Degree IN TEACHER OF PRIMARY EDUCATION.
Subject: Didactics of Experimental Sciences
Course: 17-18

Chapter 4.- Construction of Scientific Knowledge

4.1. Scientific Thought

Since its inception, humanity has needed to understand the world, its entities (objects, events, phenomena), its origin and relationships with other entities. This continuous attempt to understand reality and transform it, humanizing it, has been generating knowledge. Along with mythical explanations, humanity has been finding very different forms of rational explanations, based on the human capacity to reason, to find causes and laws that explain the world and what happens in it.

In fact, it is the scientific community who constructs rational explanations of the world and the whole set constitutes the product of science. Its motivation is the human capacity to pose questions and therefore we can define science as a human activity that tries to exercise rationality to reveal the mysteries of the world, reproducing the natural and physical phenomena of it.

For Bunge (1985): "Science is a style of thought and action: precisely the most recent, the most universal and the most profitable of all styles". As with all human creation, we must distinguish in science between scientific work (research) and its ultimate goal (the creation and use of scientific knowledge).

We can say that science is characterized by its objectives, method, rationalism and realism (Izquierdo et al., 1999). Its objective is to explain surprising and problematic facts of the natural and physical world and to act on them. Your method can not be defined as unique and exclusive; responds to a process that, starting with a question and starting from a first explanatory model, continues with a set of activities that lead to validate it; it is a method characterized by putting in constant relation the data coming from the experience with the theoretical elaboration. The rationalism of science must be understood from the impossibility of knowing whether a theory is true or false, as a constant “go and back” between the hypothesis with theoretical reference and the context of reality. The realism of science means that although science takes facts from the reality of the world to explain them, it turns them into scientific facts, seen from the theory.

The form, the method and the language that science uses can be learned and are a fundamental objective of scientific education.

In this way, and taking into account the ability of people to store and transmit information through writing, the body of knowledge of the different sciences has been shaped.

4.2. Scientific Knowledge

Nowadays, we can say that scientific knowledge is presented as a set of related facts, concepts, laws, theories and models related to each other trying to explain and interpret the aspects of the world that constitute its object of study.

Scientific facts

When we refer in everyday life to something that constitutes “a fact”, we want to indicate that it is something sufficiently verified, which it occurs in nature as a real and true phenomenon. Some examples of facts would be:

- A magnet attracts a metal needle.	*- A dog has four extremities.*
- Sugar tastes sweet.	*- Pure water boils at 100º C*

Science builds its knowledge about the world with the aspiration that it be true. In this sense, the "scientific facts" would constitute the fixed, permanent and independent knowledge of the subjective opinion of the scientists on a concrete part of the world. In fact, the most solid contribution that can be made to the progress of science is the discovering a new fact.

The belief that the empirical basis is common to all human beings and that facts are the foundation of scientific knowledge has a long tradition and is also maintained by many scientists. Thus, theories would be human constructions, while the facts are real. (Echeverría, 1998).

This view of scientific facts is not the one currently held by most philosophers and scientists. In the first place because a fact -"gross fact"- is not the same as a scientific fact. Let's see the following example:

- Observe what happens when we add sugar into the water and leave it a certain time.
The gross fact is: "I see that the sugar goes to the bottom of the glass at the beginning and step by step it disappears until, at some point, the process stops the water looks the same as at the beginning".
The scientific fact is: "Sugar dissolves in water".

- Observe what happens when we water a plant.
The gross fact is: "The water disappears".
The scientific fact is "the plant absorbs the wáter."

In definitive, observation is not a passive intellectual operation. Also, scientific experience is different from common experience because it depends on prior knowledge. This prior knowledge is not simple as in most cases to observe a scientific fact you must first "know how to see" and this requires learning.

Scientific concepts

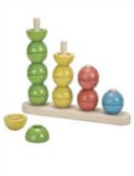
The scientific concepts would be, the first link with which science tries to explain and interpret the world. The world is not structured itself in a univocal way. We are the ones who structure it by projecting our concepts onto it. Thus, properties such as temperature or intelligence are not intrinsically qualitative or quantitative, but that character only resides in the concepts we use to talk about them. However, once certain concepts have been introduced in a certain way, we can no longer use them at our whim, but only following the profiles that reality adopts when projecting such concepts (Mosterín, 1987).

