by the philosophy of science, does not allow for any other of Schwab's commonplaces to serve as object.

What, then, of the other commonplaces? Other than subject matter, commonplaces appear as secondary, complementary, to the phenomenon of science teaching. Besides its major role in imparting information about the science content, science teaching practice also tells us about itself[11]. Thus, it shows that the process of science education is, indeed, constrained by the kind of teacher (e.g. his academic background), the kind of student (e.g. his prior knowledge, conceptions), and the environment (e.g. the kind of laboratory, computers). Their importance for the effectiveness of science teaching is well established. But in no way can any of these replace science content as an object of the phenomenon of science teaching.[12] Accordingly, we distinguish between *denotative* (primary) and *connotative* (secondary) meanings of science teaching. We should also add conceptual meanings by which science is represented in science teaching (Fig. 7).

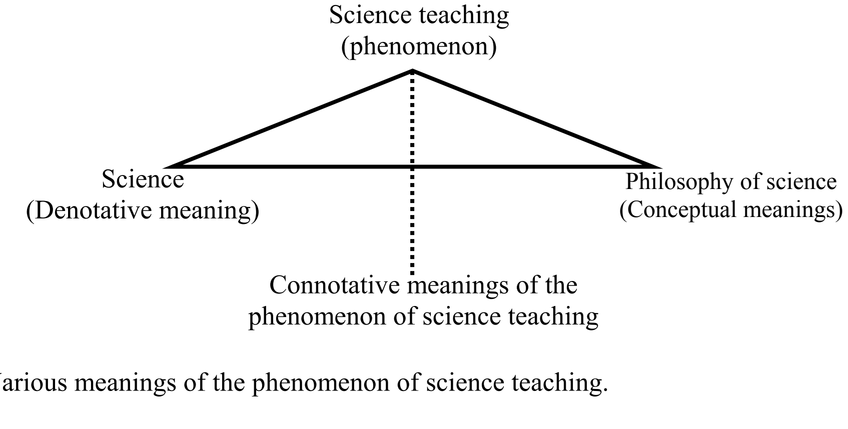

Figure 7. Various meanings of the phenomenon of science teaching.

We admit that our approach conflicts with that of Schwab who regards all four commonplaces as being of equal status. Such an approach would require a semantic triangle for each of his commonplaces and this would conflict with the basic idea of the unity of object, its sign and its concept. Thus, if “student” was the object, and “the ability to study science” would be the concept, and the sign could be “didactics” or “psychology of science teaching”, but never “science teaching”. This critique of Schwab's approach presents an important element of the view developed here.[13]

In passing, we make a few comments on the conceptual meanings of science as expressed by science teaching. As stated above, the phenomenon of science teaching represents the phenomenon of science. In general, phenomena are recurring events. Such are the events which constitute science teaching (curricula, textbooks, demonstrations, lessons). They represent the events in science (theories, discoveries, studies, experiments). We address solely cultural events, not natural ones. But, the interpretation of events cannot ignore the historical chain in which they are links. Therefore, in the course of representing science, science teaching necessarily “says” something about the history of science – an important aspect of all science teaching (e.g. Matthews 2000, Galili and Tseitlin 2003).[14] Even if a particular teacher deliberately ignores the historical aspects of science, his/her teaching still says something about it, viz. that science has no history (anti-historicism).

Since science is, to a large extent, a discursive phenomenon, it includes, among other important subjects (conceptual meanings), the “style” of scientific discourse or thought. Thus Max Born (1953) wrote:

> I venture to make a conjecture with regard to the phenomenon which might be labeled 'stability of principles'. I believe that, although some principles are constant, there is a general tendency for most ideas to change with time. Changing very slowly, they cause certain philosophical periods to be associated with specific ideas in all areas of human activity, including science. Pauli, in his letter to me, used the term 'style': styles of thought – not only in art but also in science. Adopting this term, I state different styles of physical theory. It is this feature that provides a sort of stability with regard to principles of thought. The latter are perceived as a sort of a priori in a particular period.

Therefore, if a curriculum ignores style, or any other meta-scientific concept, it conveys to the learner that the status of the ignored subject is inferior to that of other subjects. This feature of conceptual meanings distinguishes them from connotative meanings.

Finally, before we proceed with our model, we note that science teaching as a phenomenon can be often represented by a degenerate semantic triangle in which ideas of a philosophical nature appear as spontaneous, naïve, or even not acknowledged (Fig. 8).

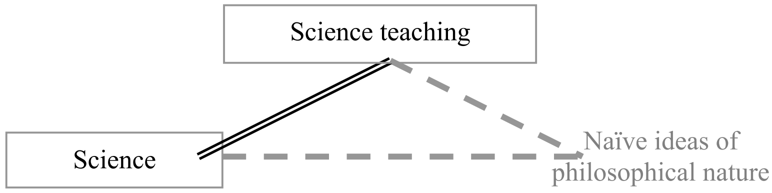

Figure 8. The phenomenon of science teaching where philosophical views are absent or under-evaluated.

We can also appreciate the inverted case of the above degenerate model, when the science activity of a researcher depends on (signifies) the education he or she obtained. Although the object and sign have exchanged roles, the philosophical meaning of the relationship often remains shaded.

Schwab (1978) was the first (in recent times) to advocate the inclusion of the philosophy of science into science curricula as substantive and syntactic knowledge. This represented the first step in breaking degeneracy by the inclusion of philosophical content. Other researchers currently have expanded this approach so as to include other components of the philosophy of science, such as logic and ethics (Matthews 1994). Halloun and Hestenes (1998) showed the positive effect of having proper views about science on the performance of students in science courses.

A mistaken perception of science teaching

There is a complex relationship between science, science teaching and education (researchers in these three areas are often spread among three departments of the same university). A common misconception is that science teaching represents a sort of fusion between science and education. It is true, of course, that the subjects are closely related and have overlapping activities. A person believing in their contiguity could suggest the triangle of meanings of science education shown in Figure 9.

