Meaning and symbolization in scientific contexts

MARIA TARANTINO
University of Bari (Italy)

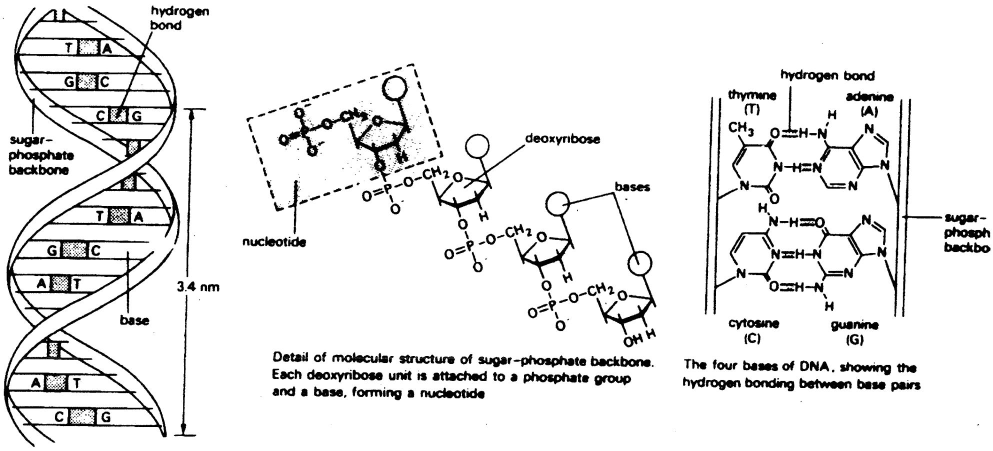
Psycholinguists and cognitive scientists seem to agree that in science education knowledge acquisition and discourse processing skills depend on the meaning which the protagonists of the pedagogic interaction use to interpret thought processes and to explain objects and events of the factual world. The question remains open, however, as to how this meaning is established, transmitted and expanded (cf. Anderson 1980, Erickson 1984).

The working hypothesis presented here is that in scientific contexts meaning has a composite nature and that it depends on thinking, perceptual, rhetorical and pragmatic processes which are concomitant of specialist training and practices. Such processes are anchored into epistemic, methodologic and symbolic referents which relate to 'transdisciplinary' and 'multidisciplinary' models of investigation and argumentation. They guide both the growth of knowledge about nature and the organization of discourse upon this knowledge. The students of science are trained to interpret and map aspects and events of the physical world through the orchestration of concepts, procedures, and codes whose meaning are discipline-based and grafted on to mathematic, geometric, physical, visual and verbal systems of representation. Through the educational process, the cognitive, perceptual, and communicative skills of the learners are enriched with the conceptual models, strategies and symbolic patterns which lend meaning to the languages used in the research domains which partake in the development of science.

I must first specify that the model suggested here relates to meaning attribution, acquisition and communication in the fields of research and pedagogy known as the hard natural sciences. In such contexts the term 'scientific' denotes knowledge of facts, phenomena and causes verified by following the Galileian method of inquiry, explanation and description of nature. This method develops on -systematic observation of events and processes; – hypotheses about their nature; – setting of theoretical models which may explain their properties; – causes and effects; – delimitation of experimental possibilities in consideration of cognitive and mechanical tools available; – experimental tests; – evaluation of findings; – validation of hypotheses; – deduction of possible explanation, generalization and application.

Through this approach and by following Galileo's suggestions that the book of nature should be read and mapped in terms of mathematic, geometric and physical concepts, procedures and conventions, science has succeeded in visualizing, understanding and explaining more and more complex realities.

A clear example of this feat may be given by relating to the discovery of the fundamental constituents of genetic material: deoxyribonucleic acid (DNA). The nature of this molecule has been determined by theoretical and experimental means and its qualitative and quantitative dimensions have been identified on mathematic, geometric, physico-chemical grounds. Then its constituent properties have been termed by drawing on disciplinary semiotic contexts. This can be appreciated from the following figure:



Double helical structure of DNA

Detail of molecular structure of sugar-phosphate backbone. Each deoxyribose unit is attached to a phosphate group and a base, forming a nucleotide

The four bases of DNA, showing the hydrogen bonding between base pairs

Molecular structure of DNA

In this diagram, the elements and processes which constitute 'deoxyribonucleic acid' are visualized in three-dimensional space. This representation provides a concrete picture of the basic constituents of DNA: sugar phosphate, thymine, adenine, cytosine, guanine and of their interrelation. Besides defining the content of each constituent, the conceptual, visual and symbolic display reveals the features which differentiate the specific molecule from other vital agents, such as ribonucleic acid (RNA), which contribute to the metabolism of the cells of living organisms. As is usual with the scientific universe of discourse, the term-symbol 'DNA' and its characterization at the different dimensions make the concept a member of a systematic semiotic domain, give it trans-linguistic value and open it to further investigation and definition. Clearly, to access and use the terms, concepts and relations which can support a discussion on the specific subject one must draw on complex semiotic webs and be aware of the cognitive, procedural and instrumental components of the relative research and discursive field (cf. Tarantino 1997).