The first thing that comes to mind is the great variety of scientific concepts that exist and their differences in nature. As an example, we can present the following list:
Electron - Speed - Mountain - Fish - Moon - RNA - Gen - Erosion - Quark - Virus - Heat - Black hole - Eye - Electric current Cell - Light - Force - Energy - Atom

Some of them, like fish, force or heat come from ordinary language; while others, such as RNA or entropy constitute creations linked to new discoveries or theories. But both are articulated in a thousand different ways in the bosom of multiple theories.

Different ways to classify the scientific concepts

In the first place, we can distinguish three large groups of concepts:



Qualifiers: Refer to a particular group of objects or events with something in common. In ordinary language, nouns and adjectives correspond to classify concepts. In science, concepts are classified in sets called classifications (ways of ordering knowledge)

When we speak of a classification, we hope several aspects: it is perfectly delimited the domain or domain of individuals that we are going to classify; each concept corresponds to at least one individual in that área; no individual falls under two different classification concepts and all individual of the area falls under any of the concepts of classification. Examples of very important classifications in the sciences are: the "periodic table of the elements" or the "Linnaeus classification of living organisms".

Comparative: Serve to establish comparisons. In natural language, they correspond to the comparative degree of the adjectives. These allow to differentiate more finely and represent a first step for the introduction of metric concepts. A typical example is the hardness used in mineralogy.

This concept of hardness, applied to the domain of minerals, is based on the scratch test. Given two mineral samples A and B, we say that A is harder than B only if A lines B, but B does not line A. And we say that A coincides with hardness with B (or that A and B are samples of the same mineral) if it happens that neither A strikes B nor B strikes A.

Metrics: (also called quantitative concepts or magnitudes): Used to measure a certain entity, so include a unit to measure assigning real numbers (scalar magnitudes, mass or time) or vectors(vector magnitudes, force or velocity) to objects or events.

They have no correspondence in ordinary language and are, therefore, an original creation of scientific languages. They have huge advantages over comparatives and qualifiers. The scientific vocabulary is much simpler, clearer and more manageable, and facilitates the search for scientific laws. But, above all, the metric concepts allow us to apply to a field of research all the algebra of real numbers, thus constituting a bridge between the real world and the ideal world of mathematics.

In second place, another way to classify scientific concepts is to differentiate between **concrete and abstract concepts**.

❖ *Concrete concepts*: Two types can be distinguished:

Type 1: Define attributes and examples that are observable directly with our senses; for example: insect, plant and mineral.

Type 2: Represent unobservable entities that are only accessible to our senses through instrumentation. For example, bacteria and viruses.

❖ *Abstract concepts*: Those that have no perceptible examples or have defined details or attributes that are not perceptible. Examples, quarks, black holes, energy, density, etc.

This classification depends on the observation capacity. Future technological advances could allow us, perhaps, to observe things that are not possible today. For example, before the electron microscope was discovered, viruses were unobservable entities, so in those times they would be classified as abstract concepts.

In third place, we can classify scientific concepts trying to differentiate between those that refer to **material entities or their properties** and those that refer to **processes**. Most scientific concepts can be included in the "matter" or "process" category. For example, concepts included in the category of "matter" (animal, tree, water, mountain, etc.) can be said to have color, weight, occupy space, have surface, etc. From the concepts included in the category of "processes" we can say when they occurred, how long they lasted, what was the cause or purpose.

For example, the alimentary relationships (process) in an ecosystem are established between animals, plants and medium (materials).

4.3. Scientific laws, theories and models

Scientific laws

A scientific law can be defined as a proposition that expresses a regularity that we find in the phenomena that occur in nature, that is accepted by all and that, generally, has a wide field of application. Laws express dependency relationships between events or phenomena. The trust you have in a scientific law once accepted is such that, from now on, you doubt before anything else that of the same law.

Examples of scientific laws:

❖ “In chemical reactions the total mass of the substances that react (reactants) is equal to the total mass of the substances (products) that are formed” (Lavoisier's Law).

❖ “Individuals resulting from the crossing of homozygous parents are phenotypically and genetically equal to each other” (1st Mendel's Law)

❖ “Every body continues in its state of rest or uniform motion in a straight line unless it is forced to change that state by a force” (1st Newton´s Law).