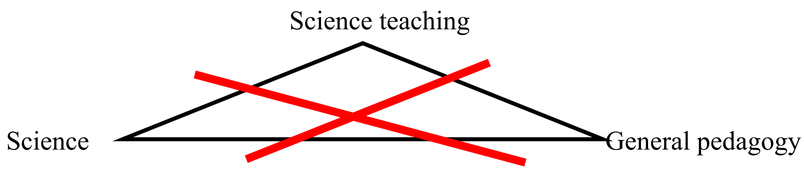

Figure 9. A hypothetical "semantic triangle" combining science, science teaching and education.

In this triangle, however, the side connecting science with education is invalid because education does not represent the concept of science. Experts in education usually avoid dealing with scientific content when addressing science education.[15] Hence this triangle should be modified by breaking the link between science and education, forming an open figure (Fig. 10).

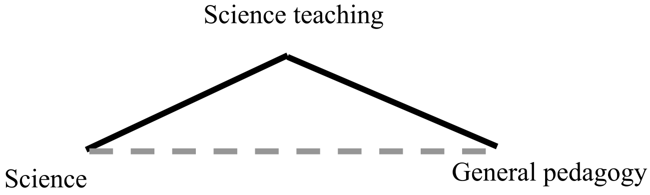

Figure 10. Relationship between science, science teaching and education.

The broken line in this figure represents the fact that there is no object-concept relationship between science and general pedagogy. We have used here the term “general pedagogy” since in the case of the particular pedagogy of science teaching the situation changes. Its semantic aspects, being closely related to connotative meanings of science teaching, deserve another investigation.

In passing it is of interest to note that, with regard to *social* science and the liberal arts, Barthes (1968) put forward a different relationship between science and its teaching. We have regarded natural science and science teaching as object and sign respectively. Barthes regarded social science as the sign of what is taught at university, viz. the university curriculum (Fig. 11).[16]

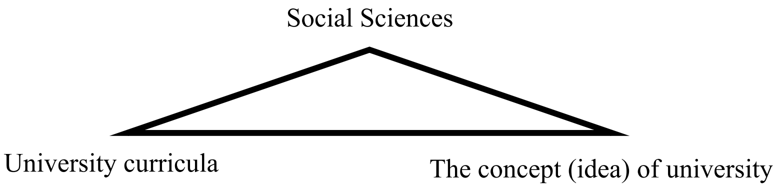

Figure 11. Barthes’ vision of the semantic relationship involving teaching of social science or liberal arts.

The connotative meanings of science, then, include ideologies which participate in consolidating the idea of the university and, as such, penetrate, one way or another, into the curriculum by determining the subjects it includes and those it must not. This phenomenon is especially striking when we observe university activities in totalitarian societies.

We can apply the approach of the semantic triangle shown in Figure 11 to any science, for example, physics. Within this approach we need a new meta-language to address physics teaching. We called it, schematically, the philosophy of physics teaching (Fig. 12).

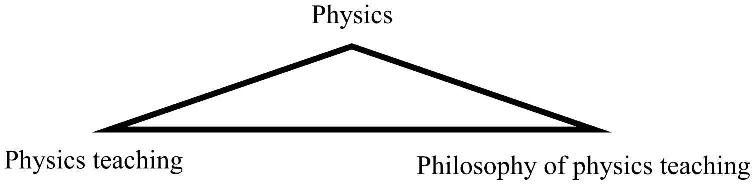

Figure 12. The semantic relationship expressing the view when physics (subject matter) represents the way it was taught in accord with certain philosophy of physics teaching.

Below we will show that seeking an improvement in science teaching implies providing it with meaning, and that this can be delivered by the philosophy of science. Similarly physics, too, obtains its meaning in “the “philosophy of physics teaching”. Thus we realize that physics itself is interested in the development of the philosophy of science teaching.

Teaching science in the framework of the Levi Strauss (anthropo-)semiotic approach

During the past half-century science teaching has generally neglected the philosophy of science, corresponding to the degenerate semantic triangle (Fig. 8). In this context it is instructive to consider the semiotic approach of Levi-Strauss (1966). This involves a pseudo-binary relationship with the *sign* occupying an intermediate position between the *percept* (the mental image of the object) and the *concept* (Fig. 13).

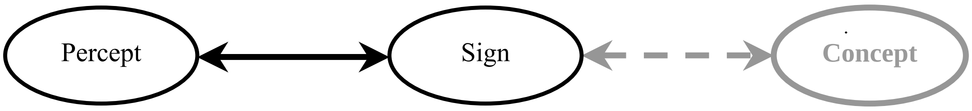

Figure 13. Constituents of Levi-Strauss' semiotic model.

The pair percept – sign corresponds to a side in Frege’s triangle. Percept replaces object and sign includes elements of concept. In this scheme the sign has become downgraded from its status in the triangle where it occupies a vertex and designates the triangle. Here it is inferior to the concept. Levi-Strauss proceeded and introduced another pair, percept – concept, corresponding to the basis of Frege's triangle (Fig. 14).

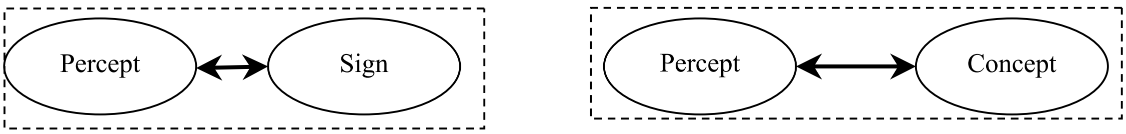

Figure 14. Levi-Strauss' complementary pairs.

If we apply the Levi-Strauss approach to science teaching, we obtain a structure partially resembling the one we have addressed above (Fig. 8): science teaching, the sign, occupies an intermediate position between science and the philosophy of science. In other words, science teaching provides the student with a kind of initial view of the meaning of science, which is ultimately provided by the philosophy of science.