This awareness builds on transdisciplinary and multidisciplinary sources of knowledge, meaning and discourse. Transdisciplinary sources are termed mathematics, geometry, physics, chemistry and statistics. These disciplines elaborate the principles, rules, norms, conventions and operative strategies that govern scientific research and discourse. As a consequence, they provide the basic cognitive, procedural and symbolic systems required across all the field of study concerned with scientific education. Multidisciplinary study fields are, instead, the knowledge domains which explore aspects of the factual worlds in depth and from different perspectives. Such disciplines ground their epistemic and discursive practices on the conceptual, procedural and semiotic webs provided by transdisciplinary subjects, but combine them with analytic and procedural tools of interrelated fields of research (cf. Tarantino 1995). For instance, molecular biology encompasses, concepts, terms and operations which draw on biochemistry, cytology, histology, genetics, enzymology, immunology. In turn each of these branches of research constitutes an independent discipline with specific thematic focus and interests. Obviously, the different fields of research, constellating the scientific universe, work in syntony in the effort to systematize and improve theoretical, experimental and applicative knowledge domains.

Obviously, linguistic studies contribute to scientific development both as transdisciplinary and as multidisciplinary subjects. The former role is played by general linguistics (GL) which systematizes the rules and principles and establishes the norms of grammatical correctness. The latter include language for specific purposes (LSP) studies, which are concerned with discourse features. In other words, they combine questions of grammatical precision with concerns related to content, epistemic and pragmatic aspects of text organization. Even though woven into other systems of conceptual and semiotic representation, the language system has a fundamental role in the creation and transimission of meaning in science.

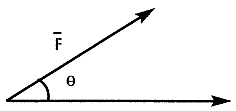
The students of science realize that meaning has a primary role in scientific education soon after entering university. Usually their previous formal studies will show inadequate to meet the challenges posed by the transidisciplinary subjects when studied in the advanced academic settings. In this context, the learners must engage in acquiring the cognitive, pragmatic and discursive maturation required to map the physical reality according to the scientific method. This maturation will depend on a stage-by-stage process which will result in the development of schemata: «...networks of concepts and relationships that guide thinking processes» (Selz 1913, 44), as well as of skills to handle problems and discuss and represent them according to the multi-dimensional system of science.

The students who will specialize in the different branches of research and teaching may start their journey through formal training with the knowledge that the word 'work' has a synonym in the lexis 'labour', that both linguistic items can signal manual, intellectual and other activities and that they may be associated with schemata and discussion on employment, wages, trade unions. Soon they will experience a semiotic shift which involves logical, perceptual, semantic and motor extension. They will learn that in scientific domains the term 'work' has one precise meaning: **exchange of energy** which is measured in **joules** (**J**) and that the schemata related to this term depend on well defined concepts and symbols such as: **force vector** (F), evaluated in **newtons** (**N**), and **displacement vector** (**s**), gauged in **metres (m)**.

They will be introduced to the algebraic formula defining **W**:

$$\mathbf{W = F\ s\ cos\theta}$$

where **F** is a constant force; **s** represents the distance covered by the object in linear motion; **q** accounts for the angle of $\overline{F}$ with respect to $\overline{S}$. At the same time, they will be demonstrated that this simple equation involves physical and mathematical concepts which have a precise geometrical representation:



The students will be trained to use the concepts and procedures embedded in the formula and diagram above first in their elementary version, then integrated with other concepts and symbols of varying complexity as required to solve theoretical and practical problems related to different realities and purposes (cf. Kuhn 1970). In the process, their conceptual world will expand and they will learn that the symbols used in this and other scientific contexts are international standard units (IS) with specified quantitative and qualitative values.

The students will find out that in scientific environments the term 'energy' in not an abstract concept since it has concrete qualitative and quantitative dimensions which depend on the processes which generate it. In view of such processes, energy will be classified as potential, kinetic, thermal, atomic, electromagnetic, chemical. They will also discover that energy transformation and transfer are responsible for macroscopic and microscopic processes such as the birth of a star or the production of DNA. More importantly, they will learn to calculate, explain and illustrate such processes in precise details by drawing on the semiotic and verbal systems of the different disciplines which make up the specific curricula.

Through the staged process which leads them from elementary to more complex systems, classifications and activities the students of science become «... users of special subject languages by degrees and repeat in some sense the process of the development of the special language itself» (Sager et al. 1980, 39). This exploration makes them aware also of the 'ontology,' 'causation' and 'epistemology' which drive scientific models, investigation and argumentation (cf. Searle 1990).

Even though the cognitive, pragmatic and discursive development is of a more complex nature than the one related to children second-language learning contexts, in science education, the knowledge acquisition process seems to share analogies with Titone's Holodynamic Model (1973). It involves interactional, cognitive, pragmatic and linguistic development grafted on to tactic, strategic and ego-dynamic levels of operations.

