Degree IN TEACHER OF PRIMARY EDUCATION.
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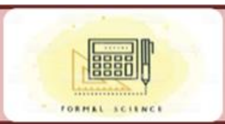
Chapter 1. Nature of Science

1.1. Concept of Science

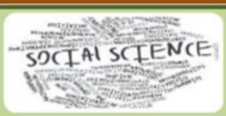
Although the nature of human beings always faces the eternal question: **what is science**, we can define it as the set of knowledge obtained through observation and reasoning, systematically structured and deduced from general principles and laws. However, these general laws and principles are not always definitive since they can always be modified or advanced. One example is the gravitation´s laws, which remained unquestionable for two centuries until the behaviour observed on the planet Mercury did not conform precisely to them. In this case, Einstein's theory of relativity helped to explain this discrepancy, leading to a correction of the laws. Therefore, **Science is the current verification without absolute certainty**. Science as a concept is known as systematised knowledge, developed through methodically organised observations, reasoning and evidence.

Science uses different methods and techniques to acquire and organise the knowledge based on a set of objective facts accessible to some observers, and a criterion of truth and permanent correction. In that sense, we can divide Science as follows (scientific disciplines):



Set the logical reasoning and work with ideas created by the mind (**inductive logic method**): mathematics, logic, etc…

Their main purpose is the study of nature (**scientific method**): biology, physics, geology, chemistry, etc…



Work with the aspects of the human being (**method depends on each particular discipline**): anthropology, economy, history, psychology, etc…

1.2. Scientific knowledge

Every Science has its specific method, but, two main activities of Science are the basis of the principles of scientific knowledge:

1. **Experience** is the main driving force behind the principles of scientific knowledge, but they can be hypotheses or postulates.
2. Based on the principles, Science uses the **demonstration** to draw conclusions.

Some of the characteristics of scientific knowledge are:

- It is **objective** because it is valid for all individuals and not only for one. The guarantee of objectivity is the techniques and methods of research and testing.

- Scientific knowledge is **critical** because it seeks to distinguish between truth/false justifying their knowledge showing evidence (**informed**).
- **Planning**, through the methods of research and testing, leads to scientific knowledge. The researcher follows procedures, develops its task based on a previous plan.
- **Verification** is possible through the adoption of the review of the experience.
- It is **systematic** because it is an orderly unit; new knowledge is integrated into the system, interacting with those that already existed.
- It is **unified** because it looks for the knowledge of the singular and concrete, of the general and abstract, or the identical and permanent things.
- It is **universal** because it is valid for all people without recognising borders, does not vary with the different cultures.
- It is **rational** because Science uses the intelligence of reason to learn new aspects.
- Scientific knowledge is **provisiona**l because Science does not stop; it continues its research to understand reality better. The search for truth is an open task.
- It is **communicable** through the language of Science. It is precise and unambiguous, understandable to any trained personnel, who will be able to check the validity of the theories in their more relevant aspects and verifiable.

Nowadays, scientific knowledge is a set of related facts, concepts, laws, theories and models interconnected trying to explain and interpret the aspects of the world.

Scientific facts: It is something sufficiently verified in our daily life, which occurs in nature as a real and genuine phenomenon. Some examples of facts would be:

- A dog has four extremities. - Sugar tastes sweet. - Pure water boils at 100º C

In that 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. Therefore, discover a new fact is the most substantial contribution to the progress of Science. However, in this view of scientific facts, we have to distinguish between a fact – "gross fact"- is not the same as a scientific fact. Let us see the following example:

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

- ***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 at the beginning and 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”.

Scientific concepts: They are the first link to try to explain and interpret the world. Their introduction leads to a structuring of the world. 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 - Blackhole - 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 discoveries or theories.

Different ways to classify the scientific concepts

In the first place, we can distinguish three broad 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, these concepts are not usually introduced in isolation, but in sets called classifications

Examples of significant 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 clear example is the concept of hardness, applied to the domain of minerals.

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 magnitude, force or velocity) to objects or events.

They are the original creation of scientific languages and have huge advantages over comparatives and qualifiers. The scientific vocabulary is much simpler, more precise and more manageable, and facilitates the search for scientific laws.

In the second place, we can differentiate between **concrete and abstract concepts**.

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

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

Type 2: Represent unobservable entities only accessible to our senses through instrumentation — for example, bacteria and viruses.

❖ *Abstract concepts*: They do not have obvious examples or defined details/attributes. Some examples: quarks, black holes, energy, density.