These ideas bring us to another cultural notion – *bricolage*, the craft of manipulating objects at hand (a well determined set) towards a certain goal. Indeed, science teaching, situated between science and the philosophy of science, recruits elements from science. The bricolage nature of science teaching expresses itself by manipulating scientific texts without creating new scientific knowledge. Teaching is concerned with elements of knowledge which can be arranged and explained in other ways. It therefore stands in contrast to both science and the philosophy of science, both of which are open to new concept constructions and interpretations. The situation resembles the relationship between engineering and technique, where the latter uses the former as tools, describes and explains them, but never creates new ones. As shown in Fig. 15, in this perspective *sign*, *bricolage* and *science teaching* have similar status, as do *percept*, *previous constructions* and *science*.

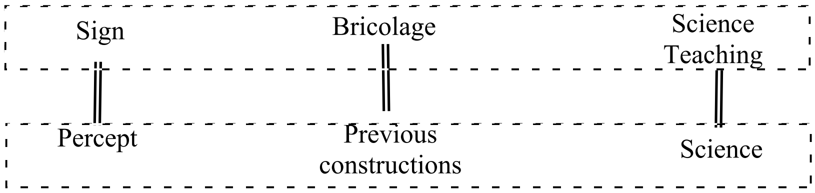

Figure 15. Symbolic representation of the relationships between *sign*, *bricolage, science teaching* and *percept*, *previous constructions, science*.

An interesting implication follows. While the philosophy of science (that conceptualizes science) can be unambiguously expressed[17], science teaching inevitably possesses certain vagueness, owing to the act of signification. Both teacher and learner have to struggle to enable the latter to understand and assimilate elements of scientific knowledge. This is difficult for a variety of reasons (skills, abilities, background knowledge, social environment, etc.). Levi-Strauss (1966) wrote:

> …the concept seeks being readily understood, whereas its sign allows, and even requires, the incorporation of human nature into the situation. In other words, the sign (according to an accurate but difficult to understand, remark of Peirce) is "addressing somebody".

A striking feature of science teaching, if it is recognized as a bricolage activity, is its finiteness, despite the activity of science educators who continuously create new analogies, metaphors and simplifications in order to elucidate concepts and theories. Educational products are constructed and arranged by different authors in different countries for different types of consumer. In a sense, curriculum designers remind one of myth tellers who break old myths into pieces in order to create new ones. The experienced listener may recognize the same elements and the same heroes from the limited space of mythological repertoire. The play, however, is always essentially limited.

However, as a result of these reconstructions a new phenomenon may occur: the previously presented goal in the course of bricolage activity may become a means for a new goal, and the previously used means may become the new goal. Thus, originally, the goal of science teaching was science itself. That the teaching should be interesting and attractive for the learner was a secondary consideration. As time progressed, however, science teaching began to focus on the effect that a knowledge of science would have on student skills, such as the power of reasoning and the ability to solve problems, and science began to be considered by many, as a tool for developing the thinking power of children (Anderson et al. 1970) or contributing to their scientific literacy (AAAS 1990). Among the new goals were to provide: enjoyable schooling ("science is fun"), useful information and skills ("science is relevant"), individual social safety ("science is a reliable and worthy investment"). We thus observe the exchange of goals and means which is a fundamental feature of bricolage culture occupied with the given set of elements. This situation will not change as long as science and science teaching continue to possess the degenerate semiotic structure of sign-object.

Features of science teaching as a bricolage activity

As a result of constructing patterns of scientific knowledge, education practitioners have developed valuable views on how science should be presented to novice learners. Multiple attempts to interpret and explain science in different ways have led to the discovery of various meanings of and interrelations between different elements of knowledge. Shulman (1986, 1987) defined this understanding of science as pedagogical-content knowledge (PCK).

For example, seeking learners' understanding of electrical circuits, physics educators revealed the special importance of the microscopic picture of processes which had been neglected in traditional presentations and practical problems.[18] In order to convey coherence in teaching electromagnetism educators introduced relativistic ideas already in introductory physics courses.[19]

Generally, one can identify three important features of science teaching related to its *bricolage* nature.

Firstly, the process of comprising various elements of scientific knowledge for the goal of teaching causes "centripetal curricular forces", creating a certain holistic view on the world[20], sometimes even beyond science itself.[21]

Secondly, when using science as a resource, science teaching chooses and organizes elements of scientific knowledge according to certain levels of complexity and evaluated validity. Thus the bricolage nature of the science curriculum necessarily reflects and expresses certain attitude to disciplinary knowledge, including science fundamentals, concepts and paradigms.[22]

Thirdly, as any bricolage, being oriented to practical goals science curriculum often and naturally gravitates towards such curricular forms as solving problems and practical assignments. Hence, theoretical content and the historical and philosophical aspects of science receive much less attention and sometimes disappear.

Departure from bricolage: the removal of sign degeneracy

Despite the important advantages due to its bricolage nature, changes in science teaching remain limited for the same reason. This might dissatisfy educators seeking essential progress. Is there any hope for new meanings to be developed in science education? The answer to this question may be "Yes" if we can remove degeneration and restore the triangular semantic pattern of the sign (Fig. 16a). Thus, the pair *Previous constructions – New construction* forms a triad with *Engineering* (Fig. 16b) (Levi-Strauss 1966). Similarly, to *Science – Science teaching* we can add the *Philosophy of science* (Fig. 16c). This step provides new meaning for science teaching which cannot be found in science content.