A current and philosophically accepted view is that laws are constructions made by scientists that fit very well with reality, so it seems that nature manifests its own order through them. Therefore, there are “laws of nature”, independent of our understanding. There are only laws that are known and practiced, so it does not make any sense for a scientist to enunciate a law if the scientific community does not accept it and does not practice it (Echeverría, 1998).

Laws are abstractions of reality in which only the relevant factors of situations or phenomena appear. They can be represented by mathematical expressions that relate two or more variables (P.V. = n.R.T) and can also be formulated verbally. Mathematical language, in addition to presenting the law in a precise and compact way, has the advantage of facilitating the work of extracting consequences from those laws, by allowing to carry out logical operations with them.

It is also important to emphasize that a law is an advanced stage in scientific development, since it relates concepts that have had to be studied and established previously.

Scientific theories

Although it is a concept on which there are many points of view, we could say that theories, according to Bunge (1985), the scientific theories are very compact systems of ideas (concepts, laws, hypotheses, logical relations, etc.).

We can highlight some examples of scientific theories that have exerted and exert great influence in the development of scientific thought:

❖ The heliocentric theory of Copernicus. The theory of universal gravitation of Newton.
❖ The Atomic theory of Dalton. The Evolutionist theory of Darwin.
❖ The cell theory of Ramón y Cajal. The theory about the Origin of Life of Oparín.
❖ The theory of the Relativity of Einstein.
❖ The theory of plate tectonics. The "Big-Bang" theory about the origin of the Universe.

Scientific theories are valued for their ability to explain and predict phenomena in a certain field. The greater the field of application of a theory, the more it will be valued, as well as the simplicity in its formulation.

All scientific theories are:

Partial as only deal with certain aspects of reality	Approximate, in the sense that they are not error-free
They are complex structures, not easily refuted by simple observations	They are valued for their ability to explain and predict phenomena in a given field.

In many cases, even in the field of science, the words "model" and "theory" are used as synonyms. In the following section, when talking about models, we will try to differentiate both terms. As Bunge (1985) says "theories are not models, but include models"

Scientific models

In the field of empirical sciences, the term “model” is used in two senses:

Model as "system in which what the theory says is fulfilled". (Mosterín, 1987).

In Sciences, it often happens that the system is intended to describe theoretically is enormously complicated (to construct a theory that helps us to explain and predict). Then, we follow an indirect path. We look at another system that is simpler or better known than the first, but that possesses some of its features or characteristics, that resembles it in some aspect that intuitively seems relevant to us. If we do not find such a system, we build it (with plastic, wood and steel or, at least, with the imagination). In any case, we find two systems: the one that interests us, the real system, but that is too complicated or unknown, and the one that resembles it in something, but that is simpler or better known or more easily studied. We create a theory that adequately describes the operation of the simple system, which has the simple system by model. And, finally, we try to apply that same theory to the complex or unknown system.

Model as "representation of something" (Estany, 1993).

When using the term model as a synonym of "representation of something", we must distinguish between various types of representation.

❖ Scale models: They can be defined as the set of all the simulacra of material objects, both real and imaginary, that preserve the relative proportions. Examples of scale models are models, planes, miniature cars and reproductions of human organs that are used for teaching purposes.

❖ Analogue models: The fundamental objective of analogue models is to explain an unknown field by resorting to a known one. Sometimes they also have a didactic function, but unlike scale models, they require a greater resemblance, both in the elements of both structures and in their dynamics. The history of science provides abundant examples of the role of analog models in scientific development.

- E. Rutherford and N. Bohr took the solar system as an analog model to explain the atom, saying that the structure of the atom is analogous to the structure and functioning of the solar system.
- Ch. Huygens elaborated his wave theory of light with the help of suggestions derived from ideas, already familiar in his time, of sound as a wave phenomenon.

This meaning of model would be similar to the one proposed by Mosterín (1987) as "a system that serves as a model for a theory".

❖ Theoretical models: While some authors consider that "theoretical models" are the same as "theories", others consider that it is necessary to differentiate both terms. Thus, the "theoretical models" are usually considered as "a more quantitative and exact theory than the original theory that is established in more general terms". They would be included within the theoretical models, the mathematical models, and those from which it is not possible to find material systems to represent them or they would be too complex.