The framework which establishes knowledge and meaning in scientific contexts features two major classes of interactants. The first is made up by expert/researchers who have «...two principal functions – research and the transmission of acquired learning – ...» (Lyotard 1989, 4). The second includes novice/learners who aspire to become researchers in the specific field. The experts draw on knowledge about general and specific aspects of nature, familiarity with the scientific method and its rules, competence in the use of techniques, instruments, conventions, terminological and symbolic structures through which science progresses and is represented. It falls on them to initiate the novices into the complex and variegated fields of study which contribute to scientific knowledge and to help them «...develop a system of references which organizes and structures notions of the special subject...» (Sager et al. 1980, 40).

The development of this system is initiated by anchoring the learners' previous knowledge and concepts to the scientific models of representation and visualization of reality. This process has six fundamental protagonist: 1) nature i.e. the **referent** of every scientific observation; 2) accumulated basic and specialist knowledge about the **referent;** 3) the scientific method; 4) the teacher/informer; 5) the student/receiver and user; 6) the operations which support the learning teaching process.

The teacher provides information verified through scientific inquiry about the 'referent' and must then support what he says with proofs which may be theoretical or factual. He also illustrates the functioning of the instruments which have contributed to the findings, draws and explains diagrams, discusses mathematical formulae and applies them to solve problems. He defines the meaning of the terms used in reference to the disciplinary context. His lectures includes writing, drawing, problem posing and solving tasks, logical explanation of the thinking and manual steps involved in the tasks.

The students participate actively in the classroom interaction by following the teachers' procedures and by assimilating the concepts and strategies discussed. They learn to observe, analyze and describe aspects of reality according to the scientific method. In the early stages of their studies, they simulate problem solving activities by applying the logico-pragmatic approaches exemplified by the teachers in class or in the lab. Later, they will use what they have learned to map and understand new and more and more complex situations.

At the end of the academic journey, the students will usually have acquired the knowledge and the procedural skills required to study, phenomena with the aid of complex instruments visualize and represent what they can either observe or hypothesize by means of mathematic, geometric, graphic and verbal codes. The elementary concepts and procedures mastered at the beginning of the scientific studies become «...tacit knowledge, exemplars and rules which can be retrieved when required» (Kuhn 1970, 191). The mature students will be able to discuss the models used by their teachers to represent the 'referent', criticize them and hypothesize possible improvements. In other words, they will have acquired the tactic, strategic, conceptual and discursive patterns which establish them as members of disciplinary communities. As such they will also know what can be done, said, verified, explained according to present knowledge standards and rules.

The hypothesis touched on would require a more extended analysis than the time and space available allow. However, the brief overview presented seems to support the conclusion that meaning and knowledge acquisition and expansion in science are intimately connected with the conceptual, pragmatic and symbolic webs which underlie scientific growth. As a consequence the process which generates meaning in this context cannot be effectively explored without giving appropriate attention to the disciplinary-based variables which determine understanding and discourse expansion.

Psycholinguistics and cognitive psychology have already emphasized the the need to explore how meaning is acquired, transmitted and developed in tertiary education settings. In so doing, they have also revitalized the discussion on the function that questions of truth conditions and semiotic features can have in discourse coding and decoding processes. It seems appropriate to conclude that theoretical and applied linguistic studies should consider the discussions provided by the sister disciplines and include concerns as to how cognitive, procedural and symbolic models shared by the interactants can influence communication, and then extend their models accordingly.

REFERENCES

Anderson, J. R. 1980. *Cognitive Psychology and its implications.* New York, John Wiley

Erickson, G. 1984. Theoretical and Empirical Issues in the Study of Students Conceptual Frameworks. In P. Nagy ed. *The Representation of Cognitive Structures.* Toronto, OISE

Lyotard, J. F. 1989. *The Postmodern Condition: A Report of Knowledge* (Trans. G.Bennington, B. Massumi), Minneapolis, UMP.

Kuhn, T. 1970. *The Structure of Scientific Revolutions.* Chicago, UCP.

Sager, J. C.; Dungworth, D.; McDonald, P. F. 1980. *English Special Languages: Principles and practice in science and technology,* Wiesbaden, Oscar Brandstetter Verlag KG.

Searle, J. R. 1990. Consciousness, Unconsciousness and intentionality. In A. Anderson, J. Owens eds., *Propositional Attitudes; the Role of Content in Logic, Language, and Mind.* Stanford, SUP.

Selz, O. 1913. *Uber die Gesetze des Geordneten Denkverlaufs.* Stuttgart, Spemann.

Tarantino, M. 1995. Observation; the polysemic key of Pandora's box hope. In *Proceedings of the 10th LSP Symposium on Multilingualism in specialist communication, I,* 301-317, Wien, UWP.

Tarantino, 1997. Interdisciplinary knowledge, models and experimental evidence: the mainspring of scientific discourse. Paper in print : *Rassegna Italiana di Linguistica Applicata.*

Titone R. 1973. A psycholinguistic definition of the Glossodynamic Model of language behaviour and language learning, *Rassegna Italiana di Linguistica Applicata. XI, 2-3,* 1-20.