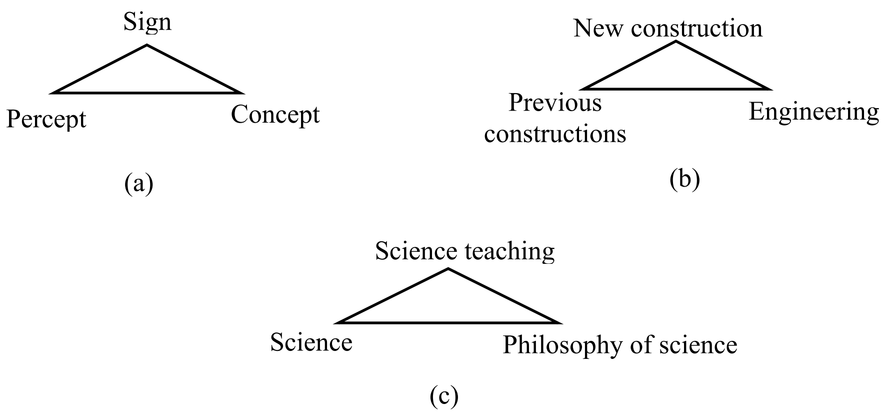

Figure 16. Overcoming degeneracy in the pairs (a) *Percept - Sign*; (b) *Previous constructions – New construction*; (c) *Science - Science teaching*.

Indeed, Schwab had suggested this step with regard to scientific curricula in his seminal work "Problems, Topics, Issues" (1964) which incorporated epistemological and ontological philosophical aspects of scientific knowledge into curriculum. His proposal represented a transition from instruction based on craft to instruction including engineering. Similarly, learning by enquiry was introduced into the teaching of biology (e.g. Schwab 1964b). Since then this method has been widely adopted, discussed and investigated (e.g. Amir and Tamir 1994).[23] Recently, we have suggested breaking the bricolage degeneracy of science education by teaching a discipline-culture instead of a discipline (Tseitlin and Galili 2005).

Some educators have already prepared the basis and conditions for "non-bricolage" science teaching by advocating the introduction of the history and philosophy of science into the regular science curriculum. Matthews (1994) reviewed progress in this area, and the contents of the present Journal reflect the ongoing discourse in this domain of educational research[24].

Further progress: expansion into the humanities?

At the present time, however, most science teaching retains its bricolage nature of activity. Nevertheless, society is changing markedly and, in relation to this, the current crisis in science education is a cause of concern to many of its practitioners.[25]

Many researchers have grappled with the question of how science should be taught in contemporary society, where basic values and people's interests undergo fundamental changes.[26] One possibility is the STS (Science-Technology-Society) approach, which regards the *social relevancy* of the learned material as both the *starting* point and *central* point of science instruction (e.g. Yager 1985, Fensham 1986, De Boer 1991).[27] Others suggest the application of research-based pedagogy and research-guided support of problem solving (e.g. Handelsman 2004). Still others proposed broadening of the curriculum by introducing the culture of science, thus matching the newer cultural interests of students (Tseitlin and Galili 2004). We believe that the introduction of the philosophy of science into science teaching would lead to new types of curriculum or, at least, a marked improvement in existing ones.

Of course, we realize that if we remove bricolage from science teaching, we may find that the philosophy of science only partially represents the actual cultural expansion of the curriculum. This is because it is difficult to restrict a philosophical discourse to a certain issue, to isolate it in a certain area. To a great extent philosophical discourse is inter-contextual. Therefore, a curriculum based on a certain philosophy of science will inevitably touch on the issues posed not by the philosophy of science, but rather by Philosophy with regard to science. Perhaps quite unexpectedly for some, such a curriculum will find itself addressing not only epistemology, but also domains such as ontology (materialism versus idealism), logic, ethics, values, feminism, etc. (Matthews 1994). All these, although strongly interwoven into the philosophy of science, belong to general philosophy. Nowadays, educators advocate addressing such topics in science curricula. This represents a move towards the humanities, as shown by the semantic triangle of Fig. 17.

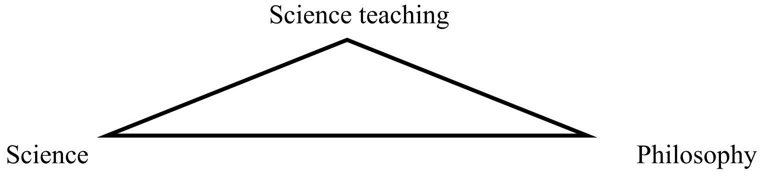

Figure 17. Movement of science teaching into humanities (philosophy).

Unlike the triangle of Fig. 6, the triangle of Fig. 17 does not present the semantic triangle of Frege, because philosophy is more than a concept of science. Within such an educational approach, the learning material and subsequent class discussions may shift from pure science. Such a shift implies destruction of the sign "science teaching" – a break between the sign (the phenomenon of science teaching) and what it is supposed to signify (the phenomenon of science). Through its teaching science will meet the discourses it often avoids in other circumstances: aesthetical, ethical, logical, etc.

The philosophy vertex of the semantic triangle (Fig. 17) suggests such a teaching in which the scientific content is presented as a "cultural adventure" and science appears within a wider framework of human thought. We thus see that science (physics, biology) competes with their predecessor, natural philosophy, as to which presents the more inclusive picture of the world (just as physics competes with mathematics regarding conceptual leadership in their relationship)[28].

The semantic triangle and the individual knowledge

Science teaching, like science itself, is a social phenomenon and cannot be regarded either as independent of people or as the same for all individuals. Despite having well defined concept and conceptions, it varies from person to person. With regard to teachers this fact presents an obvious problem. The knowledge of the teacher depends on his/her level of training and experience, as well as on whether he/she was trained as a scientist or science educator.

The semiotic approach provides a framework within which it is possible to represent the knowledge regarding science teaching (as a phenomenon) held by individuals and its specific features (Stepanov 1971).