This classification depends on observation ability. Future technological advances could allow us, perhaps, to observe things that are not possible today. For example, viruses were unobservable entities before the discovery of the electron microscope, so in those times, so they had a classification 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**. The "matter" or "process" category includes most scientific concepts. For example, concepts included in the category of "matter" (animal, tree, water, mountain) have colour, weight, occupy space. 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, there is an alimentary relationship (process) in an ecosystem between animals, plants and medium (materials).

1.3. Scientific laws, theories and models

Scientific laws: In definition, a scientific law expresses a regularity of phenomena in nature, everybody accepts it and, generally, has a wide field of application. Laws express dependency relationships between events or phenomena. Full confidence in an accepted scientific law leads to no doubt about the law itself. 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) formed" (Lavoisier's Law).

❖ "Everybody continues in its state of rest or uniform motion in a straight line if there is not a change caused by force" (1^{st} Newton's Law).

Currently, scientific laws are constructions that fit very well with reality, so it seems that nature manifests its order through them. Therefore, there are only laws that are known and practised, and it does not make sense for a scientist to make a law if the scientific community does not accept it and does not practice it (Echevarria, 1998).

Laws are abstractions of reality with relevant factors of situations or phenomena. They can be represented by mathematical expressions that relate two or more variables ($P.V. = n.R.T$) and formulated verbally. It is also important to emphasise that law is an advanced stage in scientific development since it relates previously studied and established concepts.

Scientific theories: Although it is a concept with many points of view, we could say that, according to Bunge (1985), the scientific theories are very compact systems of ideas (concepts, laws, hypotheses, logical relations). We can highlight some examples of scientific theories that have exerted and exert considerable influence on the development of scientific thought:

- ❖ The theory of universal gravitation of Newton. The Atomic theory of Dalton.
- ❖ The cell theory of Ramón y Cajal. The Relativity theory of Einstein.
- ❖ The theory of plate tectonics. The "Big-Bang" theory about the origin of the Universe.

Their ability to explain and predict phenomena in a specific field are some of the most valuable characteristics. The higher the field of application of a theory, the more it will be valued. Also, scientists will value 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, we use the words "model" and "theory" as synonyms. We will try to differentiate both terms in the following section. As Bunge (1985) says "theories are not models but include models."

Scientific models: We can use the term "model" in two senses in the field of empirical sciences:

Model as " a system that fulfils the theory says". (Mosterín, 1987). In Science, the theoretical description of a system is often confused because of its complexity. So, we follow an indirect path. We observe another system that is simpler with some similar characteristics or is similar in some relevant aspect. Then we create a theory that adequately describes the simple system. Finally, we apply that 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 are a set of the simulacra of material objects, both real and imaginary, that preserve the relative proportions. Examples of scale models are planes, miniature cars and reproductions of human organs used for teaching purposes.

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

- E. Rutherford and N. Bohr took the solar system as an analogue 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.

➢ 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 “a more quantitative and exact theory than the original theory that established in more general terms”.

However**, how is scientific knowledge produced?**

1.4. Scientific Method

The scientific method is the way ordered to proceed to the knowledge in the area of a scientific discipline. It has the goal to determine the rules and testing of the research to achieve the scientific truths. It includes the study of how the human mind orders knowledge and extends it. Since we cannot identify and characterise a single scientific method, we are going to use the denomination of **scientific methodology** (and even methodologies). It is a more open term and, gives more idea of general procedures than of concrete steps or stages. We will try to highlight some general characteristics on two levels of scientific methodology:

Level 1. Analyse of different parts of the fundamental processes

❖ **Identify and define problems**: One of the essential aspects of scientific work is to delimit and define clearly and precisely the problem. In many cases, scientists must carry out work of reflection and analysis based on previous knowledge and observations of reality.

❖ **Define hypothesis**: It is a statement that responds to a problem or question posed, and it has a background of truth based on theoretical and experimental foundations. Taking that statement as accurate, we can establish predictions about real situations.

❖ **To experience**: It means studying the phenomena under controlled conditions focusing on the fundamental aspects of interest and avoiding/controlling everything that can be an accessory. It is the process to test the hypothesis and requires to perform two types of tasks: first, the design of the experiment and second its execution. The design of the experiment supposes a mental process in which it is necessary:

a) *Analyse the situation focusing on the variables* that intervene or could intervene: we can highlight a) the *dependent variable*: variable to be measured; b) the *independent variable*: on which we find out its dependence and c) *variables to control*: those that can affect others. This type of analysis is called "control variables".

b) *Decide the actual conditions of the experiment*: materials and instrumentations, the number of observations.