4.4. How is scientific knowledge produced?

The scientific methodology

Since we can not identify and characterize a single scientific method, we are going to use the denomination of scientific methodology (and even methodologies) which is a more open term and that gives more idea of general procedures than of very specific steps or stages. We will try to highlight some general characteristics and fairly accepted features of the scientific methodology. We are going to do it on two levels:

1º Level: Analyze of different parts of the basic processes

❖ Identify and define problems

One of the important aspects in scientific work is to delimit and define clearly and precisely the problem to be addressed, normally, part of problematic situations, open and, often, confusing. The clarification of these aspects requires, in many cases, an important work of reflection and analysis based on the already existing knowledge and, in some occasions, on the observations made from the reality.

❖ Define hypothesis

A hypothesis is a statement that responds to a problem or question posed, and it has a vein of truth based on theoretical and/or experimental foundations. Taking that statement as true, we can establish predictions of natural situations that have to be fulfilled.

❖ To experience

It means studying the phenomena under conditions controlled by scientists. This allows focusing on the fundamental aspects of interest and avoiding or controlling everything that can be accessory. It is the process to test the hypothesis is carried out. Basically, it requires to perform two types of tasks: first the design of the experiment and second its execution.

The design of the experiment supposes an intellectual process in which it is necessary:

a) Analyze the situation focusing on the variables that intervene or can intervene: the variable that I want to measure (dependent variable); from which we want to find out its dependency (independent variable) and which other variables can affect and we do not want it to do so (variables to be controlled). This type of analysis is called "variable control".

b) Decide the concrete conditions of the experiment: materials and devices to be used, number of observations that will be made, etc.

The realization of the experiment requires, in some cases, manual skills to handle the devices and instruments needed; as well as precision and rigor in the measurements and observations made. In other cases, simply wait for the results provided by the instruments used.

❖ To get data: observe, measure

Observe

It is a process in which we put into play our sensory and conceptual systems, so observation is dependent on our ideas. Even to use simple statements that do not seem to imply theoretical load (observational statements), the language of some theory (understood here as an idea) must be used (Chalmers, 1989). Scientific observation is used, in many cases, of devices capable of extending sensory sensations to surprise limits. The observation can be qualitative or quantitative. Quantitative observation is called measurement.

❖ To measure

It is to compare an amount of one magnitude with another quantity of the same magnitude taken as a standard. The scientific community has agreed on the magnitudes considered fundamental and their units of measurement (International System of Units) so they form a universal language which makes measurement a process understandable to anyone. Even if the instruments are really accurate and the person who uses them really rigorous, the measurement is always associated with a degree of uncertainty or error (sensitivity of the instruments and errors of the users), so one can never consider any rigorously accurate quantitative observation, and the qualitative observations are even less so.

❖ Record and classify data

Data are the product of qualitative and quantitative observations. The registration of the data can be done in different ways: written descriptions, drawings, numerical tables, diagrams, maps, etc. There is no one proper way to record the data. This will depend on the type of data, the specific circumstances in which they are collected and what they intend to do with them. It is important is to collect the data as they are produced.

Classification means ordering the data. Scientists classify in order to simplify the object of study and present the data available in some way that allows us to think better about them and can extract guidelines or general ideas. The classifications are based on criteria established by the researchers. These criteria can change if they change the knowledge or the points of view adopted and, therefore, the classifications are not static but are modified as a result of the changes of criteria.

❖ Interpret data: Induce and Deduct

These are very important logical processes of thought in the construction of scientific knowledge. An induction is an affirmation (about the properties, behavior, etc.) carried out on all the elements or individuals of a group based on the knowledge of only a part of the individuals of that group.

On the opposite, a deduction is an affirmation (about the properties, behavior, etc.) of an object, individual or particular situation, based on the rules of properties, behavior, etc., of the group to which that element belongs. For example, given the fact that metals expand when heated, it is possible to deduce the fact that railway rails (made of metal) will also expand with heat.

❖ Communicate

Science is a social activity and, therefore, communication plays a fundamental role in so that generated knowledge by scientists (private science) can become socially accepted as a scientific knowledge (public science), which we colloquially understand as “Science”.

“...scientific knowledge must not only be communicable, but must have been communicated in order to be scientific”. (Echeverría, 1998).

2º Level: Analyzing a model that explains what a research process is.