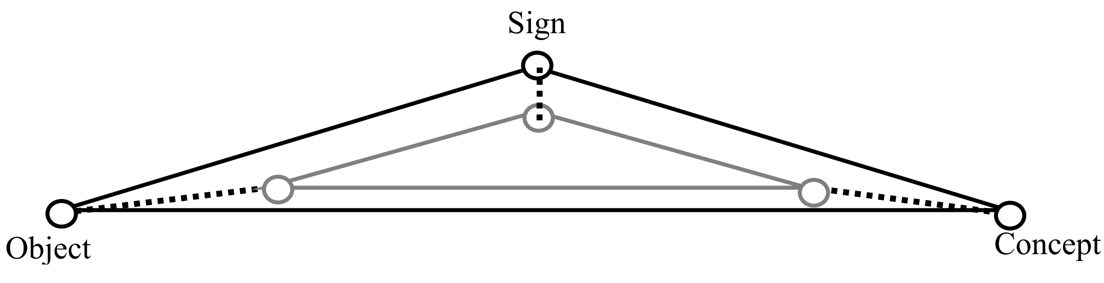

Figure 18. Doubling of the semantic triangle.

When a person reflects on an object or phenomenon, he/she, in a sense, doubles it in his/her cognition by giving it a personal meaning. This is illustrated in Fig. 18 where the outer semantic triangle represents a real object, its sign and its concept (or cultural phenomena, as in Fig. 6). The inner triangle applies to the individual. Thus there are two vertices for the object, one for the real world (or society) and the other for the mind of the individual. The latter corresponds to the impression of the object (such as the perception of spherical nature of a ball). Similarly there are two concept vertices, because the concept developed by an individual (based on the senses) will be different from that constructed by society generally. Accordingly, the sign applying by the individual, is different from that adopted socially.

In summary, the external triangle may be identified with the abstract notions of "community consensus knowledge" (Redish 2003) and the internal one reflects the "personal knowledge" of the science user.[29] For example, Tall and Vinner (1981) reported that different individuals possess different "concept images" of the same mathematical notion. The dissonance between concept *definition* and concept *image*, which we could represent as a dissonance between internal and external triangles, has been identified as a cause of a failure of performance and learning in mathematics (ibid.).

We illustrate, in Fig. 19, three cases where the deformation of the inner triangle reflects the education background of the teacher.

Figure 19a could apply to a practicing scientist who also teaches a university course. His/her perception of science is the result of personal experience, but his/her ideas of teaching, as well as of the philosophy of science, are commonly intuitive (since neither science teaching nor philosophy of science courses are usual requirements for science majors). His/her philosophy may come from chance remarks heard in lectures, personal reflections or texts of prominent scientists (such as Einstein, Bohr or Heisenberg[30]) who occasionally reflected their philosophical views. Such sources seldom connect science with its teaching. A scientist-teacher realizes that there is a big gap between scientific practice and science as a subject of learning in educational institutions. At the same time, he/she understands the necessity of teaching science to the next generation and is often frustrated by his/her inability to provide the learner with the adequate image and spirit of science. He/she thus cares mainly about the *accuracy* of what he/she imparts, the scientific correctness of the delivered material.

Figure 19b might be relevant to a science teacher in an elementary or middle school, who has been trained solely within the stream for prospective teachers. Here, concepts of science come from teacher training courses together with pedagogical knowledge. The ideas of the philosophy of science may be totally lacking (or, at best, intuitive), since this subject is usually absent from such curricula. The educator may believe that what he/she teaches is true science, and his/her major concern is with the *clarity* of the material and its *assimilation* by the students. In cases of problems with subject matter, such a teacher normally turns to practicing scientists.

Figure 19c reflects a high school teacher trained in a special stream of a university science teaching department. He/she would have been exposed to the fundamentals of philosophy of science, as well as to the theory of science teaching. However, this educator is somewhat distant from actual science practice and sees science schematically, through its meta-languages. Here there might be a problem in identifying the *learning* of science with the *practice* of science. Such confusion would be enhanced by the problematic and sometimes misleading analogy between student and researcher (Tzeitlin and Galili 2005).