❖ **To get data**: *Observe*. It is a process dependent on our ideas because we use our sensory and conceptual systems. The observation can be qualitative or quantitative. A quantitative observation is called measurement.

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). They form a universal language which makes measurement a process understandable to anyone. However, there is always a degree of uncertainty or error in the measurement (sensitivity of the instruments and user errors), so we never consider a strictly accurate quantitative observation. Qualitative observations are even less so.

❖ **Record and classify data**: Data is the product of qualitative and quantitative observations and can register in different ways: written descriptions, drawings, numerical tables, diagrams, maps. This recording is not unique and depends on the type of data, the specific circumstances of the collection and what they intend to do with them. It is essential to collect the data as we produce them, to classify them (order them to simplify the object of the study), present them to allow reflection and extract general ideas. Scientists can modify the data classification according to the criteria.

❖ **Interpret data**: *Induce and Deduct*: These are fundamental logical processes of thought in the construction of scientific knowledge.

- *Induction* is a statement about all individuals in a group based on the knowledge of only a part of it.
- *A deduction* is a statement about an object, individual or situation in a group, based on its properties and behaviour. For example, metals expand when heated, so we can deduce that railway rails (made of metal) will also expand with heat.

❖ **Communicate**: Science is a social activity and communication plays a fundamental role in making the knowledge generated by scientists (private science) socially accepted as scientific knowledge (public science). It is what we colloquially understand as "Science".

Level 2: Analyse a model that explains what the research process is.

The research process: Scientific research is an extraordinarily complex collective process involving some or all the basic scientific processes described above, as well as other factors related to personal, scientific 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, modify beliefs and attitudes of the scientific community and enable technical applications and generate new problems.

1.5. Scholar science. Didactic Transposition

Scholar science

When we refer to Science in the context of formal education, we talk about scholar science and, that is different from both the science of scientists and common knowledge. Scholar science is a social product, institutionalised and regulated, whose main objective is to promote the science education of students of all educational levels. Scholar science is an evolutionary process according to which science education implies, among other aspects, establishing bridges between scientific knowledge, as expressed by scientists, and knowledge that students initially build from their everyday knowledge.

Didactic transposition

The process of selection of school content is called "didactic transposition" and does not consist, in the case of Science, 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 as the Science of scientists, the characteristics of students and social requirements. The recognition of this process by teachers is a vital aspect of Science education. It is about defining a set of essential knowledge in Science and useful for students to explain and interpret the world around them (see, for example, the differences between the classifications of the animals in the textbooks and the zoologists one). Scholar science curriculum usually reflects those aspects considered socially relevant at the time of their preparation, not only issues considered strictly scientific but also specific 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 as those related to an environmental ethic.

1.6. Other types of knowledge

The term "knowledge" is the ability to act, process and interpret information to generate more knowledge or give a solution to a problem. Scientists and researchers define this term in two ways: a) as a mental representation of reality and b) how it is carried out the transmission of the information from one entity to another. According to these definitions and the methods used to construct or to generate knowledge, the division is:

Intuitive knowledge: In definition, it is the knowledge acquired by nature, and everyone has in one degree or another. In other words, the intuition works as a principle to the solution to a problem or situation based on the informal sector and rapid processing of cognitive experiences and Science is full of intuitions, some that lead to success, others that lead to the error but that produce a new experience corresponding to a new intuition more successful.

Empirical knowledge: It is based on experience and, ultimately, in the perception, because it shows what exists and its characteristics, but it does not explain that something must be in a certain way. Therefore, empirical knowledge comes from the observation of our environment, but not everything we learn is by empiricism, since, after the observation of the phenomenon, the human being tries to reproduce it and control it, and from it, scientific knowledge appears.

Religious or traditional knowledge: Religion is an element of human activity that usually consists of beliefs and practices on issues of existential type, moral and supernatural. There is the talk of "religions" to refer to specific forms of manifestation of the religious phenomenon, shared by the different human groups. Some religions behave in strict ways, while others lack formal structure and integrate into the cultural traditions of the society or ethnic group. The term refers to both the personal beliefs and practices how to collective rites and teachings.

Philosophical Knowledge: It comes from the systematic and methodical reflection on human existence and everything around us, giving rise to fundamental truths about life and the universe. This philosophical knowledge is permanently open to revision. It can offer more than one vision of the same phenomenon under study, and even contradictory ones, while scientific knowledge focuses on more specific aspects and usually has a single vision of a phenomenon (although it is also revisable).

1.7. References

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