The research process

Scientific research is an extraordinarily complex collective process involving some, or all, of the basic scientific processes that we have described or all of them, as well as other factors related to personal issues, from the scientists themselves, and social issues. As highlights of scientific research can highlight the following:

A. Identification and definition of problems (research questions).

Presentation of clear and precise problems starting from initially more open and confused situations.

The formulation of precise questions and/or problems is based on the knowledge available at that time or problems generated in previous research.

B. Once the problems or research questions have been raised, the research phases are:

- Formulation of hypotheses (verified predictions based on theoretical and/or experimental foundations)
- Strategies for testing hypotheses (design and realization of experiments).
- Interpretation of the results of the research (contrast the results with the hypotheses).
- Communication of results and exchange with other research teams.

C. Conclusions of the research process.

They may simply contribute to falsify or verify the hypotheses raised or, more profoundly, modify beliefs and attitudes of the scientific community.

They can also enable technical applications and generate new problems.

In definitive, a good research is the one that answers a question and raises some new ones, and, the conclusions lead to a re-thinking of the research process in one or some of its phases.

4.5. School science. Didactic Transposition

School science

When we refer to the science that is taught in the context of formal education, we talk about school science and, with this denomination, we want to highlight that it is different both to the science of scientists and to everyday knowledge. The three types of knowledge, the daily, the scientific and the scholar, are differentiated by the objectives they pursue, the world they are interested in, the methods used for their construction and the criteria for their validation.

School science is a social product, institutionalized and regulated, whose main objective is to promote the scientific education of students of all educational levels. There are different ways of understanding school science. Here we will consider it as an evolutionary process according to which teaching science implies, among other aspects, establishing bridges between scientific knowledge, as expressed by scientists through their writings, and the knowledge that students can build, initially from their daily knowledge

Didactic transposition

The process of selection of school content is called "didactic transposition" and does not consist, in the case of science, solely and exclusively in a simplification of scientific knowledge to make it available to students of different educational levels. It involves a complex process of restructuring scientific knowledge involving various factors among which can be highlighted: the science of scientists, the characteristics of students and social requirements. The recognition of this process by teachers is a key aspect in the teaching of science.

It is about defining a set of knowledge that are considered basic in each of the fields of science but that, at the same time, are useful for students to explain and interpret the world around them (see, for example, the differences between the classifications of the animals that zoologists make and those that are presented in the textbooks of the initial levels of teaching).

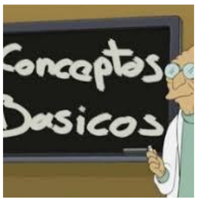
School science curricula usually reflect those aspects that are considered socially relevant at the time of their preparation, not only issues considered strictly scientific but also certain socio-cultural requirements that society poses to the school.

For example, society currently considers that the school should contribute to the development of certain types of values, among which can be cited those related to an environmental ethic. These requirements are included in the current curricula in Spain, and it permeates the teaching of many of the curriculum areas, including those of Knowledge of the Environment.

School science is constituted by an integrated body of conceptual, procedural and attitudinal contents selected, though not only, from the body of scholarly scientific knowledge

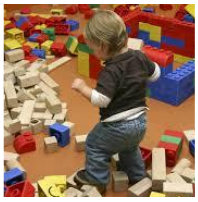
Types of contents

The contents of the curriculum are considered as the objectives of the teaching-learning process. They can be of many kinds and encompass very diverse realities from the point of view of their character and their properties. Basically, we can establish three different types of contents:



Conceptual: knowledge of facts, concepts, laws, theories and models that are considered basic and fundamental in the different sciences.

Procedural: knowledge and use of strategies, techniques and skills that are considered important and basic in the processes of construction of scientific knowledge.



Attitudinal: assimilation of attitudes, values and norms that govern the construction and use of scientific knowledge in our society - "scientific attitudes" - and of attitudes regarding science and its learning.

The differentiation of these three types of content is a didactic distinction but this does not mean they are going to present and work in class separately or there are no relationships between them. It is a way of expressing that, within the set of knowledge or cultural forms that we want our students to learn, there are aspects of a different nature that will require different teaching-learning strategies.

The didactic analysis, by teachers, of these types of contents: their identification and characterization (differences and similarities) as well as their relationships, will help to present them to the students so that they can be learned more significantly.

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