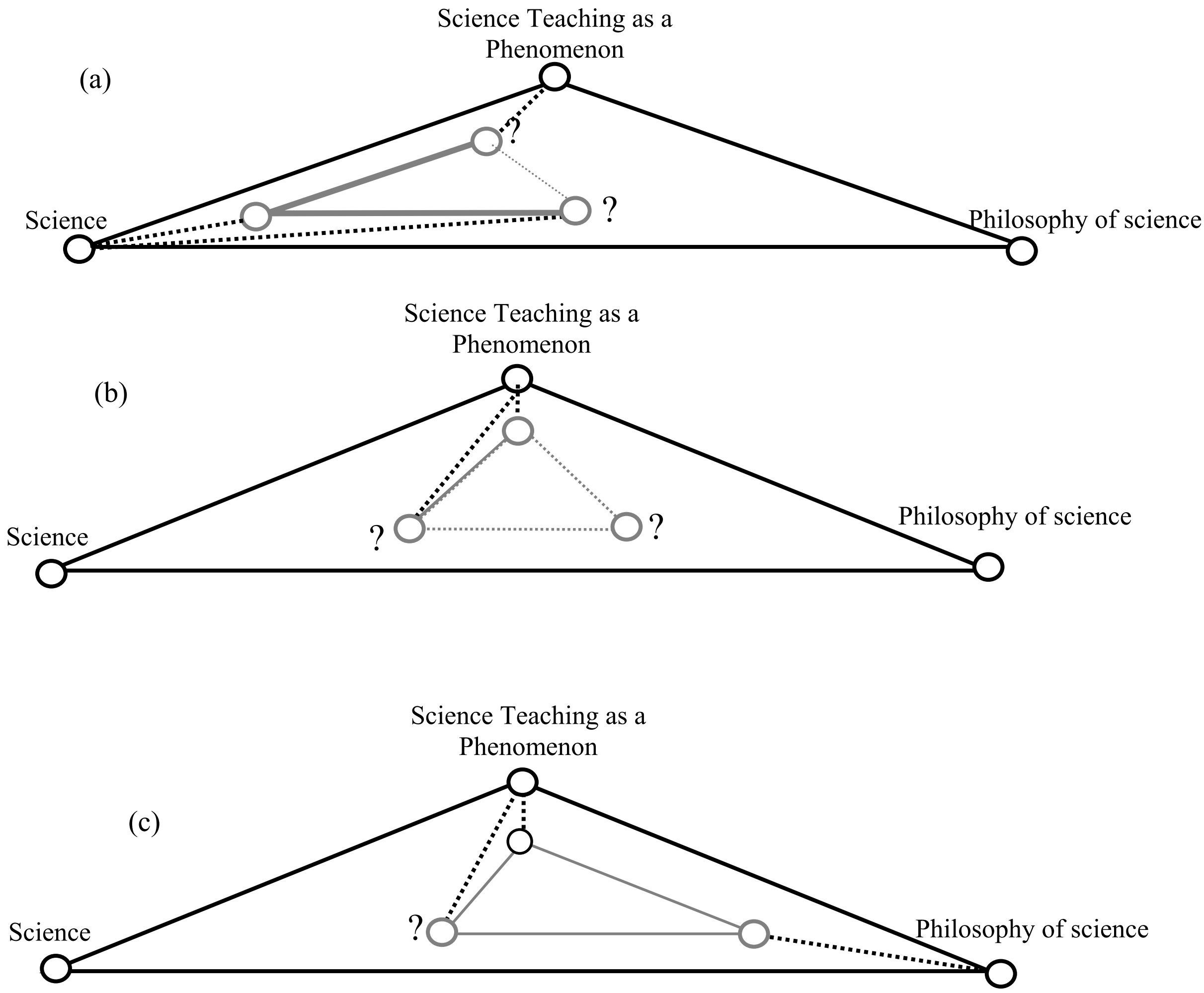

Figure 19. Doubling of semantic triangle for (a) Scientist lecturing at university; (b) Elementary or middle school science teacher; (c) High school teacher (university science teaching trainee).

We have tentatively chosen the above examples in order to represent the wide variety of the types of knowledge characterizing the community of science educators[31]. This should be taken into account in any attempt at curriculum innovation. For example, an attempt to introduce elements of research into science instruction and assessment may produce poor results if the nature of scientific research is poorly understood (Galili and Sella 2004). Similarly, the lack of an adequate background might hinder attempts to teach the philosophy and history of science (e.g. McComas 1998).

We hope that these ideas may help designing training programs for prospective educators and encourage adoption of the semantically (culturally) balanced templates.

Implications for the science teaching discourse

The semiotic view of science teaching has significant potential for contributing to the discourse on science teaching. It allows recognizing the bricolage nature of science teaching in its retaining in the attempts solely to copy science. Even our limited treatment, which has focused on "subject matter", has shown that the veracity of knowledge held by teachers is an important factor in this discourse as well as in teaching practice.

Progress could come from the removal of semantic degeneracy by including philosophy of science and, to a certain extent, general philosophy in the science teaching discourse. The fragmentation of modern science into almost self-contained subjects stands in contrast to the holistic intentions of science education. We believe that the necessary discourse on science teaching can and should produce its own distinctive *collective knowledge* and thus reconstruct science teaching in tune with the culture of contemporary society.

The process of degeneracy removal is already under way. Bruner (1960) in his important text *The Process of Education* suggested his own idea for introducing structure into the curriculum.[32] Schwab, who did not agree with these ideas, in his famous *Problems, Topics and Issues* (1964a, 1978) presented an alternative vision of the scientific method and the structure of science that should be taught. He introduced the notions of "enquiry", "substantive knowledge" and "syntactic knowledge". The works of Bruner and Schwab, both being of a critical nature, belonged to the theoretical discourse of science teaching and contributed to its maturation. The discourse was not consolidated at that time: Schwab, although he addressed philosophical issues of science and its method, never quoted Popper's fundamental contribution to this subject, and Kuhn, although he wrote about paradigms of science, never mentioned the related subject of Schwab's substantive structures.

The trend in science teaching discourse towards removing degeneracy continues.[33] If we regard science teaching as a sort of *critique of science* itself, we see the trend as leading towards the establishment of a critical philosophy of science and a kind of metaphysical theory (e.g. Arons 1997).[34] The contemporary science teaching discourse is creating collective knowledge and a "community consensus" among science educators (Redish 2003). The external semantic triangle of science teaching (Fig. 18) is thus established.

Magic of physics teaching

The bricolage nature and semantic degeneracy often prevailing in science teaching make it almost magical in character[35]. The aim of science teaching is to influence learners, but since little is known about the mystery of the learning process, teaching practitioners often tend to irrationality. The situation in a science class sometimes resembles a primitive society, practicing a system of signs rather than concepts; the science curriculum becomes fixed and sacred. Deviations from the traditional set of disciplinary topics and conceptual changes are rare. Commonly instruction in physics, for example, focuses on the drilling of standard problems, in a fixed order, without conceptual understanding (e.g. Halloun and Hestenes 1985). In a physics curriculum lacking in holistic philosophical aspects everything is equally important, and the “the order of things” is blindly and scrupulously followed: nobody knows where and what for, except the final examination. This is a salient feature of magic (Levi-Strauss 1966):

> One may say that keeping its very place makes a thing sacral and the violation of this location, even imaginary violation, appears as destruction of the whole world order; hence the object, by occupying its place, contributes to preservation of this order.

For example, the concept of weight is still usually taught in the form introduced by Newton back in 1687, despite the fact that more than a hundred years have passed after Einstein's introduction of the principle of equivalence, implying a new definition of this concept (Reichenbach 1927, Galili 2001).

Lacking a knowledge of the concept of science, education practitioners often use to imitate the goal subject. Imitating the activity of scientists becomes a pedagogical strategy of introduction to science ("Like produces like" – a magic rule). Thus immature "science projects" sometimes replace genuine learning by playing science superficially. Reasoning gives way to quoting.[36] Such training virtually presents practicing magic.

Another magical feature appears in the form of blind respect for authorities in science. This takes place when students, lacking knowledge of the subject, apply reason by quoting a person traditionally respected. Using the great names as a sole argument represents magical behavior. By contrast, break-throughs in scientific thought were made by those who were ready to challenge scientific authorities and prevailing philosophies. Quantum physics and relativistic physics originated in this way, being developed by young physicists despite authoritative resistance.

Traditionally science and magic present opposites which "...could be placed in parallel, as two means of comprehension, unequal in theoretical and practical results" (Levi-Strauss 1968). Although contrasting each other in rationality and objective causality they often are not well distinguished in science education. In the history of science, science and magic were deeply interwoven (Kearney 1971). However, the *philosophy of science,* by rectifying the concept of science and exploring its meaning, divorced science from magic. By making knowledge of scientific epistemology explicit, by addressing the nature of science and its norms, the *philosophy of science* could similarly affect science teaching, removing degeneracy from the science teaching semantic triangle.

Conclusion and implication

In this study we have applied a semiotic approach to science teaching, the latter being a sign. We were able to elucidate meanings of science teaching as a cultural phenomenon, and we suggested that it is determined by the philosophy of science. We showed that the semantic triangle represents the relationship between science, science teaching and the philosophy of science, three related cultural phenomena. Here, then, is a language by means of which the conceptualizations of science teaching can be represented, compared and discussed. Using the graphical representation of semantic triangle can support clarification of the meaning of various ideas in the discourse of science teaching.[37] It thus allows one to represent the collective knowledge of science teaching, as well as the wide spectrum of individual knowledge held by science educators, in terms of semiotic categories. It suggests a disciplinary discourse, which should include scientists, science teaching researchers, as well as philosophers of science and philosophers in the humanities. Such a discourse could affect the currently prevailing bricolage nature of science teaching and remove the degeneracy of the “science – science teaching” pair.

We anticipate the establishment of a theory of science teaching, which will serve as a meta-language for science teaching, just as philosophy and the methodology of science are meta-languages for science. Besides its heuristic importance, this meta-language would facilitate training practitioners in science education. Such a role is shown by the semantic triangle of "teaching of science teaching" (Fig. 20), which parallels that of science teaching (Fig. 6).

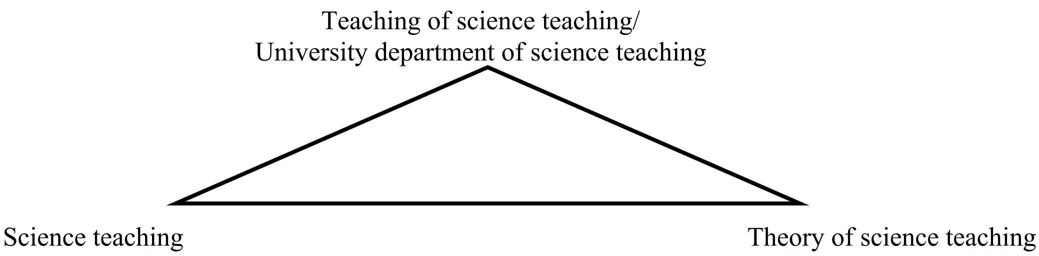

Figure 20. Semantic triangle for the "teaching of science teaching".

The theory of science teaching conceptualizes science teaching and has different connotative meanings with respect to the learner, the teacher, and the learning environment (Schwab's commonplaces). These categories present a subject for theoretical analysis in the context of various curricular strategies. Like the semantic triangle for science teaching (Fig. 6), the triangle shown in Fig. 20 expresses the idea of a cultural approach which allows a variety of education realizations according to the different theoretical interpretations of the basic categories. Despite the publications of Schwab and other theoreticians, the naïve conception of the curriculum as a mirror reflection of science still prevails. The new vision could play an important role in the training of experts in science teaching.

The semiotic approach to *science teaching* as a cultural phenomenon suggests that *science teaching* serves as a sign for *science*, just as *science* is a sign for *nature*, expressing culture.

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Notes

[1] This device of first asking a question was used in antiquity by Plato (1952), Aquinas (1952) and Galileo (1632, 1638). Collingwood (1939) has described this "question and answer" logic as the proper way to convey a full understanding of a subject. He wrote that "in order to find out his meaning you must also know what the question was (a question in his own mind, and presumed by him to be in yours) to which he has given or written an answer" and that "the meaning of a proposition is in the question it presupposes and answers". Gadamer (1975) further supported this requirement.

[2] In another paper we have addressed the question "What is science teaching?" by analyzing the status of a textbook in teaching science (Tseitlin and Galili 2004). Two questions find their parallel when considering a concrete object, say a chair. One can ask "What is it (chair)?" or "What is the meaning of it (chair)?" Here, of course, the latter question would not be asked (unless in a sophisticated context).

[3] Different authors represent the same ideas by different terms. Thus character, sign vehicle, word could be also used for sign; referent and thing for denotatum; meaning and notion for concept (Noth 1995).

[4] Another of Frege's examples, that "morning star" is the same as "evening star", became famous.

[5] In certain cases, of course, it might be possible to explain a proper name. Thus Aristotle could be explained as "a great philosopher" or "a student of Plato". However, this cannot be expected of a generic reader. Such an understanding requires more than knowledge of the language; it requires familiarity with a culture.

[6] Let us bring another example to clarify our intention. Consider the word *clock*. It signifies a certain object (detonate) – a device for measuring time. This device, in its turn, is widely considered as a sign of time. Our interest in science teaching is similar to regarding the device "clock" as the sign of time.

[7] Examples in recent time are Mach, Einstein, Bohr, Born, Landau, Feynman, Cooper and Glashow who were active on the frontiers of physics research but wrote popular accounts of introductory and advanced physics, as well as essays addressing philosophical reflections (e.g. Heisenberg 1958).

[8] The teacher is challenged regarding the nature of science when he/she is asked "What color are atoms?" or "In my experiment pV varied. Is the law wrong?"

[9] This statement refers to the degree of complexity of the curricula (such as how much mathematics is used) and, to a lesser extent, to the concepts and types of knowledge addressed (Tseitlin and Galili 2005).

[10] It has been suggested that we teach "critical thinking" and "problem solving" using physics as a tool.

[11] In poetry, this might be the major message.

[12] The commonplaces of student, teacher and environment belong to different semantic triangles related to science education. Multiple triangles representing closely related ideas in education recall the plurality of lexical genres discussed by Bakhtin (1986) suggesting existence more than one "genre" of science teaching research in parallel. In a given educational context we may adopt any of these genres independently or in combination.

[13] The mentioned connotations of science teaching definitely deserve attention of researchers. Here we, however, restrict ourselves solely to the science teaching with regard to its subject matter.

[14] The Harvard project, presenting physics in its historical context (Rutherford et al. 1970) is famous. Another approach, recently suggested, presented physics as a family of discipline-cultures, sharing an arsenal of concepts. Each discipline-culture included, in its periphery, both historically surpassed and more advanced ideas regarding the same discipline (Tseitlin and Galili 2005).

[15] This is true, at least, with respect to science teaching at advanced levels of instruction.

[16] Barthes's view was that social sciences were not determined by specific boarders of knowledge (which, in any case, are often vague), by special research method (which varies from area to area) or particular ways of presentation. He suggested that society had decided that certain areas of knowledge are to be taught as social science at the university. This view, of course, is highly debatable.

[17] Clarity of concept meaning does not imply a fixed idea. Concepts often have a rich history of change in meaning (e.g. Jammer 1957).

[18] Eylon and Ganiel (1990) stated the need for the micro-macro relationship to be explained in physics instruction. This was implied by Chabay and Sherwood (1995) and Galili and Goihbarg (2005).

[19] Traditionally electromagnetism is taught within introductory courses without mentioning the relativistic nature of electromagnetism. The latter is required for the meaningful learning (Galili and Kaplan 1997).

[20] Introduced by science educators this knowledge can be related to the *syntactic* knowledge stated as necessary for science education by Schwab (1978).

[21] Curriculum designers and teachers sometimes oversimplify scientific knowledge, making it even wrong for the sake of simplicity. For example, electromagnetism is often presented as coherent with Newtonian physics (Galili and Kaplan 1997, Tseitlin and Galili 2005).

[22] Introduced by science educators this knowledge can be related to the *substantive* knowledge (Schwab 1978).

[23] As a result of the efforts of these educators, a special research-based matriculation examination in school biology was introduced into the Israeli system of education. Its ideology stemmed from the ideas of Schwab.

[24] The reports from four international conferences of the International History, Philosophy and Science Teaching Group contain pertinent materials: http://www.ihpst.org

[25] This crisis is cultural. It manifests itself in the fall of student numbers in science classes in high schools where science is an elective subject. Numbers are (proportionally) lower than they were in the sixties; more good students elect not to take science classes; hostility to science is much higher (science is identified with drugs, Chernobil and other nuclear accidents, nuclear weapon, etc.); anti-scientific feelings are common among youth (as evidenced by "gruners" and similar movements). Physics curricula presently include less material and university entrance requirements are of a lower standard. Pietschmann (2001) provides an interesting view on the present crisis in science education.

[26] For instance, the meeting “What Physics Should We Teach?”, ICPE/SAIP International Physics Education Conference, 2004, University of Kwazulu Natal, Durban, South Africa was devoted to this topic.

[27] In this connection great effort has been invested in the USA in the program "Science for all Americans. Project 2061" (AAAS 1990), and in Israel in "Tomorrow 98".

[28] One criticism of expanding into philosophy in science course is the claim that in introductory teaching it is not possible to adequately explain a wider picture from the beginning. This however should not be necessary true. Just providing a wider picture (such as by exposure of the method, or addressing the paradigm of the theory) can make the presented scientific content more meaningful for the student and make teaching an intellectually unlimited area.

[29] In Peirce's philosophy, the way in which an idea is conceived is influenced, not only by the consumer, but also by the context in which it is presented. Thus, the same sign “color” will correspond to different ideas in physical optics, art, biology, etc.

[30] A representative example from recent time is Weinberg’s book *Facing up* (2001).

[31] The deformation of the inner semantic triangle in all our examples as if supports Schwab’s (1978) negative answer to his question “Who knows?” with regard to optimal science curriculum. Our intention here was only to demonstrate the complexity of knowledge requirements facing science educators.

[32] The ideas reflect the general interest of Bruner in structuralism and the influence of Piaget (1970). See also DeBoer (1991).

[33] A recent issuer of *Science and Education* (Vol. 13, 1-2, 2004) was devoted to the meta-scientific discourse and addressed philosophical matters relevant to education. Examples of other meta-physical contributions to the science teaching discourse are Galili and Tseitlin (2003), analyzing the meaning of Newton’s law of inertia, and Tseitlin and Galili (2005), suggesting a new cultural paradigm of physics teaching.

[34] Science teaching is often accompanied by comments or value statements regarding various elements of scientific knowledge. For example, teachers and students use to express their preferences (positive and negative) for certain types of knowledge: operational definitions, microscopic models, conceptual explanations, etc.

[35] We understand the term magic (*ars magica*) to be defined as the “Use of means (such as charms or spells) believed to have supernatural power over natural forces” (Encyclopedia Britannica).

[36] Courses focused on preparation for examinations often teach procedures regardless conceptual understanding. This spreads in the public an image of science as a collection of rules and recipes for solving problems instead of theories and ideas explaining nature, being of limited validity and a subject to change and improvement.

[37] This procedure resembles the use of diagrammatic methods in theoretical physics. For example, Feynman diagrams symbolically represent the complex mathematical expressions accounting for the processes which occur among elementary particles. Although, in principle, there was nothing new in replacing a mathematical expression by a diagram, in practice this led to the method of renormalization, a major advance on the theoretical front. Today, presentation of elementary particle physics without diagrammatic formalism would be unthinkable.